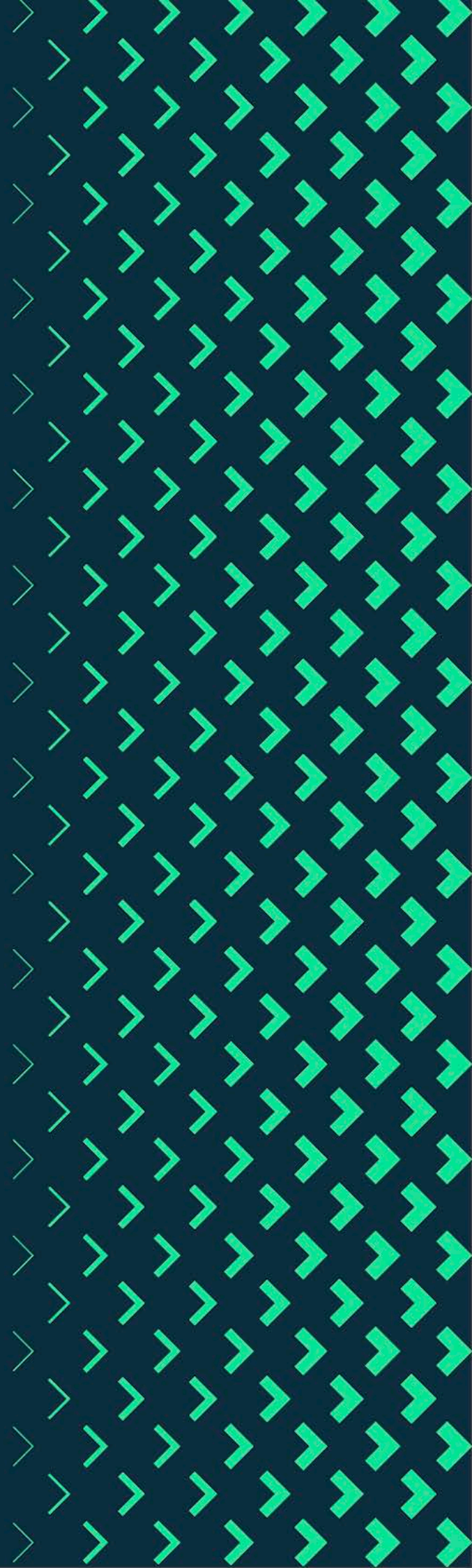


Design and Technology Education: An International Journal

30.3



Design and Technology Education: An International Journal

Design and Technology Education: An International Journal (DTEIJ) is an open access journal published three times a year by the Design and Technology Association, UK

Editors

Prof Kay Stables, Goldsmiths, University of London, UK
Dr Lyndon Buck, University of Southampton, UK

Editorial Team

Dr Sarah Davies, Associate Editor, Nottingham Trent University, UK
Dr Matt McLain, Associate Editor, Liverpool John Moores University, UK
Gary Underwood, Associate Editor, University of Southampton, UK
Cath Dishman, Liverpool John Moores University, UK
Laura Martin, Design and Technology Association, UK

Editorial Board

Prof E Stephanie Atkinson, University of Sunderland, UK
Dr Hilda Ruth Beaumont, University College London, UK
Dr Erik Bohemia, Western Norway University of Applied Sciences, Norway
Dr Donal Canty, University of Limerick, Ireland
Dr Christine Edwards-Leis, St Mary's University College, London, UK
Dr Wendy Fox Turnbull, Waikato University, New Zealand
Prof Richard Kimbell, Goldsmiths, University of London, UK
Bill Nicholl, Cambridge University, UK
Dr Marion Rutland, Roehampton University, UK
Tony Ryan, Design and Technology Association, UK
Dr Niall Seery, Athlone Institute of Technology, Ireland
Dr David Spendlove, University of Manchester, UK
Torben Steeg, Manchester Metropolitan University, UK
Dr Belinda Von Mengersen, Australian Catholic University, Australia
Prof Marc de Vries, Delft University of Technology, The Netherlands

Contributions

All contributions and materials for review should be made through the Journal website at: <https://openjournals.ljmu.ac.uk/DesignTechnologyEducation>

D&T Association membership

To join the D&T association, or request further details on membership please contact: Jacqui Eborall, Membership Secretary
Tel: 01789 470007
email: membership@data.org.uk

Disclaimer: The views and opinions expressed in this journal are those of the authors and do not necessarily reflect the official policy or position of the Design and Technology Association

Creative Commons License

This work is licensed under a Creative Commons Attribution 4.0 International License. Authors who publish with this journal agree to the following terms:

Authors retain copyright and grant the journal right of first publication with the work simultaneously licensed under a Creative Commons Attribution License that allows others to share the work with an acknowledgement of the work's authorship and initial publication in this journal

Authors are able to enter into separate, additional contractual arrangements for the non-exclusive distribution of the journal's published version of the work (e.g., post it to an institutional repository or publish it in a book), with an acknowledgement of its initial publication in this journal

<https://creativecommons.org/licenses/>

DTEIJ is currently indexed by:

Scopus
ERIC
DOAJ
Cabells
Google Scholar

**Volume 30
Number 3**
*ISSN 2040-8633
(online)
December
2025*

Issue 30.3 December 2025

Table of contents	2-3
--------------------------	-----

Editorial

Extending our reach, adding literature reviews to the Journal's repertoire	4
---	---

Kay Stables, Goldsmiths, University of London, UK

Lyndon Buck, University of Southampton, UK

Reflection

Reflecting on the Implications of the 2025 Curriculum and Assessment	5-9
---	-----

Review for Design and Technology in England

Matt McLain, Liverpool John Moores University, UK

Alison Hardy, Nottingham Trent University, UK

Abstracts

Abstracts for each of the 9 articles published in this issue of the Journal	10-15
--	-------

Research articles

The way Technology Teachers Think: The Role of Metaphor and Reflection for Technology Education practice	16-32
---	-------

Andreas Larsson, Linköping University, Sweden

Generative AI – Creative Pedagogy Versus Creative Application	33-48
--	-------

Dale Addy, Watkins College of Art, Belmont University, USA

Assessing Students' Computer Programming Skills: How Technology Teachers in Sweden Evaluate Learning in Grades 4–6	49-71
---	-------

Eva-Lena Bjursten, Mälardalen University, Sweden

Lena Gumaelius, KTH Royal Institute of Technology, Sweden

Eva Hartell, KTH Royal Institute of Technology, Sweden

Designing for Entrepreneurship: STEM-Based Approaches in Primary Education	72-99
---	-------

Cemre Saraçlar, Independent Researcher, Türkiye

Ahmet Oğuz Akçay, Eskisehir Osmangazi University, Türkiye

Engin Karahan, Middle East Technical University, Türkiye

A repurposed geometric reasoning model for Engineering Graphics and Design: a conceptual paper	100-121
---	---------

Vernon Candiotes, University of Pretoria, South Africa

Willem Rauscher, University of Pretoria, South Africa

Sonja van Putten, University of Pretoria, South Africa

- The invisible remains invisible: a study of systems thinking in compulsory school students' descriptions of a wastewater system** 122-142

Nina Emami, KTH Royal Institute of Technology, Sweden

Susanne Engström, KTH Royal Institute of Technology, Sweden

Claes Klasander, Linköping University, Sweden

- A Serious Game Proposal for Raising Awareness on Sustainable Development in the Built Environment** 143-165

Burcu Olgen, Concordia University, Canada

Negarsadat Rahimi, Concordia University, Canada

Carmela Cucuzzella, Université de Montréal, Canada

Literature reviews

- Design Thinking in educational publications: A document analysis of books Issued by Turkish Public Institutions and implications for the Technology and Design course** 166-193

Ahsen Öztürk, Kütahya Dumlupınar University, Türkiye

- Recurriculation of Engineering, Technology, and Technical Education Programmes for the adoption of Industry 5.0** 194-225

Sunkanmi Afeez Yekinni, University of Nigeria, Nsukka, Nigeria

Theresa Chinyere Ogbuanya, University of Free State, South Africa

Abdifatah Ahmed Ali Afyare, Salaam University, Somalia

Editorial: Extending our reach, adding literature reviews to the Journal's repertoire

Kay Stables, Goldsmiths, University of London, UK

Lyndon Buck, University of Southampton, UK

In this final Issue of 2025, we are pleased to share ten articles with our readers, two of which are appearing under a new category for the Journal as we are introducing a new section that focuses on literature reviews. The Journal has always been open for these but, in the past, very few have been submitted. Literature reviews are valuable documents for researchers to share as, while not presenting a specific research project, they are research articles in their own right in that the authors have undertaken to research what has been written on a specific aspect of research undertaken in previous years. Literature reviews pull together a treasure trove of insights, focused on a specific topic drawn from recent research, along with research undertaken over preceding decades. Those producing literature reviews also tend to take a neutral stance, enabling a range of perspectives on a topic, allowing a reader to scan the range, consider the perspectives presented and gain new insights into a topic that can be both enlightening and challenging.

In the two literature reviews in this issue quite different topics have been presented – one on an analysis of books issued by Turkish Public Institutions, focusing on Design Thinking and the other providing insights into the rearticulation of Engineering, Technology and Technical education in the light of Industry 5.0. The topics are quite different, but the scope of each is impressive. Both reviews draw on research from an international range of articles from recent and historic eras. Both also go beyond the reviews of the literature and focus on implications for Design and Technology Education. We look forward to receiving further literature reviews delving into all aspects of Design and Technology education that we can share in future issues.

In addition, this Issue includes seven research articles submitted from across Canada, South Africa, Sweden, Turkey and USA; on primary, secondary and tertiary education; and on topics ranging across computer programming skills, engineering graphics and design, generative AI and creativity, metaphor and reflection, STEM-based approaches, and sustainability.

Summaries of research articles and literature reviews can be scanned in the Abstracts section of this issue.

Finally, we have a very English reflection piece that considers the impact of a newly introduced Curriculum and Assessment Review in schools' education.

We hope this final issue of Volume 30 provides something for everyone and we look forward to presenting Volume 31 in 2026.

Reflecting on the Implications of the 2025 Curriculum and Assessment Review for Design and Technology in England

Matt McLain, Liverpool John Moores University, UK

Alison Hardy, Nottingham Trent University, UK

Introduction

This reflection critically examines the implications of the 2025 Curriculum and Assessment Review (CAR) for Design and Technology (D&T) education in England. Drawing on our role as expert advisors to the Department for Education (DfE), we explore the Review's recommendations for clarifying the subject's purpose, refining curriculum content, and embedding sustainability, social responsibility, and inclusivity. We argue that while the Review articulates a progressive vision for D&T, significant challenges remain in addressing systemic barriers such as declining participation, inequitable access, and assessment practices. The discussion highlights opportunities for strengthening applied knowledge areas (digital literacy, oracy, and climate education) while cautioning against structural constraints that risk further marginalising the subject. We conclude that realising the Review's ambitions requires targeted investment in teacher development, infrastructure, and inclusive curriculum design, alongside assessment reform. Without these measures, D&T's potential as a vital bridge between creativity, technology, and societal needs may remain unrealised.

As expert advisors to the DfE's CAR panel following the interim report (DfE, 2025a), we welcome the final report's recognition of D&T as a vital subject within a world-class curriculum (DfE, 2025b). This reflection bridges our discussions with the DfE and our public response to the final report, focusing particularly on its recommendations for D&T. We also critically analyse the implications of the CAR for D&T by comparing them with recommendations for art and design (A&D), science, and geography.

The Report positions itself as evidence-led, inclusive, and forward-looking, aiming to “ensure the curriculum is fit for purpose, addresses the rich knowledge and skills people need to thrive in a fast-changing world and encourage a love of learning” (DfE, 2025b, p.9). For D&T, this vision translates into two overarching recommendations:

1. **Clarify the subject's purpose** by articulating aspirational aims that emphasise its distinct body of knowledge and capabilities.
2. **Refine the D&T curriculum and GCSE subject content**, including:
 - a. Explicitly addressing sustainable solutions to design challenges.
 - b. Embedding social responsibility and inclusive design throughout the design process.
 - c. Developing critical decision-making skills in material selection.
 - d. Ensuring that realising designs remains integral to pupils' D&T experience. (paraphrasing of DfE, 2025b, p.70)

These recommendations align with our own vision for a future-facing D&T curriculum; one that equips young people with the capability to ideate, realise, and critique designs in response to complex societal and technological challenges (McLain et al., 2019).

Opportunities and Challenges

The Report marks a (potentially) significant moment in the evolution of England's national curriculum. D&T occupies a uniquely complex position, bridging traditional academic, practical, and creative domains while carrying the legacy of its vocational roots (Hardy, 2025). We see the recommendation for aspirational aims as an opportunity to advance the subject while building on its history. We propose these two aspirational aims for D&T:

- Develop design and technology capability through selecting knowledge of how to imagine, create and critique artefacts, systems or models for a range of contexts, purposes and users.
- Develop conceptual, procedural, and contextual knowledge to critically evaluate the societal, cultural, and environmental impacts of design and technology.

The Report's emphasis on critical design-making skills, sustainability, social responsibility, and inclusivity aligns well in these aspirational aims. However, realising this potential will require significant investment in teacher training, infrastructure, and curriculum development. The Review's ambitions risk being undermined if not matched by systemic support.

The Report recommends that the curriculum should place rich knowledge and skills at its heart. However, in D&T, the subject's intention lies in what pupils do with that knowledge, which we think are addressed in these two aims. Firstly, to make purposeful changes to the made world through their active use of knowledge and skills; and secondly, to use their developing knowledge to understand the wider impact of D&T.

Applied Knowledge Areas

Next, the Review also states that D&T should contribute to applied knowledge areas (often called 'life skills') including climate education and sustainability, digital literacy, and oracy. Geography and science are recommended to focus on teaching about climate change, and sustainability is the focus for D&T – again its knowledge for action and change, rather than the theoretical or scientific aspects. This is an opportunity for real discussions between subjects to clarify subject-specific knowledge and where these can be drawn on between subjects – not as simple cross-curricular themes, but rather to strengthen learners' knowledge and skills.

The applied knowledge areas of digital literacy and oracy in D&T will need further development during the next stage of the review, when curriculum drafters and stakeholders shape the aims, purpose, and content for each subject. The report defines digital literacy as "the knowledge, behaviours and confidence required to use technologies and computer systems creatively, safely and effectively" (DfE, 2025b, p.36), with the example of D&T using 3D modelling. We know that digital literacy in D&T already goes further than this with computer aided design (CAD), digital fabrication (including 3D printing), and programming microcontrollers (DfE, 2013, 2015a, 2015b), for example. We suggest that the scope of digital literacy in D&T should include digital collaboration, communication and presentations.

Finally, oracy. Using precise terminology to articulate ideas, concepts and process to others and for a range of audiences has gradually faded from the D&T curriculum. Yet language is what enables pupils to think clearly and engage in meaningful conversations about design with teachers, peers, and eventually, for some, with professionals across the breadth of design practice. The next phase of the national curriculum development offers space to revisit and research effective strategies for teaching and pupils learning design and technology vocabulary that go beyond a simple word wall or textbook glossary.

Future school planning must move past form-filling exercises and formulaic, assessment-driven portfolios, that merely show where and when these applied knowledge areas are taught, learned, and demonstrated. In D&T, we have an opportunity to share what is already being done and what more we could showcase to other subjects.

Access, Equity, and Assessment

The Report also reaffirms D&T's status as a foundation subject at key stages 1 to 3 (primary through to lower secondary) and as an entitlement subject at key stage 4 (upper secondary) in all state schools, placing it back as an essential component of a general education for all children in compulsory education. However, it also acknowledges a troubling picture of declining access and participation in D&T, evident through GCSE and A Level entries, which has been an issue since 2004 (McLain, 2025a). Only 57% of state-funded schools entered pupils for GCSE D&T in 2024/25, with access significantly lower in schools serving disadvantaged communities. The analytical annex (DfE, 2025c) highlights persistent disparities in uptake by socio-economic status, gender, and special educational needs. For example, pupils from disadvantaged backgrounds and those with special educational needs and/or disabilities (SEND) are markedly underrepresented in D&T entries, raising concerns about equity and inclusion. This suggests we need to investigate schools' structural systems and decisions made by D&T teachers that may be causing or affecting these disparities. Our view is that if a recommendation for inclusive design to be embedded within the D&T curriculum then, as a subject, we must reflect on our pedagogical, curriculum and assessment decisions; including what we exclude and consign to the past.

A comparative analysis with the A&D curriculum underscores these concerns. A&D enjoys significantly broader access, with 94% of schools offering qualifications in the subject. Gender participation is more balanced, and the subject benefits from a stronger cultural and creative education narrative. Moreover, A&D's assessment model, which includes substantial coursework, contrasts with D&T's more examination-centric approach. The Review's call to reduce the volume of GCSE examinations and explore alternative assessment methods could benefit D&T, but only if accompanied by structural changes to its qualification design.

Policy and Progression

The proposal to remove the English Baccalaureate (EBacc) as a performance measure may offer some relief, potentially freeing up curriculum space for practical and creative subjects, like D&T, that were marginalised under the last curriculum review (DfE, 2025d, Whittaker, 2025, Hardy 2017). Yet, the retention of the EBacc's structure within Progress 8 as an "Academic Breadth" bucket suggests that the underlying hierarchies of subject value may persist. Without a more fundamental rebalancing of accountability measures, D&T risks remaining marginalised in the curriculum offer of many schools. This should be a cautionary tale for other countries around

the world as they review their curricula; particularly where ideologically narrow conceptions of knowledge rich curricula dominate (McLain, 2025b).

The Food and Nutrition Dilemma

Finally, the Review's treatment of food and nutrition (F&N) represents a significant shift, renaming the former "Cooking and Nutrition" and granting it distinct aims and a purpose of study within D&T, as a "parent" subject DfE, 2025b, 2025d). While this acknowledges the subject's broader scope (emphasising practical cookery, sustainability, and healthy eating) it stops short of elevating F&N to a standalone subject, as some stakeholders advocated. This decision reinforces its dependency on D&T, which risks constraining its identity and progression pathways, despite the Report's call for clearer curriculum detail and stronger post-16 routes into food-related careers. The implications for D&T are twofold: on one hand, the integration maintains the historic connection of food, as a material for designing and making, within D&T by embedding life skills and interdisciplinary links; on the other, it may dilute focus on core design principles if F&N dominates practical skill development. Ultimately, the review's approach reflects a compromise, strengthening food education without fully resolving tensions around subject autonomy and curriculum coherence. The decision to have separate stakeholder groups for D&T and F&N (with little interaction between the two) during the review process reinforced the divisions, with the recommendations failing to grapple with the complexity of the relationship between food a D&T imposed in the last review. The Review effectively kicks the can down the road, leaving the D&T and F&N communities to work with potentially unresolvable issues or a braver future review.

Conclusion

The Review offers a mixed outlook for D&T. It articulates a progressive and relevant vision for the subject but stops short of addressing the structural and systemic barriers that have led to its marginalisation. Although the panel may argue this was beyond their remit, ensuring D&T thrives within a world-class curriculum requires policymakers to go beyond curriculum reform and tackle issues of access, equity, assessment, and progression.

For equity in D&T, strategic support for the subject and its education community must be addressed through both policy and practice. This includes:

- Targeted investment in teacher education and development, particularly in schools serving more disadvantaged communities.
- Infrastructure funding to ensure all schools have access to the resources (including appropriate tools, materials, and spaces) needed for high-quality D&T education.
- Inclusive curriculum design that reflects diverse learners' needs, interests, and lived experiences.
- Assessment reform that values practical and creative work, reducing reliance on high-stakes examinations that disadvantage certain groups.

Only then can D&T fulfil its potential as a vital bridge between creativity, design, technology and the future of life and work - where all pupils can flourish.

References

- DfE (2025d). *Government Response to the Curriculum and Assessment Review: November 2025*. <https://www.gov.uk/government/publications/curriculum-and-assessment-review-final-report-government-response>
- DfE (2025c). *Curriculum and Assessment Review: Analytical Annex to the Final Report: November 2025*. <https://www.gov.uk/government/publications/curriculum-and-assessment-review-final-report>
- DfE (2025b). *Curriculum and Assessment Review: Building a world-class curriculum for all: Final Report*. <https://www.gov.uk/government/publications/curriculum-and-assessment-review-final-report>
- DfE (2025a). *Curriculum and Assessment Review: Interim Report*. <https://www.gov.uk/government/publications/curriculum-and-assessment-review-interim-report>
- DfE (2015b). *Design and Technology GCE AS and A Level Subject Content*. <https://www.gov.uk/government/publications/gce-as-and-a-level-design-and-technology>
- DfE (2015a). *Design and Technology GCSE Subject Content*. <https://www.gov.uk/government/publications/gcse-design-and-technology>
- DfE (2013). *National curriculum in England: design and technology programmes of study*. <https://www.gov.uk/government/publications/national-curriculum-in-england-design-and-technology-programmes-of-study>
- Hardy, A. L. (2025). *A subject in search of a purpose: the evolving identity of design and technology education* [online]. London: Edge Foundation. Available at: <https://www.edge.co.uk/research/learning-from-the-past/the-evolving-identity-of-design-and-technology-education/>
- Hardy, A. L. (2017). How did the expert panel conclude that D&T should be moved to a basic curriculum? In E. W. L. Norman, & K. Baynes (Eds.), *Design epistemology and curriculum planning*. Loughborough Design Press.
- McLain, M. (2025a, November 3). Design and technology's practical and creative skills should see it revived in the school curriculum. *The Conversation*. <https://doi.org/10.64628/AB.57tkaqyxk>
- McLain, M. (2025b). *How to Talk to Knowledge-Rich Ideologues about Design and Technology Education*. <https://www.linkedin.com/pulse/how-talkknowledge-rich-ideologues-design-technology-education-matt-d4zre>
- McLain, M., Bell, D., Wooff, D. and Morrison-Love, D. (2019). How technology makes us human: cultural and historical roots for design and technology education. *Curriculum Journal*, 30(4), 464-483. <https://doi.org/10.1080/09585176.2019.1649163>
- Whittaker, F. (2025, November 5). DfE ignores Francis review and proposes sweeping Progress 8 reform. *EducationScape*. <https://educationscape.com/news/dfe-ignores-francis-review-progress-8-reform>

Abstracts

In this section we present the abstracts for each research article published in this issue of the journal. The abstracts are arranged in the same order as the full articles. We hope this is a useful addition to the journal and welcome feedback on the approach.

The way Technology Teachers Think: The Role of Metaphor and Reflection for Technology Education practice

Andreas Larsson, Linköping University, Sweden

Abstract

This study investigates how technology teachers reflect on their practice by examining the metaphorical structures that underpin their reasoning. Drawing on Conceptual Metaphor Theory and supported by an AI-assisted Metaphor Identification Procedure (MIP), the analysis focuses on recurring metaphorical themes that shape how teachers make sense of challenges, plan instruction, and imagine future classroom scenarios. The results reveal a set of interrelated themes—such as time as a resource, learning as motion, teaching as burden, and structure as cohesion—that reflect and reinforce a view of teaching as a managed and goal-oriented activity. These metaphors are not merely descriptive devices; they function as cognitive tools that organise experience and support pedagogical decision-making. By framing teaching through metaphors of motion, containment, construction, and effort, teachers can navigate complex classroom dynamics and articulate a coherent sense of professional agency. The findings suggest that metaphor plays a dual role in reflection: both representing experience and guiding prospective reasoning. In this sense, metaphors support what is often described as reflection-for-action, where familiar conceptual frames are used to simulate possible futures. By surfacing these metaphorical patterns, the study contributes to a deeper understanding of how teachers conceptualise their work and offers a foundation for professional dialogue and development in technology education.

Generative AI – Creative Pedagogy Versus Creative Application

Dale Addy, Watkins College of Art, Belmont University, USA

Abstract

Generative Artificial Intelligence (GenAI) is rapidly changing and influencing the advertising and graphic design industries. GenAI is reimagining workflows and modifying the skills required for new graduates to secure their first jobs. Agencies are investing in AI technologies, and creative

departments are leveraging GenAI for client engagement and conceptual development. However, design educators have been slow to adapt to this change. This lag risks leaving graduates unprepared for a creative industry in the midst of a technological transition. This qualitative study investigates how GenAI is being utilized in creative departments and how design educators are responding. Based on in-depth interviews with agency leaders and design faculty across the United States, a learning gap was made apparent. Agency leaders see GenAI as an essential creative tool for accelerating ideation and concept visualization, while educators remain cautious and prioritize foundational design training. Early pedagogical adopters understand the benefits of integration, but most curricula incorporate GenAI inconsistently, often relying on individual faculty initiative. The findings reveal the need for design educators to help students embrace GenAI as a tool that expands creative exploration and conceptual thinking. In an effort to remain relevant, graphic design educators must train students in both design and GenAI fundamentals. The ability for graduates to create authentic, human-centered design work will be the definition of success in an AI-driven creative industry.

Assessing Students' Computer Programming Skills: How Technology Teachers in Sweden Evaluate Learning in Grades 4–6

Eva-Lena Bjursten, Mälardalen University, Sweden

Lena Gumaelius, KTH Royal Institute of Technology, Sweden

Eva Hartell, KTH Royal Institute of Technology, Sweden

Abstract

This study aims to deepen the understanding of how computer programming is taught and assessed in Swedish schools by focusing on teachers' perspectives. It explores how technology teachers (teaching years 4–6, students aged 10–12) perceive their roles and responsibilities in teaching computer programming, primarily within the technology subject, and examines what computer programming content is taught and assessed. The research is based on a survey and interviews with seven experienced teachers who taught computer programming before it became mandatory. The findings reveal similar views among the teachers but also significant variation in assessment practices, categorized into four distinct personas, ranging from a strong disciplinary content and product focus to a weaker disciplinary content and process orientation. The discussion reflects upon how these variations may be influenced by teachers' backgrounds, computer programming knowledge, and unclear policy documents. The conclusions suggest that, due to this variety, Swedish students may not be equally equipped with the digital skills needed for participating in a digitalized society. To enhance equity, we argue that teachers need better preparation to effectively integrate computer programming skills across subjects. Additionally, we recommend clearer national guidelines on how to teach computer programming and how to assess this subject content in compulsory education.

Designing for Entrepreneurship: STEM-Based Approaches in Primary Education

Cemre Saraçlar, Independent Researcher, Türkiye

Ahmet Oğuz Akçay, Eskisehir Osmangazi University, Türkiye

Engin Karahan, Middle East Technical University, Türkiye

Abstract

This study aims to enhance primary school students' entrepreneurial skills by integrating STEM education. Employing a qualitative action research design, the study involved 19 fourth-grade students (aged 9–10) selected via convenience sampling. Over a six-week period totaling 18 instructional hours, researchers implemented two STEM-based activities aligned with the study's objectives. Data were gathered from multiple sources, including video recordings, e-portfolios, student journals, researcher journals, and student-generated artifacts. The research was guided by a framework encompassing 22 entrepreneurial skills, categorized into three domains: knowledge, skills, and attitudes. Findings indicate that while students did not demonstrate complete competence in all areas, particularly within the entrepreneurial aptitude domain, they showed notable development in their understanding, practical skills, and attitudes related to entrepreneurship.

A repurposed geometric reasoning model for Engineering Graphics and Design: a conceptual paper

Vernon Candiotes, University of Pretoria, South Africa

Willem Rauscher, University of Pretoria, South Africa

Sonja van Putten, University of Pretoria, South Africa

Abstract

Engineering Graphics and Design is a South African school subject which is foundational to fields such as mechanical, electrical, and civil engineering. However, persistent shortcomings in this subject's instruction have been documented in the South African National Senior Certificate examiners' reports over the past decade. These issues stem primarily from ineffective instructional strategies and a lack of structured reasoning development. These methodological deficiencies may influence the development of learners' visuospatial reasoning skills and conceptual understanding. The situation is exacerbated by the fact that no model for developing such conceptual understanding and reasoning currently exists in the Engineering Graphics and Design field. The need for such a model prompted our search for a suitable model for the structured development of visuospatial reasoning skills, culminating in this conceptual paper. We address the gap by demonstrating how the van Hiele model of geometric reasoning can be particularised to suit the needs for the development of visuospatial reasoning skills in this subject. Our methodology involved the extraction of nine cognitive descriptors from the

relevant literature dealing with the van Hiele model. We explain how these descriptors align with Engineering Graphics and Design reasoning requirements. The proposed model offers both diagnostic capabilities for assessing student reasoning levels and instructional guidance for systematic skill development. It is recommended that empirical studies be conducted to test the usability of this repurposed model both in teaching and in the evaluation of the levels of reasoning in assessments.

The invisible remains invisible: a study of systems thinking in compulsory school students' descriptions of a wastewater system

Nina Emami, KTH Royal Institute of Technology, Sweden

Susanne Engström, KTH Royal Institute of Technology, Sweden

Claes Klasander, Linköping University, Sweden

Abstract

This study investigates how ninth-grade students in Swedish compulsory school describe and explain a technological system: the wastewater system. The analysis focuses on students' verbal explanations while illustrating their self-drawn models of the system. Eleven students (aged 15–16) participated through semi-structured individual interviews. Transcripts and models were analysed using Hallström et al.'s (2022) classification model for system understanding and thematic analysis. The results indicate that most students were able to identify the system's purpose, namely, the collection and treatment of domestic wastewater, and describe components such as household outlets, sewer pipes, and treatment plants. However, their descriptions were largely linear and focused on visible components, such as inlets and manholes. Few references were made to energy flows, information control, system boundary, or interdependencies with other systems. Most students' reasoning remained at the Multistructural level; only two demonstrated relational understanding, and none reached an extended abstract level. The thematic analysis revealed that students faced difficulties in understanding temporal processes, feedback mechanisms, and the consequences of system failures, highlighting difficulties in grasping system complexity. The study calls for instruction that explicitly makes hidden structures, interconnections, and sustainability aspects visible in technological systems. It proposes combining student-generated drawings with visualizations, simulations, and structured reflection to promote deeper and more transferable systems thinking in technology education. Although grounded in a Swedish context, the findings and suggested teaching strategies may inform broader educational settings and contribute to strengthening systems thinking as a core competence in technology education globally.

A Serious Game Proposal for Raising Awareness on Sustainable Development in the Built Environment

Burcu Olgen, Concordia University, Canada

Negarsadat Rahimi, Concordia University, Canada

Carmela Cucuzzella, Université de Montréal, Canada

Abstract

Interactive serious games enhance science-based communication and promote deeper learning about sustainable development. It is yet undiscovered that how can AI-augmented interactive experiences enhance the engagement and spread awareness. This study proposes an AI-augmented digital serious game in public installation format. First, the study introduces a serious board game centered on Sustainable Development Goal (SDG) 11 to test the learning aspects and the engagement of the game. The study hypothesizes that a serious game with a clear message, engaging mechanics, and appealing design can significantly enhance understanding of sustainability's relevance to everyday life. Using a Research through Design (RtD) approach, the study incorporated iterative feedback from pilot tests. These tests highlighted the effectiveness of problem-solving and group discussions in fostering engagement. The insights directly informed the design of the digital version, which emphasizes streamlined and accessible gameplay.

Design Thinking in educational publications: A document analysis of books issued by Turkish Public Institutions and implications for the Technology and Design course *

Ahsen Öztürk, Kütahya Dumlupınar University, Türkiye

Abstract

This research aims to investigate how the design thinking (DT) approach in education is defined and implemented in related books published by public institutions in Türkiye. The document analysis method, a qualitative research method, was used for data collection and analysis. Seven books published by the Republic of Türkiye Ministry of National Education (MONE) and the Scientific and Technological Research Council of Türkiye (TÜBİTAK) were selected as the data. Findings indicate that DT is perceived as a human-centered and interdisciplinary problem-

* This article was produced from the study titled "What Does Design Thinking Mean in Turkey? Analysis of DT-related Books Published by Public Institutions", which was presented as an extended abstract at EDUCONGRESS 2022 (International Education Congress) on 18.11.2022.

solving process that requires a set of skills and mindsets and incorporates some values associated with 21st-century skills. In the books, the matter of how to develop a designer's mindset and skills in non-designers – teachers and students – is generally overlooked or under-emphasized. Therefore, the DT approach in education is not comprehended and practiced as a holistic approach that requires the interaction between relevant processes, mindsets, and tools. Considering the findings, incorporating the human-centered, experimental, and collaborative characteristics of the DT approach into the educational culture or teaching method can help teachers and students to adopt DT as a holistic approach rather than just a problem-solving process. The DT approach can also be employed as a tool to establish a context for technology teaching or integration. In line with this, some strategies are proposed to strengthen the integration of the DT approach within *Technology and Design* education. This research is considered significant in terms of providing teachers with a perspective on the DT approach and how it is integrated into *Technology and Design* education.

Recurriculation of Engineering, Technology, and Technical Education Programmes for the adoption of Industry 5.0

Sunkanmi Afeez Yekinni, University of Nigeria, Nsukka, Nigeria

Theresa Chinyere Ogbuanya, University of Free State, South Africa

Abdifatah Ahmed Ali Afyare, Salaam University, Somalia

Abstract

Industry 5.0 is a new emergent industrial revolution that admits and promotes mutual and coordinated interaction of industrial workers' brains and creative skills, and artificial intelligence machines' qualities to maximize production in industries. Thus, the advent of Industry 5.0 demands new skills, knowledge, attitude and responsibilities/roles from workers to enable them to fit the positions. Consequently, Industry 5.0 has significant implications for engineering, technology and technical education programs. These programs need to be reshaped for the purpose of producing worthwhile graduates that can easily be absorbed into Industry 5.0. However, this article focuses on the 'recurriculation' of engineering, technology and technical education programs for adopting Industry 5.0. The article is anchored on a literature review. Specifically, the article dwells briefly on the pre-industrial revolution, Industry 1.0, Industry 2.0 and Industry 3.0. The article explicates on Industry 4.0 and Industry 5.0. Similarly, the article identifies problems that emanated during the Industry 4.0 era. It explains the importance of human beings in industries. Also, this article explains the needs for improving the knowledge, skills and attitude of industrial workers during Industry 5.0. Being a program where knowledge, skills and attitude needed in industry 5.0 can be acquired, the article briefly conceptualizes engineering, technology and technical education. Furthermore, the article explains the concept of recurriculation of engineering, technology and technical education programs. Finally, the chapter explains the phases for the recurriculation of engineering, technology and technical education programs.

The way Technology Teachers Think: The Role of Metaphor and Reflection for Technology Education practice

Andreas Larsson, Linköping University, Sweden

Abstract

This study investigates how technology teachers reflect on their practice by examining the metaphorical structures that underpin their reasoning. Drawing on Conceptual Metaphor Theory and supported by an AI-assisted Metaphor Identification Procedure (MIP), the analysis focuses on recurring metaphorical themes that shape how teachers make sense of challenges, plan instruction, and imagine future classroom scenarios. The results reveal a set of interrelated themes – such as time as a resource, learning as motion, teaching as burden, and structure as cohesion – that reflect and reinforce a view of teaching as a managed and goal-oriented activity. These metaphors are not merely descriptive devices; they function as cognitive tools that organise experience and support pedagogical decision-making. By framing teaching through metaphors of motion, containment, construction, and effort, teachers can navigate complex classroom dynamics and articulate a coherent sense of professional agency. The findings suggest that metaphor plays a dual role in reflection: both representing experience and guiding prospective reasoning. In this sense, metaphors support what is often described as reflection-for-action, where familiar conceptual frames are used to simulate possible futures. By surfacing these metaphorical patterns, the study contributes to a deeper understanding of how teachers conceptualise their work and offers a foundation for professional dialogue and development in technology education.

Keywords

Conceptual metaphor theory, Metaphorical thinking, Teachers' reflection, Technology education

Introduction

Research into the metaphorical nature of teachers' reflections has become a well-established approach to understanding how language influences the way teachers perceive their curricula (Worden-Chambers, 2020), professional identity (Authors-a; Martínez-de-la-Hidalga & Villardón-Gallego, 2017; Thomas & Beauchamp, 2011), and their underlying pedagogical beliefs (Alger, 2009; Authors-c; Martínez et al., 2001). For example, Alger (2009) found that teachers often revise their metaphors for teaching throughout their careers, reflecting changes in their professional experiences and educational settings. Similarly, Russell and Johnston (1988) identified patterns of conceptual re-framing as teachers respond to classroom challenges and organisational demands. Even short-term interventions, such as teacher education courses, can influence metaphor use, shifting language from general clichés to more process-oriented reasoning (Kartal, 2020). Therefore, to explore these dynamics in greater depth, it is essential to uncover the underlying frameworks that shape teachers' perceptions of their practice – that is, the teachers' use of conceptual metaphor (Larsson, 2023).

Reflection – understood here as the mental processes involved in solving problems or understanding complex situations before (reflection-for-action), during (reflection-in-action), and after (reflection-on-action) teaching – has long been recognised as a valuable resource for understanding and improving professional practice (e.g., Clarke & Hollingsworth, 2002; Henze & Barendsen, 2019; Larsson & Stolpe, 2024; Schön, 2017). Reflection, however, is not a neutral or purely rational process. Instead, it can be understood as a tool through which teachers access, interpret, and reconfigure different forms of professional knowledge. When teachers describe teaching as “building¹ a foundation” or “navigating obstacles,” they are not merely using figurative language; they are engaging in a form of knowledge organisation, drawing on prior experiences, relating them to disciplinary norms, and imagining future classroom actions (see, e.g., Gibbs, 2006b; Grady, 1997). Nevertheless, little is known about how these reflective processes operate across time—before, during, and after teaching—or how they function in the specific context of technology education.

There are several reasons why technology education offers a particularly compelling context for examining the metaphoric nature of teachers’ reflection. Firstly, it evolves swiftly as new digital tools and pedagogical methods are introduced, demanding that teachers continually update their professional knowledge and skills. At the same time, those teaching programming and technology often come from highly diverse educational and professional backgrounds (Larsson & Stolpe, 2024; Reinsfield & Lee, 2021). Furthermore, technology education is characterised by fuzzy disciplinary boundaries, as it draws on knowledge from fields as varied as engineering, computer science, and the social sciences, without a single, well-defined disciplinary core. This combination of rapid technological change, diverse teacher profiles, and ambiguous disciplinary borders makes reflection on one’s practice—and an understanding of the metaphors shaping this reflection—significant. Therefore, this study aims to explore the cognitive structures that influence how technology teachers reflect on their practice. The following research questions have guided this investigation:

In what ways are conceptual metaphors associated with teachers’ experiences of teaching compulsory technology education?

In what ways do these metaphors shape shared or collective understandings of technology education?

Theoretical framework

The present study uses Conceptual Metaphor Theory (CMT) as described by Lakoff and Johnson (1980). Cognitive metaphor theory (CMT) proposes that knowledge originates from mappings between sensorimotor experiences in the real world and abstract concepts, which are then expressed through metaphorical language (Gibbs, 2006a, 2006b; Grady & Johnson, 1997; Lakoff & Johnson, 1999). Furthermore, CMT contends that some features of a conceptual metaphor are emphasised while others are de-emphasised - known as selective mapping. This results in what Koller (2020) describes as a “highlighting and hiding” in discourse, which affects perceptions of what is relevant, problematic, or possible in their teaching practice (Larsson,

¹ Metaphoric expressions will henceforth be noted using underlined font.

2022). Empirical research indicates that conceptual metaphors reflect fundamental aspects of professional knowledge and beliefs (e.g., Alarcón et al., 2019; McGarr, 2022; Munby, 1987).

One powerful role of conceptual metaphors is to develop a broader narrative (Falck & Okonski, 2022). A metaphorical scene involves actors, motivations, and actions taking place on a stage with backdrops and props. Depending on how the stage is arranged, some roles and actions are more likely to be performed than others. For example, when teachers view the classroom as a “garden” or a “battleground,” scenes are triggered that direct their attention, influence their interpretation, and shape their instructional choices based on their personal beliefs (see Koller, 2020). By supporting the flow of pedagogical knowledge, conceptual metaphors affect both the content and form of teacher reflection, helping teachers to understand ongoing situations, envision future practice, and articulate professional judgment (Larsson & Stolpe, 2024).

Methodology

Data collection

The study used data from semi-structured interviews (N = 10) with Swedish practising technology teachers, focusing on participants’ material preconditions for teaching technology education. All teachers were licensed to teach grades 4-6 (n = 6) and 7-9 (n = 4). Each interview lasted between 30 and 45 minutes. The interviews were conducted during and transcribed in real-time using Microsoft Teams (Nov-Dec 2023). The transcripts were then manually compiled into a single .txt file, resulting in a dataset of 29,134 words. No personal or contextual metadata was included in the analysed dataset. As a result, specific excerpts or coded units cannot be traced back to individual informants or interview sessions, ensuring the informants’ complete anonymity. Before the interviews, all informants received detailed information about the study’s purpose, including assurances of complete anonymity. They were also informed—in writing and verbally—about the study’s objectives, potential risks of participation, procedures for withdrawing, and data management, to which they all provided oral informed consent. Consequently, the study complies with the ethical guidelines outlined in *Good Research Practice* by the Swedish Research Council (2024).

Inspired by the PCK map approach, a theory-informed interview guide emphasising (1) the teacher’s educational background and vocational experiences, (2) the material and organisational preconditions for teachers’ practice (the learning environment), and (3) their planning, teaching, assessment, and reflection practices was developed to reflect the Refined Consensus model of PCK (RCM) (Carlson et al., 2019).

Analytical framework

The study’s analysis is based on the idea that “metaphors can be described by their position in a hierarchy according to the level of abstractness at which they are classified” (Charteris-Black, 2004, p. 244). Recognising such hierarchies can help in understanding why certain metaphors are used in specific discourses and their role in shaping, for example, pedagogic ideology and practice (Larsson & Stolpe, 2024; Charteris-Black, 2004; Koller, 2020). Therefore, the analysis will offer insights not only into what the informants say but also into how they say it and the meaning they convey.

The Metaphor Identification Procedure (MIP), developed by the Pragglejaz Group (2007), remains standard for manual metaphor identification. The procedure is based on an algorithm

that compares the meaning of a linguistic construction (often a word) within a specific context to its most basic meaning. Consider, for instance, the statements “building a bridge across the river” and “building a bridge across generations”. In the first case, the linguistic construction refers to constructing a physical structure that spans from one piece of land to another (i.e., the literal use of the term “bridge”). At the same time, the other sentence refers to overcoming differences in, for instance, ideology among age groups (i.e., the metaphorical use of the word “bridge”) – i.e., an indication that the understanding is conceptualised through the conceptual metaphor CONNECTION/UNDERSTANDING IS BUILDING A BRIDGE².

An AI-assisted MIP analysis for exploring teachers’ use of metaphors

With the increasing integration of AI in linguistic and discourse studies, researchers have examined how NLP systems can mimic or support MIP-based processes (Shutova, 2010). Most studies emphasise that although AI can improve scalability and consistency, it faces challenges with nuanced metaphor understanding, especially in ambiguous or reflective texts; therefore, researcher supervision or calibration remains necessary (Koller, 2020; Tsvetkov et al., 2014).

In this case, the study’s AI-assisted MIP-analysis utilises ChatGPT’s natural language processing (NLP) abilities, providing a systematic and replicable method for identifying minimal semantic units and conceptual metaphors for further qualitative or quantitative evaluation. During the analysis process, the author has directed each analytical step according to the MIP procedure by offering clear, operational instructions where required. ChatGPT has carried out analyses, exported results, and adapted its approach in real-time based on my feedback, ensuring that each phase aligns with the study’s specific research aims and upholds standards of methodological rigour and transparency (Table 1).

Table 1. Summary of the roles of the Author and ChatGPT and the traceability of the analysis. The table was generated using ChatGPT

Step	The Author	ChatGPT	Traceability Method
Define metaphor domain	X		Documented in prompts
Upload and structure data	X		File numbering, data structure
Extraction/filtering		X	Numbered units, code available
MIP analysis		X	Example/number links
Export/document results	X (request/review)	X (execute/export)	Downloadable outputs

The analysis proceeded according to the MIP-protocol (Pragglejaz Group, 2007):

- Extraction of semantic units (sentences): The data corpus was split into sentences by ChatGPT (a sentence is defined by punctuation marks such as a period [.] , exclamation

² Instances of conceptual metaphors will henceforth be noted using CAPITALISED letters.

mark [!], or question mark [?] and is assumed to represent a coherent thought or meaning-bearing unit within the text) to identify units containing common content words in the corpus. Each sentence (semantic unit) was marked with a unique number for traceability within the corpus.

- “Collaborative” metaphor analysis: MIP analysis was applied to the corpus. The author oversaw the analysis for the first 50 units (the practice run), correcting the LLM by providing additional context, if needed. Based on this feedback, the LLM adjusted its analytical approach, improving accuracy and alignment in subsequent analyses. After the training, ChatGPT performed MIP analyses on the remaining semantic units.
- MIP analysis: ChatGPT was prompted to automatically (1) perform a word-by-word MIP analysis of selected expressions/units, (2) allow the author to approve/improve each analysis, and (3) tabulate the result and export it to Microsoft Word.

Results

Overview of emergent conceptual metaphors

An initial MIP analysis, supported by ChatGPT, identified four recurring metaphorical themes in the corpus. Learning and development were often depicted as movement along a path, reinforcing a linear and goal-oriented view of progress. This framing closely relates to metaphors of time as a resource – something to be managed, protected, or spent – since progress along a path is seen as dependent on how effectively the teacher utilises time. A common theme throughout the teachers’ reflections is the use of construction and engineering metaphors when describing their role in the classroom. In this sense, teachers often saw themselves as organisers, builders, or mechanics, figures responsible for assembling, maintaining, and fine-tuning systems designed to support student movement and progress. Throughout the material, pedagogical challenges were frequently described using metaphors of weight, obstruction, and resistance—images that introduce tension into an otherwise forward-moving narrative. Lastly, students were sometimes portrayed as receptacles or systems to be guided and fine-tuned, indicating a technical or instrumental relationship that aligns with construction and machinery metaphors. This perspective underpins an understanding of education as a managed process where both teacher and student are parts of a larger, goal-driven mechanism.

Sometimes, the respective frames connect to emphasise values such as control, efficiency, and progression—key elements that shape how teachers view their roles. Each metaphor reinforces the others, fostering a broader mindset in which teaching is perceived as a deliberate, structured process aimed at achieving measurable objectives. The following describes each frame.

TIME IS A RESOURCE

Unit 143. “...tanken är ju liksom de håller ju på och bygger de tycker det är så himla roligt, så tiden går ju och sen märker man att nu är det tio minuter kvar och då blir det bara... nu måste vi bryta, nu måste vi städa. och sen städar vi och så blir det tack och hej.”

“...the idea is, you know, they’re working away and they’re having such a great time, so time just flies by. Then, suddenly, you realise there are only ten minutes left, and it’s

just... now we have to break off, now we have to clean up. So, we clean up, and then it's just thank you and goodbye."

The MIP-analysis has identified two metaphorical expressions: (1) "tiden går" (*time flies by*) and (2) "bryta" (*break off*) and one weak metaphorical, or partly conventionalised expression: "tio minuter kvar" (*ten minutes left*) (Table 2).

Table 2. MIP analysis of unit 143. The table was generated using ChatGPT

Expression	Translation	Basic meaning	Contextual meaning	Metaphoric
tiden går	time flies by	Motion in space	Time passes	YES
bryta	break off	Break apart, physically interrupt	End lesson/activity in an abrupt manner	YES
tio minuter kvar	ten minutes left	Remaining time	Remaining part of the lesson (part-whole-relationship)	WEAK

Overall, the MIP analysis suggests that the teacher conceptualises time through the metaphor TIME IS MOTION, a well-documented schema explored by for instance Lakoff and Johnson (1980) and Núñez and Sweetser (2006). In this framing, time is not static or limited but something that moves—or through which one moves—allowing the teacher to experience lessons as unfolding along a temporal trajectory.

The analysis also shows that lessons are conceptualised using the metaphor EVENTS ARE OBJECTS THAT CAN BE BROKEN, suggesting that when a lesson reaches its designated end, it is experienced as a rupture or a "break," which requires the teacher to adapt or reorganise the flow of activities. As mentioned earlier, PLANNING is metaphorically described as SHAPING OR ORGANISING OBJECTS INTO A FUNCTIONING, PURPOSEFUL MACHINE – a system in which each component must fit and align within the constraints of time.

Finally, time is seen as a limited "substance" – a conceptual resource that can be "left behind," "used up," or "lost." This interaction between TIME AS RESOURCE and TIME AS SUBSTANCE is somewhat ambiguous but can be understood as a form of metonymy (a part-whole structure). It enables the teacher to frame classroom experiences not as isolated moments, but as points of transition along the temporal trajectory or as general "breaking points" where activity is reorganised, rather than precisely defined moments on a clock.

LEARNING IS MOTION/PATH

Unit 414. "...och så kan man göra såna här ballongbilar... men jag skulle vilja komma längre... men det finns inte riktigt alltså... Man har inte dels tiden under den här tiden som man ska göra det och så klasstorlekarna, grupperna [mellan 22-26 elever] som man har."

*"...and you can make these balloon cars... but I'd like to go further... but there just isn't really... You don't really have the time * during the period when you're supposed to do it, and then there's the class sizes, the groups [between 22–26 students] that you have."*

The MIP-analysis has identified two metaphorical expressions: (1) “komma längre” (*go further*) and (2) “ha tid/grupperna” (*have time/groups*), and one weak metaphorical, or partly conventionalised, expression: “under den här tiden” (*during this time*) (Table 3).

Table 3. MIP analysis of unit 414. The table was generated using ChatGPT

Expression	Translation	Basic meaning	Contextual meaning	Metaphor
komma längre	get further, go further	To move further in space	Develop, make progress	YES
under den här tiden	during this period	Quantity, length	Available amount of time	WEAK
ha tiden, ha grupperna	have the time, have groups	Own, possess	Time and groups as entities to handle	YES

Overall, the MIP analysis indicates that the teacher understands development through the metaphor PROGRESS IS MOTION, which is closely linked to the broader metaphor CHANGE OF STATE IS MOTION identified by Grady (1997). In this view, development is not static or abstract, but something that happens through movement, enabling the teacher to see pedagogical progress as a process that unfolds over time.

This metaphorical mapping is further reinforced through its link to temporal framing. Although the expression “under den här tiden” (“during this period”) is classified as a weak or partly conventionalised metaphor, it adds to the overall metaphoricity of the utterance by anchoring motion in time. Progress then depends on how time is perceived and structured as something that can enable or restrict movement.

Additionally, the analysis reveals that the teacher views time and students as resources—entities that can be possessed, allocated, or utilised. This reflects a metaphorical framing where TIME and STUDENTS ARE RESOURCES FOR PROGRESS, linking organisational factors like time management and group size directly to the teacher’s perceived ability to advance learning. In this way, progress is not only associated with movement but also seen as dependent on access to and control over limited educational resources.

PROGRESS IS MOTION

Unit 60. “nej, då kanske då blir det ju till exempel, men då går jag och sätter mig kolla lite hur det går den gruppen och försöker få till se till så att alla blir delaktiga och men också typ hur man kan liksom dela upp det för att inte det ska...”

“No, then maybe, for example, I’ll go and sit down to see how that group is doing and try to make sure that everyone takes part, but also, like, how you can divide things up so that it doesn’t...”

The MIP-analysis has identified two metaphorical expressions: (1) “hur det går” (*how it goes*) and (2) “dela upp det” (*split it up*), and one weak metaphorical, or partly conventionalised, expression: “få till att” (*ensure participation*) (Table 5).

Table 4. MIP analysis of unit 60. The table was generated using ChatGPT

Swedish expression	Translation	Basic meaning	Contextual meaning	Metaphor
hur det går (gruppen)	how it goes (for the group)	Motion, moving around the room	The group's growth and achievement	YES
få till/se till att (delaktiga)	get to work/ensure participation	Do, accomplish	Foster inclusion, achieve something abstract	WEAK
dela upp det	divide/split it up	Split a physical object	Break down tasks or projects into components	YES

As in Unit 414, the MIP analysis indicates that students' progress and development are conceptualised through the metaphor PROGRESS IS MOTION. However, unlike in previous examples, there are no explicit links to time or broader transformational change. This suggests that the motion metaphor relates to more immediate or short-term progress, rather than long-term learning or development.

Furthermore, the metaphor ASSIGNMENT IS AN OBJECT THAT CAN BE DIVIDED AMONG STUDENTS arises as a central conceptual framework. The expression "vara delaktig" ("taking part") is closely associated with the idea of having or managing parts of an assignment, as if it were a tangible object meant to be shared. This perspective frames collaboration and progress within the group as collective acts of building.

In this sense, collaborative learning becomes a hybrid process: on one hand, constructing a shared object (non-metaphorical), and on the other, building a shared understanding or reasoning (metaphorical). The metaphor thus reflects an implicit distinction between theory and practice, where group work bridges the two by treating both material tasks and conceptual reasoning as tangible, distributable resources.

STRUCTURE/GROUP IS TIE TOGETHER

112. "det är det att man får eleverna känna av att det finns en röd tråd och man kan väva ihop det att allt hör ihop."

It's about giving the students a sense that there is a common thread and that you can weave things together so that everything is connected

The MIP-analysis has identified three metaphorical expressions: (1) "känna av att det finns en röd tråd" (*sense that there is a red thread*), (2) "väva ihop det" (*weave it together*), and (3) "allt hör ihop" (*everything is connected*) (Table 4).

Table 5. MIP analysis of unit 112. The table was generated using ChatGPT

Expression	Translation	Basic meaning	Contextual meaning	Metaphor
känna av att det finns en röd tråd	sense that there is a red thread	Feel a physical thread	Perceive a unifying idea or structure	YES

väva ihop det	weave it together	Weaving threads into fabric	Integrate teaching into a whole	YES
allt hör ihop	everything is connected	Be physically connected	Parts of the teaching are connected	YES

The MIP-analysis of Unit 112 shows a view of technology education as a network of ideas, leading to the metaphor TECHNOLOGY EDUCATION IS A NETWORK OF IDEAS. This metaphor bases itself on the idea of IDEAS AS OBJECTS, which are seen as entities that can be linked, woven, or structured into a coherent whole. It is similar to the previously identified frame TECHNOLOGY EDUCATION IS A MACHINE. However, here the mechanical imagery is replaced with textile metaphors—such as the “red thread” or “weaving things together”—that highlight interconnectedness rather than mechanical function.

More specifically, the metaphor IDEAS ARE OBJECTS THAT CAN BE WOVEN OR LINKED TOGETHER draws on the deeper cognitive schema RELATEDNESS IS PHYSICAL INTERCONNECTEDNESS (Grady, 1997). This enables planning to be metaphorically seen as organising and integrating objects—an act of assembling ideas into a structured pedagogical fabric. In this framing, teaching becomes a process of aligning and connecting conceptual threads, suggesting that coherence in curriculum or instruction is achieved by weaving disparate elements into a unified whole.

OBSTACLE IS CHALLENGE/BURDEN

38. “det är 28 elever när jag har teknik i 90 minuter det är en stor grupp och då kan det bli rätt tungt ibland så då gäller det att vara tydlig.”

38. There are 28 students when I teach technology for 90 minutes. It's a large group, and it can get quite heavy at times, so it's important to be clear.

The MIP-analysis has identified three metaphorical expressions: (1) “stor grupp” (large group), (2) “blir rätt tungt” (get quite heavy), and (3) “vara tydlig” (be clear) and one weak metaphorical, or partly conventionalised, expression: “det gäller att vara tydlig” (it's important to be clear). (Table)

Table 6. MIP analysis of unit 38. The table was generated using ChatGPT

Swedish expression	Translation	Basic meaning	Contextual meaning	Metaphor
stor grupp	large group	Physical size (big object)	Many people in the group	YES
bli rätt tungt	get quite heavy	Physically heavy, weighs a lot	The situation becomes demanding or exhausting	YES
det gäller att vara tydlig	it's about being clear	A rule applies; something is valid	It is important/necessary to be clear	WEAK
vara tydlig	be clear	Physically see-through, not cloudy	Easy to understand, unambiguous	YES

The MIP analysis of Unit 38 uncovers a view of teaching as a physically demanding task, leading to the metaphors TEACHING IS PHYSICAL LABOUR and CHALLENGES ARE WEIGHT. This metaphor extends the mapping DIFFICULTIES ARE PHYSICAL BURDENS (Grady, 1997), where the teacher is seen as someone who must carry or handle the instructional load. The mention of a “large group” is not just about numbers but is metaphorically represented through the schema QUANTITY IS SIZE, indicating that a high number of students is equated with a substantial mass. In this context, teaching is seen as a labour where the “weight” of the classroom must be carried and managed.

Furthermore, the metaphor CLARITY IS VISUAL TRANSPARENCY arises through the phrase “it’s about being clear,” drawing on the deeper schema KNOWING IS SEEING. In this context, clarity is not just verbal precision but the capacity to make the planning or approach to teaching visible and easily navigable for the student. Additionally, it functions as a coping mechanism that helps teachers manage the instructional load more effectively. Collectively, these metaphors build a pedagogical logic where teaching is seen as a task that demands both physical endurance and visual-spatial precision.

TEACHING IS A JOURNEY

597. ”det kan bli att man kan då ge svar eller kunna försöka förklara... olika ut och det kan ju vara att ibland så kanske man får pausa med någonting för att kunna gå vidare med någonting annat och så det ja”

It might be that you can then provide answers or try to explain... things turn out differently, and sometimes you might have to pause something in order to move on with something else, and so on, yeah.

The MIP-analysis has identified two metaphorical expressions: (1) “ge svar” (*provide an answer*) and (2) “gå vidare med något annat” (*move on to something else*), and one weak metaphorical, or partly conventionalised, expression: “pausa med något” (*pause with something*) (Table 7).

Table 7. MIP analysis of Unit 597. The table was generated using ChatGPT

Swedish expression	Translation	Basic meaning	Contextual meaning	Metaphor
ge svar	provide an answer	Place objects	Formulate/give an answer	YES
gå vidare med ngt annat	move/go on to something else	Move forward	Continue to the next part/moment	YES
pausa med ngt	pause with something	Temporarily stop movement	Temporarily interrupt activity/process	WEAK

The MIP analysis of Unit 597 indicates that the teacher perceives classroom activity using the metaphors AN ANSWER IS AN OBJECT and TEACHING IS A JOURNEY. In this perspective, answers—similar to physical objects—can be “given” to students, suggesting that knowledge is something that can be transferred from one individual to another. This view aligns with the broader metaphorical framework IDEAS ARE OBJECTS (Grady, 1997).

This view of teaching, learning, and communication reflects the well-known CONDUIT metaphor (Reddy, 1979), where knowledge is regarded as a substance that can be packaged into linguistic containers and transmitted via language. As Lakoff and Johnson (1980) argue, this metaphor involves a set of related mappings: (1) IDEAS ARE OBJECTS, (2) LINGUISTIC EXPRESSIONS ARE CONTAINERS, and (3) COMMUNICATION IS SENDING.

In this case, the CONDUIT metaphor is embedded within a broader framework where THE LESSON IS A JOURNEY. This enables communication to be conceptualised not as isolated transmission, but as a series of meaning-making events that unfold “along the way.” In doing so, the metaphor supports a view of classroom discourse as both directional and cumulative—one in which meaning is negotiated through movement across the lesson's unfolding path.

Summary of the results

The analysis identified a set of recurring metaphorical themes that shape how technology teachers consider their practice. These metaphorical themes illustrate how teachers frame their instructional reality using embodied and spatial schemas. As summarised in Table 6, these metaphors form a cognitive ecology that fosters control, clarity, and progression in the classroom.

Table 8. Overview of the main metaphorical themes in teachers' technology education. The table was generated using ChatGPT

Metaphor Family	Source Domain	Target Domain(s)	Example Expressions	Interpretative Function
Time is conceptualised as a container or resource	Container/Resource	Time, Scheduling	"add to the schedule", "get more time"	Organises teaching as the allocation of finite resources
learning and development framed as motion or a journey	Motion/Path	Learning, Development	"go further", "move on", "fall behind"	Frames progress as a journey; supports process orientation
structure and group dynamics described through metaphors of binding or cohesion	Tying/Weaving/Connection	Structure, Group Dynamics	"common thread", "weave together", "keep the group together"	Promotes coherence, integration, and belonging
Challenges conceptualised as obstacles or burdens	Burden/Weight/Obstacle	Work, Challenges	"carry a heavy load", "overcome obstacles"	Highlights the effortful, problem-solving aspect of teaching

Discussion

By drawing on Conceptual Metaphor Theory, this study has identified central aspects associated with teachers' experiences of teaching compulsory technology education and how they shape a shared understanding of technology education (Koller, 2020) and act as cognitive tools through which teachers access, interpret, and reconfigure knowledge (Authors-a; Grady, 1997; Schön, 2017). This suggests that conceptual metaphors do more than describe practice; they help structure the very processes that underpin pedagogical practice.

The results show that the teachers' reflections are framed by a relatively small number of metaphorical themes. While the expressions vary, many share deep conceptual structures grounded in spatial, embodied, and mechanical imagery (Lakoff & Johnson, 1999). Below, these themes are revisited and discussed relative to teachers' reflection and pedagogical sense-making.

Time as a Resource or Container

In several units, time was metaphorically viewed as a resource to be utilised or as a container delimiting possibilities. These metaphors reflect how teachers perceive scheduling constraints and lesson planning, not only as administrative challenges but as forces shaping the kinds of learning experiences that are possible. When teachers say they "don't have time" or that lessons "get heavy," they conceptualise time not as a neutral dimension but as a limited, tangible resource. From a reflective perspective, this framing highlights the idea of teaching under constraint, a condition that influences how teachers envisage, prioritise, and adapt their actions in advance (Schön, 1987; Clarke & Hollingsworth, 2002). Therefore, metaphors of time directly relate to reflection-for-action, i.e. thinking ahead, emphasising the practical and cognitive planning that underpin their behaviour in the classroom.

Learning and Development as Motion

A second prominent theme views learning as movement through space. Teachers described learning as "going somewhere," "reaching a goal," or "seeing how it goes," referencing the schema LEARNING IS A JOURNEY (Grady, 1997; Munby, 1987). This metaphor enables teachers to place themselves and their students along a temporal path, where progress, obstacles, and destinations can be reflected upon. The metaphor offers a framework for organising learning as a process with direction and momentum—one that can be paused, rerouted, or extended. This aligns with previous research indicating that motion metaphors are key to educational reasoning (Munby, 1987; Alarcón et al., 2019). For technology teachers, who often plan through designing step-by-step activities and iterative processes, the motion metaphor assists in managing pace and assessing growth over time.

Structure and Group as Cohesion

Teachers also view the classroom as a unit that must be "held together," "woven," or "kept in check." These metaphors draw on physical concepts of cohesion and structure (Grady, 1997; Langacker, 2002) and imply that group dynamics are experienced as matters of alignment and containment. For example, when teachers talk about needing a "red thread" through their lessons, they highlight the importance of internal consistency and narrative coherence—qualities linked to both planning and communication. This metaphorical framing helps facilitate reflective processes by offering teachers a way to visualise the relational dynamics of their instruction: how individual ideas, student needs, or curriculum components can be integrated

into a coherent whole. In this way, metaphors of cohesion support both conceptual and organisational aspects of pedagogical reflection.

Challenges as Obstacles or Burdens

Finally, pedagogical difficulty was often described as a physical load or as an obstacle to overcome. When teachers call a lesson “heavy” or “tough,” they are referencing the schema DIFFICULTY IS WEIGHT (Grady, 1997). These metaphors not only express emotional strain but also suggest a need for strength, endurance, or clarity in response. They show how teachers experience pressure, not only from workload but also in the demand to stay clear, calm, and in control (Koller, 2020). This framing relates to reflection-in-action, where teachers must quickly evaluate and respond to emerging difficulties (Schön, 1987). Furthermore, by viewing teaching as labour, this metaphor strengthens a perspective of pedagogy as embodied effort—mental and emotional work framed in physical terms.

Conclusions

This study aimed to investigate the cognitive structures influencing how technology teachers reflect on their practice, with a particular emphasis on the role of metaphor in guiding and organising pedagogical reasoning. The findings highlight three key contributions to the field.

First, while earlier studies have often treated metaphor as a reflection of belief or identity (e.g., Alger, 2009; Martínez et al., 2001; McGarr, 2022), this study suggests that metaphor also plays a generative role—enabling teachers to anticipate, simulate, and reason about future teaching scenarios. In this sense, metaphor becomes a tool for what Schön (1987) describes as reflection-for-action, a form of prospective thinking where familiar conceptual frameworks are used to project professional experience forward. These metaphors – TEACHING IS A JOURNEY, TECHNOLOGY EDUCATION IS A MACHINE – are not random linguistic choices but are grounded in embodied image schemas that shape how teachers navigate pedagogical intentions (e.g., Gibbs, 2006b).

Second, the study demonstrates how different metaphorical themes – such as time as a resource, learning as motion, and structure as cohesion – interact and reinforce each other. Together, they create a kind of cognitive ecology through which teaching is understood as a managed, purposeful, and constrained activity. Within this ecology, teachers are often seen as organisers or engineers: professionals who build, align, and sustain educational structures in response to practical and institutional demands.

Third, while the analysis reveals several recurring metaphorical themes in teachers’ reflections, these patterns seem to relate more broadly to pedagogical reasoning than to the specific characteristics of technology education. The metaphors depict how teachers organise, plan, and evaluate their teaching generally. However, they rarely highlight aspects unique to the technology subject, such as its rapid technological development, interdisciplinary nature, or practice-oriented content. Consequently, the findings indicate that teachers’ metaphorical framing largely mirrors universal features of teaching and learning rather than subject-specific aspects of technology education.

By recognising metaphorical patterns in teacher reflection, the study highlights how teachers comprehend their roles, their students, and their subject matter. Metaphors, in this context, are not merely representations of belief but tools for thinking, planning, and visualising what

teaching might become. In this way, conceptual metaphor analysis provides a valuable contribution to our understanding of teacher learning, especially within the evolving and practice-oriented setting of technology education.

While the study offers insight into the reflective discourse and instructional goals of practising technology teachers, it is based on a relatively small sample of interview data and focused primarily on metaphor use in language. Future research could extend these findings by exploring how metaphor operates in other reflective formats, such as planning documents, lesson observations, or peer discussions, and by investigating how metaphor awareness might be integrated into teacher education or professional development. Doing so may help teacher educators and policy-makers better understand the tacit reasoning that underpins pedagogical decision-making, and how such reasoning might be opened up for collaborative inquiry and growth.

Closing remarks and a methodological discussion

In designing this study, I faced a choice between using “traditional” approaches to identifying conceptual metaphors and adopting a more contemporary, AI-assisted implementation of the Metaphor Identification Procedure (MIP). The efficiency offered by AI, particularly when working with large datasets, was appealing from the outset. At the same time, I remained cautious about its limitations in producing nuanced and transparent analyses—qualities essential for metaphor research.

Ultimately, I employed ChatGPT as an “analytical partner”, using it to generate rapid and consistent initial extractions of potential conceptual metaphors. To enhance accuracy, I trained the model to (1) consider the surrounding context by revisiting the corpus and reading text before and after each semantic unit, and (2) perform a dictionary comparison, evaluating contextual meaning against the word’s most basic meaning. All results were exported outside the ChatGPT environment, and I regularly prompted the model to summarise the analysis in progress, ensuring a traceable record of how findings developed over time. Working in this manner is similar to manual metaphor identification, where online dictionaries are commonly utilised.

Reflecting on this process, I was struck by how little of a “shortcut” AI ultimately provided. A recurring challenge was the frequency of metaphor candidates that seemed plausible initially but failed under closer contextual scrutiny. These false positives highlighted the continued necessity of careful, interpretive work. Nevertheless, the processing power of ChatGPT substantially reduced the time needed for data preparation, processing, and documentation, thereby contributing to the transparency of the analysis—a key concern in a field often criticised for relying too heavily on scholarly intuition.

Finally, can ChatGPT draft a methods discussion?

*“Absolutely! Here’s a draft of a **methods discussion** for your article, written in academic English and tailored to your AI-supported, critical metaphor analysis approach. This can be pasted directly into a “Methodological Discussion” section in your paper. If you want it in Word, just say the word!*

This study employed a hybrid method that combines digital, AI-supported extraction with qualitative, theory-driven analysis to investigate metaphor use in Swedish teachers' discussions about technology education. The process was designed to balance the efficiency and reproducibility of automated screening with the depth and contextual sensitivity of human interpretation, in line with the principles of Critical Metaphor Analysis (Charteris-Black, 2004).

Unlike classical summative content analysis, which is primarily concerned with counting the frequency of words, phrases, or themes, our approach was rooted in a critical, context-oriented understanding of language. We employed the Metaphor Identification Procedure (MIP; Pragglejaz Group, 2007) to systematically detect and interpret metaphorical expressions within their discursive context. This method required analyzing not only the literal and contextual meanings of lexical units, but also the ways in which metaphors structure professional reasoning, values, and power relations in educational practice.

A key feature of our workflow was the use of both .txt and .xlsx formats. Excel files enabled richer metadata management, allowing us to retain unit numbers, categories, and analytic comments throughout the process. Automated extraction was conducted using string matching and regular expressions in Python, which accelerated the initial screening for relevant metaphorical domains (e.g., "time is a resource", "learning is building", "status is vertical space"). However, all candidate expressions were subjected to manual, context-sensitive coding to ensure alignment with theoretical frameworks and to minimise false positives.

The iterative, collaborative process between AI and the researcher enhanced both traceability and reliability. All analytical steps—from extraction to coding and summary—were documented and exported in accessible formats (Excel for tabular analysis, Word for narrative reporting), ensuring that results could be reviewed, validated, and replicated by other scholars.

One limitation of the current approach was the absence of personal or contextual metadata in the anonymised interview corpus. While this ensured participant privacy, it also restricted the analysis to discourse-level patterns, precluding person- or case-based comparisons. Additionally, the complexity of metaphorical language—often involving blended or nested metaphors—required continual interpretive reflexivity, especially when moving between Swedish source texts and English academic reporting.

In sum, this methodological design enabled a nuanced and critical investigation of metaphor in educational discourse, harnessing the strengths of both computational efficiency and qualitative insight. The combination of AI-assisted screening and manual MIP-based analysis proved effective for revealing how metaphors shape the framing and evaluation of time, knowledge, and subject status in teachers' professional reasoning." (ChatGPT – May 16th 2025)

References

- Alarcón, P., et al. (2019). "Map, Foundations, Recipe, Burden: Teachers' Conceptual Metaphors on Lesson Planning."
- Alger, C. L. (2009). Secondary teachers' conceptual metaphors of teaching and learning: Changes over the career span. *Teaching and Teacher Education*, 25(5), 743-751. <https://doi.org/https://doi.org/10.1016/j.tate.2008.10.004>
- Carlson, J., Daehler, K. R., Alonzo, A. C., Barendsen, E., Berry, A., Borowski, A., . . . Wilson, C. D. (2019). The Refined Consensus Model of Pedagogical Content Knowledge in Science Education. In A. Hume, R. Cooper, & A. Borowski (Eds.), *Repositioning pedagogical content knowledge in teachers' knowledge for teaching science* (pp. 77-94). Springer Singapore. https://doi.org/10.1007/978-981-13-5898-2_2
- Charteris-Black, J. (2004). Critical metaphor analysis. In *Corpus approaches to critical metaphor analysis* (pp. 243-253). Springer.
- Clarke, D., & Hollingsworth, H. (2002). Elaborating a model of teacher professional growth. *Teaching and Teacher Education*, 18(8), 947-967. [https://doi.org/https://doi.org/10.1016/S0742-051X\(02\)00053-7](https://doi.org/https://doi.org/10.1016/S0742-051X(02)00053-7)
- Clarcken, R. H. (1997). Five Metaphors for Educators.
- Falck, M. J., & Okonski, L. (2022). Procedure for Identifying Metaphorical Scenes (pims): A Cognitive Linguistics Approach to Bridge Theory and Practice. *Cognitive Semantics*, 8(2), 294-322. <https://doi.org/https://doi.org/10.1163/23526416-bja10031>
- Gibbs, R. W. (2006a). *Embodiment and Cognitive Science*. Cambridge University Press.
- Gibbs, R. W. (2006b). Metaphor interpretation as embodied simulation. *Mind & Language*, 21(3), 434-458.
- Grady, J. (1997). Foundations of meaning: Primary metaphors and primary scenes, University of California, Berkeley.
- Grady, J., & Johnson, C. (1997). Converging evidence for the notions of subscene and primary scene. Annual Meeting of the Berkeley Linguistics Society,
- Henze, I., & Barendsen, E. (2019). Unravelling Student Science Teachers' pPCK Development and the Influence of Personal Factors Using Authentic Data Sources. In A. Hume, R. Cooper, & A. Borowski (Eds.), *Repositioning pedagogical content knowledge in teachers' knowledge for teaching science* (pp. 203-223). Springer Nature Singapore. https://doi.org/10.1007/978-981-13-5898-2_9
- Kartal, G. (2020). Collaborative metaphor and anticipatory reflection in preservice teacher education: Is drama the answer? *Teaching and Teacher Education*, 88, 102978. <https://doi.org/https://doi.org/10.1016/j.tate.2019.102978>
- Koller, V. (2020). Analysing metaphor in discourse. In *Researching Discourse* (pp. 77-96). Routledge.
- Lakoff, G., & Johnson, M. (1980). *Metaphors we live by* [Non-fiction]. Chicago: University of Chicago Press, 1980.
- Lakoff, G., & Johnson, M. (1999). *Philosophy in the flesh: the embodied mind and its challenge to Western thought* [Non-fiction]. New York: Basic Books, 1999.
- Langacker, R. W. (2002). *Concept, Image, and Symbol: The Cognitive Basis of Grammar*. Walter de Gruyter Inc.
- Larsson, A. (2022). Reading the Code Between the Lines – Exploring the Structure of metaphors in educational programming resources. Nordic Studies in Science Education.
- Larsson, A. (2023). Metaphor in mind - Programming teachers' knowledge and beliefs in action [Linköping university].

- Larsson, A., & Stolpe, K. (2024). Exploring the metaphoric nature of programming teachers' reflections on action - a case study with teaching in mind. *International Journal of Technology and Design Education*, 34(2), 585-602. <https://doi.org/10.1007/s10798-023-09826-w>
- Martínez-de-la-Hidalga, Z., & Villardón-Gallego, L. (2017). Using metaphors to know the conceptions about the teaching profession in initial teacher education. *International Journal of Educational Psychology*, 6(2), 183-208.
- Martínez, M. a. A., Sauleda, N. s., & Huber, G. L. (2001). Metaphors as blueprints of thinking about teaching and learning. *Teaching and Teacher Education*, 17(8), 965-977. [https://doi.org/https://doi.org/10.1016/S0742-051X\(01\)00043-9](https://doi.org/https://doi.org/10.1016/S0742-051X(01)00043-9)
- McGarr, O. (2022). 'Hitting a brick wall': using conceptual metaphorical theory to explore teachers' conceptions of learning in Computer Science. *Teaching Education*, 1-14. <https://doi.org/10.1080/10476210.2022.2109623>
- Munby, H. (1987). Metaphor and teachers' knowledge. *Research in the Teaching of English*, 377-397.
- Núñez, R. E., & Sweetser, E. (2006). With the Future Behind Them: Convergent Evidence from Aymara Language and Gesture in the Crosslinguistic Comparison of Spatial Construals of Time. *Cognitive science*, 30(3), 401-450. https://doi.org/10.1207/s15516709cog0000_62
- Pragglejaz Group. (2007). MIP: A method for identifying metaphorically used words in discourse. *Metaphor and Symbol*, 22(1), 1-39.
- Reddy, M. (1979). "The conduit metaphor." *Metaphor and Thought* 2: 285-324.
- Reinsfield, E., & Lee, K. (2021). Exploring the technology teacher shortage in New Zealand: The implications for quality teaching and learning. *International Journal of Technology and Design Education*. <https://doi.org/10.1007/s10798-021-09668-4>
- Russell, T., & Johnston, P. (1988). Teachers Learning from Experiences of Teaching: Analyses Based on Metaphor and Reflection.
- Schön, D. A. (1987). *Educating the reflective practitioner: Toward a new design for teaching and learning in the professions*. Jossey-Bass.
- Schön, D. A. (2017). *The reflective practitioner: How professionals think in action*. Routledge.
- Shutova, E. (2010). Models of metaphor in NLP. Proceedings of the 48th Annual Meeting of the Association for Computational Linguistics,
- The Swedish Research Council (2024). Good Research Practice.
- Thomas, L., & Beauchamp, C. (2011). Understanding new teachers' professional identities through metaphor. *Teaching and Teacher Education*, 27(4), 762-769. <https://doi.org/https://doi.org/10.1016/j.tate.2010.12.007>
- Tsvetkov, Y., Boytsov, L., Gershman, A., Nyberg, E., & Dyer, C. (2014). Metaphor detection with cross-lingual model transfer. Proceedings of ACL,
- Worden-Chambers, D. (2020). The role of conceptual metaphors in novice teachers' developing curricular knowledge: a case from second language writing. *Teacher Development*, 24(2), 184-203.

Generative AI – Creative Pedagogy Versus Creative Application

Dale Addy, Watkins College of Art, Belmont University, USA

Abstract

Generative Artificial Intelligence (GenAI) is rapidly changing and influencing the advertising and graphic design industries. GenAI is reimagining workflows and modifying the skills required for new graduates to secure their first jobs. Agencies are investing in AI technologies, and creative departments are leveraging GenAI for client engagement and conceptual development. However, design educators have been slow to adapt to this change. This lag risks leaving graduates unprepared for a creative industry in the midst of a technological transition. This qualitative study investigates how GenAI is being utilized in creative departments and how design educators are responding. Based on in-depth interviews with agency leaders and design faculty across the United States, a learning gap was made apparent. Agency leaders see GenAI as an essential creative tool for accelerating ideation and concept visualization, while educators remain cautious and prioritize foundational design training. Early pedagogical adopters understand the benefits of integration, but most curricula incorporate GenAI inconsistently, often relying on individual faculty initiative. The findings reveal the need for design educators to help students embrace GenAI as a tool that expands creative exploration and conceptual thinking. In an effort to remain relevant, graphic design educators must train students in both design and GenAI fundamentals. The ability for graduates to create authentic, human-centered design work will be the definition of success in an AI-driven creative industry.

Keywords

Graphic Design Pedagogy, Generative Artificial Intelligence, Creative Workforce Preparation, Conceptual Thinking, Authenticity in Design, AI in Creative Industries

Introduction

A design educator's goal is to teach students the necessary skills to gain employment upon graduation. The new point of differentiation is the understanding of Generative Artificial Intelligence (GenAI) in the marketing industry as a whole, but specifically within the creative department. A July 2025 *Business Insider* article stated, "The largest agency groups, like Publicis and Omnicom, have pledged to invest hundreds of millions in AI over the next few years as they adapt their businesses to harness the technology" (O'Reilly, 2025). Agencies, big and small, are embracing GenAI in hopes that this new technology will streamline business and creative processes. Because of this, design educators must embrace GenAI and train students how to appropriately and ethically harness this new tool.

The implementation of GenAI, along with an unstable business environment, has led to tighter marketing budgets. The marketing research firm COMvergence states, "Preliminary findings [2025] suggest a 68% decline in the number of pitches and a 37% decline in their value in the first half of this year compared to the same period in 2024" (O'Reilly, 2025). This uncertainty could lead to fewer new hires, which could be highly consequential for recent graduates. The

creative professional of the future must augment their creative skills with strong GenAI skills to secure and keep a job.

The goal of this research is to discover what GenAI skills design students need in order to compete in the modern creative agency. This is important because there seems to be a disconnect between the world of design pedagogy and design practice. Design educators are often hesitant to teach GenAI before students have a sound understanding of basic design principles and ideation techniques, which can only be achieved through rigorous training. However, design graduates must understand how and when to properly implement this new creative tool to stay relevant in today's creative workforce.

The Evolution of AI

Artificial Intelligence (AI), began as the concept of “Thinking Machines” at the Dartmouth Conference in 1956 and has been evolving ever since. The overarching concept of AI encompasses everything from Narrow AI, such as personal virtual assistants like Siri, dedicated to specific tasks within defined parameters, to General AI, which refers to machines that can learn and apply that knowledge to different scenarios. General AI is just theoretical, at this point, with research being conducted to one day make it a reality (Syracuse, 2025). Underneath that large umbrella of AI, there are three categories: Machine Learning, Deep Learning, and Natural Language Processing. Machine Learning (ML) is AI that “allows systems to learn from data without the need for specific programming” (Syracuse, 2025). Machine Learning can recognize patterns to predict outcomes. Deep Learning is a subgroup of Machine Learning which “mimics the structure of the human brain using artificial neural networks. These networks enable machines to recognize complex patterns and make sophisticated decisions” (Syracuse, 2025). Natural Language Processing (NLP) allows machines to process and respond with an accurate understanding of human language.

Generative AI (GenAI) uses DL [Deep Learning] to fabricate new content. This new content can be anything from text to music to imagery. “Generative AI can take raw data—say, all of Wikipedia or the collected works of Rembrandt—and ‘learn’ to generate statistically probable outputs when prompted” (College of Education at Illinois, 2024). GenAI trains on large data sets to recognize patterns and specific features. Using these patterns and features, GenAI can create new content that mirrors the characteristics of the data set it was trained to utilize (College of Education at Illinois, 2024).

Literature Review

AI & Pedagogy

Given the relative newness of GenAI being applied to the creative field, the academic literature on the implementation in creative pedagogy is limited (Hwang & Wu, 2025). For this reason, the literature review includes works that address teaching with artificial intelligence in general, not solely in the creative field. The literature that does exist regarding GenAI in creative pedagogy reveals mixed feelings regarding the implementation into design coursework. On one side, Mohd Firdaus Naif Omran Zailuddin et al from the Universiti Malaysia Kelantan state: “As AI tools become more advanced, there is a concern that students may rely too heavily on these technologies... (and) it could compromise their ability to think outside the box and develop their unique design aesthetic” (Zailuddin et al., 2024).

Conversely, Montathar Faraon et al., from Kristianstad University in Sweden, argue that GenAI could complement Bloom's Digital Taxonomy, citing that divergent thinking is a key component in the "creating" process. Faraon et al. assert that GenAI can be used to generate a myriad of divergent ideas by mixing "novel combinations" with familiar thoughts to supplement the pool of potential solutions (Faraon et al., 2023).

The literature shows cautious optimism toward the incorporation of GenAI. However, most of the literature issues warnings that the implementation of GenAI into design teaching could degrade the development of conceptual thinking in students (Muji et al., 2023; Faraon et al. 2023; Hwang & Wu, 2025). Therefore, GenAI's implementation should be coupled with the standard design curricula, focusing on design history, traditional ideation skills, and basic design principles, ensuring students receive solid foundational training (Hwang & Wu, 2025; Zailuddin et al., 2024). GenAI must also be implemented early and throughout the rigor of design training. This way, GenAI can be reinforced as a tool, where appropriate, and not just a quick answer to a creative problem. In the GenAI era, it is essential for design educators to not only prepare students for the repercussions automation is currently having in design, but also to explore what it means to be a designer in the future (Hwang & Wu, 2025).

AI & Business

Business leaders are embracing the use of AI to help their employees become more productive. An April 2025 *Inc.* article states that CEOs are demanding employees embrace AI, even saying, "Performance reviews will now consider employees' AI usage" (Blum, 2025). In the creative field, GenAI is openly embraced as a tool to enhance an agency's productivity, allowing them to deliver their creative product quicker than before (SCAD, 2024). This increased speed and productivity directly equate to the bottom line of any business.

Not everyone is on board with the AI push. According to a May 2025 *Inc.* article:

Researchers at Duke University's Fuqua School of Business, Management and Organizations determined that many employees attach a considerable degree of stigma to colleagues using AI in the workplace. They found that biases against apps not only dissuade many workers from using them in fear they may be looked down upon by AI-wary colleagues (Crumley, 2025).

This sentiment is nothing new. The idea of "mechanophobia - the fear of machines - is a prime example of this resistance to technological change" (Fleischmann, 2024). Mechanophobia has been around since the Industrial Revolution. Even before that, in the mid-1400s, scribes who produced illuminated manuscripts tried filing suit to get the implementation of Johannes Gutenberg's movable type printing press stopped before it ever got off the ground (Meggs & Purvis, 2016). The perception of AI use is different depending on the perspective of the person being asked. Some think it will enhance creativity, while others feel it will cheapen the profession.

Methodology

Following the literature review, a qualitative research approach was deemed most appropriate for this study. Fifteen executives from regional to international creative agencies based in the United States were contacted via email. From this initial contact, eight agencies agreed to be interviewed. Eight in-depth interviews were initiated, with one agency choosing to end the

interview after a couple of questions. Along with the agencies, nine graphic design faculty at universities and colleges from across the United States were contacted. In total, 14 interviews were conducted, with seven being at the creative director level or above on the agency side, six from the academic side, and one hybrid who is an agency owner and adjunct faculty at a private career-focused art and design college. The academic participants ranged from visiting professors to department and program chairs. The average interview length was just under 33 minutes, with the longest being 47 minutes and the shortest being 24 minutes.

For the agency interviews, interviewees were asked a series of ten questions about their agency's use of GenAI. Follow-up questions were asked to gain insight into their opinions around GenAI, ethically and creatively. Finally, each creative leader was asked how they would approach teaching GenAI to the next generation of creatives.

For the academic interviews, design faculty were asked a series of seven questions to understand if and how they were implementing GenAI into their courses. Follow-up questions were asked to gain insight into how each professor's students felt about the incorporation of GenAI. Finally, each professor was asked about the ethics of GenAI and how they feel it could potentially change the creative industry.

Upon completion of the interviews, a hybrid deductive and inductive coding approach was taken. A sampling of the deductive pre-set codes is as follows: AI for Research; AI for Conceptual Development; AI for Finished Art; AI Ethical Challenges; AI Guardrails; Agency of the Future; Hireability of AI Portfolios. A sampling of the inductive open codes used is as follows: Caution toward AI; Optimism about AI; Industry Challenges Due to AI; Fear for the Next Generation.

Given the continually changing nature of GenAI, it is difficult to make concrete assumptions. However, while this is a limited study, paired with the literature, a clear picture has developed, showing an urgent need to address GenAI skills in creative pedagogy.

Agency Interview Findings

Account Service

The literature's conclusion that GenAI is being readily adopted by creative agencies is supported by the interviews. Every department is utilizing AI tools to improve workflow. Agencies are using AI tools like Google® Gemini® and Microsoft® Copilot® to help synthesize meeting notes and prepare a plan of action merely moments after a meeting. Nicole Satterwhite, Co-CEO and Owner of Willoughby located in Kansas City, Missouri, says Gemini "meeting notes are amazing...It allows us to immediately email a client and say, 'Here's what we heard. Here's everyone's to-do list.'" Satterwhite says this allows everyone in the meeting to be engaged and eliminates the need for a dedicated note taker. Mark Scrivner, CEO of Snapshot, located in Nashville, Tennessee, echoed Satterwhite's comments, saying that incorporating the AI features of CustomerIQ® into the agency/client interactions has sped up the time it takes to recap and relay next steps to the client. "What used to take our accounts team, maybe an hour after a call, may take them ten minutes to go through and proof before it gets sent over to the client," said Scrivner.

Conceptual Thinking

Creative departments are embracing the power of GenAI to help develop and present the

agency's conceptual thinking. Dan Magdich, VP/Executive Creative Director at Brunner with offices in Atlanta, Georgia, and Pittsburgh, Pennsylvania, stated, "I honestly can't think of a member of our creative team from myself down to our juniors who doesn't use some sort of AI integration daily...I'm using ChatGPT® more than Google®. It's a helpful tool just to do research." Creative departments are also harnessing the power of ChatGPT to enhance their conceptual thinking. Several interviewees said they will turn to ChatGPT to help add to the pool of ideas during a project's conceptual development. ChatGPT is asked to add ideas once a creative team has a lull in their thinking, while others are asking ChatGPT to role-play during conceptual development. Robert Froedge, Partner/Integrated Creative Director at Lewis with offices in Nashville, Tennessee, Birmingham, and Mobile, Alabama, stated: "We have asked ChatGPT to pretend they are a creative partner... I can say, as a strategist, as a writer, as an art director, as a designer...so giving it a context allows you to use it however you want."

Creative departments are moving away from scouring stock photo sites for hours on end in search of images to help bring visual form to concepts. Instead, they are turning to GenAI platforms like Midjourney®, DALL-E®, and Adobe® Firefly® to create the image they envision for presentations. Froedge explains that stock photography is often limiting.

You can't change the perspective. You can't change the type of camera used. You can't change the atmosphere. You can't change the environment. The clothes the person has on. All of that stuff is so easy with prompting. I can create a visual and say, 'I want the perspective to be lower, I want it to be a darker day. I want them to be in more casual clothes.' It makes experimentation much easier (R. Froedge, personal communication, March 18, 2025).

The use of GenAI is not limited to imagery either. Copywriters are using GenAI platforms to help overcome writer's block, or to take their copy and craft it in different voices. Rodrigo Foggiano, UX Designer and Business Analyst at Integritas Solutions, Inc., headquartered in Austin, TX, said, "It [ChatGPT] is able to shave off several hours of work, just to unblock you from having that initial documentation done." GenAI platforms allow creatives to flex their creativity in ways they were unable to before GenAI. Designers and art directors are utilizing built-in Adobe® AI functions to help generate thumbnails in greater quantity than could be done by hand in the same amount of time (P. Bukengolts, personal communication, May 22, 2025). This idea aligns with Stanford University's "Human-Oriented" Artificial Intelligence Institute (HAI) philosophy that "artificial intelligence should enhance human skills, not replace humans" (Li et al., 2020). It is not that creatives are allowing GenAI to do the conceptual thinking for them; instead, they are using GenAI to help add to the pool of potential ideas that could then be reviewed, combined, and massaged to create better ideas.

Broadcast Presentation

Agencies are utilizing GenAI platforms like Runway® (runwayml.com) to create pitch videos that mirror the final product. Combined with an AI voice model like ElevenLabs® (elevenlabs.io), and presenting video concepts with still image storyboards is a thing of the past. This is not to say that Runway and ElevenLabs will replace producers, directors, and voiceover talent. These platforms are just tools to get presentations closer to the finished product, faster and more economically than previously possible. Magdich explained:

We use ElevenLabs for [preliminary] scratch voiceover. I feel like [scratch voiceover] is always a pain...It's like, 'Okay, who's available to read this? Well, I don't really want to keep pulling people away from this project to record a scratch read. Now with ElevenLabs, you upload the script, pick the voice, and modify it. It sounds like AI, but that's [still] really helpful for a scratch read (D. Magdich, personal communication, March 28, 2025).

AI Concept Development Versus Finished Work

It is important to note that all of the agency leaders interviewed were adamant to emphasize that GenAI is only used for conceptual development and as proof-of-concept client presentations. GenAI work is never used as final art unless the client is notified and a paid subscription is used (N. Satterwhite, personal communication, April 11, 2025). Even then, GenAI work is avoided for final art unless there are no other viable or feasible options. All of the agencies are aware of copyright issues with GenAI products and are striving to ensure their work is ownable and not derivative. The ownership issue surrounding GenAI use has prompted the 4As (American Association of Advertising Agencies) to explore standards for content provenance, trust in advertising, and potentially the need to disclose when AI is used in advertising (American Association of Advertising Agencies, 2025). This initiative is just getting started, but it is fraught with issues of when disclosure is necessary. As stated in the 4As Guide to Content Provenance:

Should disclosure be mandated only for content created entirely by AI, or should it also apply when AI is used for more subtle adjustments? Establishing these thresholds is a nuanced task, and over-disclosure may risk diminishing the impact of transparency altogether (American Association of Advertising Agencies, 2025).

The issue is that GenAI is already integrated into the industry-standard Adobe® Creative Cloud® software, so it is virtually impossible to say without a doubt that any artwork does not incorporate some type of AI manipulation.

Maintaining Authenticity

Another key point mentioned was the need to maintain authenticity. Both Scrivner and Froedge work with clients in the healthcare/medical field, where trust is paramount. Both stated that they would never use GenAI to produce anything that represented a patient statement or testimonial. Scrivner even said, “We don't even proof [medical-related work] through an AI platform. We don't ever want it to show up as it's been written by AI.” This added layer of scrutiny may be unnecessary, but it is something Scrivner feels strongly about in trying to protect the integrity of his agency's work.

Other Cautionary Tales

Several agency leaders mentioned pitfalls they have encountered, such as AI hallucinations. An AI Hallucination is a fabrication that contains misleading or even false information presented as fact (IBM, 2023).

Others mentioned bias and stereotypes that are common among GenAI models (Fleischmann, 2024; L. Haines, personal communication, April 7, 2025). Maria Gualtieri of Brunner states:

[There is an] inherent bias that's in AI because it's all information that we [community at large] put in, and that reflects sometimes the worst part of our society. I don't think it's something that students are even aware of unless you've been affected by it (M. Gualtieri, personal communication, March 28, 2025).

Still another risk is that while GenAI platforms are enabling creative departments to bring their concepts to life, there are also significant budget considerations. Gualtieri warns, “The danger of [GenAI] is misrepresenting what's possible based on the client's budget.” This means GenAI can produce something that would be cost-prohibitive to recreate for final art, which can cause awkward conversations with agency clients.

Finally, all the agency leaders stated that GenAI is not as simple as it seems. There are often frustrations with image creation and getting the exact content being sought. There are specific nuances in how prompts need to be written for the best output. Daniel Summers, Director of User Experience at Integritas Solutions, Inc. said that while AI incorporation is encouraged, “People can waste a lot of time trying to get AI to do a task that they can knock out relatively quickly.” While GenAI is the new tool agencies are trying to find ways to use, it is evident that GenAI tools are not suited for every task. The challenge is in determining the best ways to utilize GenAI.

Agencies are harnessing the power of GenAI tools for creative workflows. For this reason alone, young creatives also need to embrace GenAI, not to use it as a crutch, but rather as a tool to enhance their own productivity.

Academia Interview Findings

Early Adopters

Of the seven schools represented in this study, only one is teaching GenAI in every aspect of the curriculum. That one outlier is a non-traditional finishing school specifically for advertising creatives. Most students at this school have already worked professionally and seek to change careers or enhance their portfolios (B. Cleveland, personal communication, March 11, 2025). At the other universities and colleges in this study, GenAI is being introduced at the class level, based on the individual professor's preference, not as an institution-wide mandate. Professor Leslie Haines at Middle Tennessee State University School of Journalism and Strategic Media stated:

I had students not get jobs a few years ago because they didn't have any motion graphics. I think it's going to be the same with AI. If we can't at least have them demonstrate some understanding...then we're doing them a disservice (L. Haines, personal communication, April 7, 2025).

From this study, California Polytechnic State University, San Luis Obispo (Cal Poly SLO), and Savannah College of Art and Design (SCAD) are making the biggest strides towards GenAI implementation. The Cal State University (CSU) system as a whole seeks to become the premier university system in AI technology (S. Frantz, personal communication, April 4, 2025). In January 2025, the CSU system put out a visionary statement reading in part: “The California State University system is taking a bold step forward with an innovative artificial intelligence strategy designed to enhance student success and transform the educational experience...ensuring students are well-prepared for an AI-driven workforce” (California State University, 2025).

Likewise, professors and administrators at SCAD worked with industry leaders to publish their *AI Insights 2024*, which compiled what SCAD sees as the proper way forward in utilizing GenAI in creative development. Even as Cal Poly SLO and SCAD embrace GenAI, the implementation is still very much an individual professor's decision.

GenAI is clearly on the radar of every school and is being reviewed as a way to prepare graduates for their careers. The June 2025 *Report: Higher Ed 'Re-Norming' With Tech* by Tyton Partners stated, "While only four percent of administrators agreed that student literacy of generative AI is measured as a learning outcome at their institution currently, 39 percent indicated it will be in the next three years" (Mowreader, 2025).

Rapid Change

The implementation of GenAI in design curriculum is more complex than adoption in the creative business. While design educators recognize the need to incorporate GenAI, modifying curricula is often a lengthy process. Also, the GenAI space is changing so rapidly, educators struggle to discern which applications are the best to promote and teach. Bart Cleveland, Founder of Job Propulsion Lab, stated, "It's kind of like the early days of browsers...when there were so many early browsers that thought they were going to be king, and ended up being nothing." Even with so many options, educators understand they cannot take a wait-and-see approach to GenAI (B. Cleveland, personal communication, March 11, 2025). For this reason, most faculty are staying with the Adobe products for now (S. Frantz; L. Haines; F. McGill, personal communications, 2025). The Adobe Creative Suite, the industry-standard software, already has several built-in GenAI functionalities. Adobe Firefly is a text-to-image GenAI platform similar to DALL-E and Midjourney. Some faculty members interviewed for this study stated they prefer the Adobe Firefly application because it is trained on the Adobe Stock Library, while other platforms are trained on imagery from the internet at large (L. Haines; F. McGill, personal communications, 2025). Also, most design students have the Adobe Creative Cloud's monthly subscription included, in full or in part, through their institution's tuition, making the adoption of Adobe Firefly a more cost-effective option (L. Haines, F. McGill, personal communications, 2025).

Also, it is difficult to tackle the enormity and ethical implications of GenAI while also teaching basic layout and typography. As Fish McGill, Program Director, Dynamic Media Institute/Associate Professor, Communication Design at Massachusetts College of Art and Design (MassArt), stated, "Students just getting their head around being a designer is so enormous for them." There is something about struggling to find a design solution that is good for a design student's growth. A firm foundation in design fundamentals is critical for students to develop the necessary design taste and skills to succeed (F. McGill, personal communication, April 24, 2025). For seasoned professionals, a tool that speeds up the creative development process is a welcome addition to their workflow. However, for students who are just beginning to understand the design craft, adding a quick workaround is not the best idea.

Design educators have recognized the need for students to be familiar with GenAI as demanded by the professional community (Fleischmann, 2024). Design faculty also have to work to destigmatize the GenAI issue with students and encourage a sense of discovery and play, while also helping students understand that GenAI might not always be the right choice (J. Cooper & S. Frantz, personal communications, 2025).

Discussion

Employability

This study has explored how the creative business is evolving because of GenAI. This technological shift is reminiscent of the one that occurred in the latter part of the 1980s through the early 1990s with the introduction of the Macintosh® computer and Adobe software, which ushered in the current agency production workflow and completely changed the production process (King, 2011). The introduction of GenAI is a similar revolutionary change. Most of the creative professionals in this study saw the potential of GenAI to help their agencies work faster, giving them time to focus on the creative part of their jobs (P. Bukengolts; R. Froedge; D. Magdich; N. Satterwhite, personal communications, 2025). However, tasks that can now be handled quickly by AI applications, such as photo searches, photo manipulation, and comp preparation, were typically relegated to entry-level employees. These tasks were how young creatives often broke into the business (L. Haines, personal communication, April 14, 2025). The potential lack of job opportunities for new graduates is a widely mentioned concern among design educators (Fleischmann, 2024; Matthews et al., 2023; Meron, 2022). However, as Froedge specifically states:

If a student came in with a book [portfolio] full of AI work, I would want to talk to them about it... I'd want to know how you used the tools. If the book is fantastic, and it was AI, I would have to strongly consider making a play for that person (R. Froedge, personal communication, March 18, 2025).

Mark Scrivner from Snapshot Interactive put it even more succinctly, stating, “AI is not going to replace people. It's gonna replace people that don't learn AI” (M. Scrivner, personal communication, March 11, 2025). It is currently unknown how GenAI will affect hiring decisions in the creative field. However, it is obvious that employers who participated in this study are seeing GenAI usage as a necessary skill for new graduates.

GenAI for Final Art

How long agencies will use GenAI just for concept development is yet to be determined. An example of GenAI art as final art comes from the highly respected design firm Pentagram and the Performance.gov website they created. Through initial handmade explorations, coupled with the GenAI application Midjourney, Pentagram created a total of 1,500 icons for the website (Pentagram, 2024). The GenAI-generated artwork used in the Pentagram project was based on original sketches by designers at Pentagram; however, the firm received backlash when the process was documented on Pentagram's social media and in a December 2024 article in *Fast Company* titled “Pentagram partner Paula Scher unapologetically defends using generative AI” (Wilson, 2024).

As agencies and the public get more comfortable with GenAI, there will assuredly be more examples of GenAI-created artwork making its way into the mainstream for commercial purposes. Not using GenAI tools will almost seem like a hindrance to a creative agency. However, we must understand and stay focused on the fact that GenAI is simply a tool, not the solution, and not a replacement for human creativity (Zailuddin et al., 2024).

Roadblocks to Acceptance in Academia

Issues of plagiarism and academic misconduct due to students' use of ChatGPT on academic

papers aside, the main issue preventing design professors from embracing GenAI is the inherent value of struggle. It takes time and exposure to good work, along with trying, failing, and trying again, to hone the craft. Design faculty must be deliberate in how GenAI is introduced. They cannot simply transition coursework over to prompt creation (Fleischmann, 2024; Matthews et al., 2023; Meron, 2022). Educators must first ensure that design fundamentals are firmly in place. Sara Frantz, Chair of the Art and Design Department at Cal Poly SLO, put it this way. “We’re treating it like new Adobe software. We can be freaked out about this, and it could put people out of business, or we could harness it for good” (S. Frantz, personal communication, April 4, 2025).

GenAI for Divergent Thinking

Divergent thinking is essential for creative development. It is also an area where many design students struggle. Typically, students come up with two or three ideas and consider the concept phase complete. However, design educators and professionals alike recognize that the first ideas are often trite and superficial, and the best ideas require effort to uncover. This is where GenAI can be especially helpful. The more ideas that are generated, the better. Eventually, everyone hits a creative wall—when no new ideas come to mind. At that point, GenAI applications can be a valuable tool. With a simple query, an application like ChatGPT or Copilot can provide a range of new ideas to consider. Keep in mind, these are just ideas, not necessarily “good ideas.” Maria Gualtieri of Brunner suggests, “Using [GenAI] like a creative partner to springboard, not replace the creative process” (M. Gualtieri, personal communications, 2025). This underscores the purpose of divergent thinking: to generate as many ideas as possible, whether good or bad. These ideas can then be combined, reshaped, twisted, tweaked, or revised to develop better ideas. GenAI didn’t come up with the ideas, but it instead played the part of collaborator, feeding the idea engine to help bring forth the truly original ideas.

The importance of Traditional Design Skills and Context in the GenAI Era

As stated, GenAI has the ability to enhance the conceptual development process by introducing new and different ideas quickly. With skilled designers, this can be an enormous time saver. However, Jonas Oppenlaender from the University of Jyväskylä, Jyväskylä, Finland, argues that “little to no human creativity may be involved in producing art with text-to-image synthesis” (Oppenlaender, 2022). An effective concept is created when meaning is built into the imagery. That can only happen through an understanding of contemporary or historical context and audience understanding and empathy. For these reasons, design academia must continue to focus on traditional design skills, art and design history, and audience empathy to train students to create art that is meaningful beyond pure aesthetics. GenAI can be a helpful tactical tool, but design faculty must never let it supplant the humanness of the creative process.

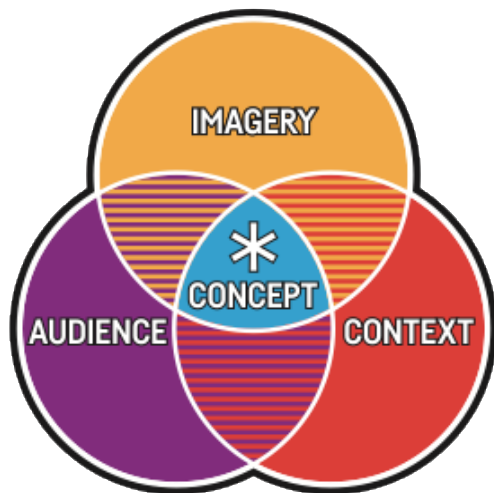


Figure 1. A meaningful concept is more than just an image. The image must be paired with audience insight and contemporary or historical context to be effective

Roadmap for Teaching GenAI

Based on the study's findings, it is imperative to implement a pedagogical framework to address teaching GenAI. From speaking with the academic study participants, there is a reluctance among design students to embrace AI. The rationale for this is not easily identifiable. Environmental concerns were mentioned, along with the fear of AI taking jobs. Some feel that using GenAI is cheating the creative process. However, what some may think of as cheating may just be using new tools as effectively as possible (Michels, 2023). This is certainly the approach creative agencies are taking. Even with these fears, GenAI must be taught to prepare graduates for a creative career. Based on the study, an approach similar to Bloom's Digital Taxonomy is recommended.



Figure 2. A stair-stepped approach to teach GenAI skills

- 1. Understand: Demonstrate what GenAI is and how it works**
- 2. Collaborate: Utilize GenAI as a creative collaborator**
- 3. Create: Construct conceptual imagery utilizing GenAI and human-centered insights**
- 4. Master: Compose video elements with GenAI and discern the proper applications**

STEP 1: Understand

This initial stage will work to demystify AI in general. "An initial pedagogical approach to AI can aptly begin with addressing preconceptions and attitudes among learners. This includes alleviating both unfounded fears and tempering inflated expectations" (Jaakkola, 2025).

Discussions and assignments could focus on how AI works and how it should be used. The focus of this stage is to use AI as a research companion, with special emphasis placed on the ethical questions surrounding AI.

Step 1 Goals: Gain a general understanding and comfort level with AI.

Appropriate Applications: Large Language Models (ChatGPT, Copilot, etc.).

STEP 2: Collaborate

This stage will demonstrate how to use AI as a concepting partner. When creating concepts, human intuition and ideation should always be exhausted first. However, once the creative wall has been reached, LLMs can be used to insert a new batch of ideas to help start the next round of concept development. This phase will not only introduce AI as a collaborator but also stress the importance of continual concept development well past an initial set of ideas.

Step 2 Goals: Use AI as a tool to break creative blocks.

Appropriate Applications: Large Language Models (ChatGPT, Copilot, etc.).

STEP 3: Create

This stage will introduce prompt writing skills necessary to achieve the desired still-image results with a GenAI application. Special attention should be placed on the exploration of how different prompt development can shift the emphasis and appearance of the image produced. This phase will help students understand proper prompting techniques and demonstrate that GenAI applications are not the end of the image development process. More often than not, GenAI-generated images need to be edited or manipulated with other digital tools, such as Photoshop, to achieve the desired effect. Understanding this shows how GenAI can be used as a tool to enhance creativity in skilled hands, rather than making everyone a prompt engineer.

Step 3 Goals: Use GenAI as a building block tool to enhance image creation.

Appropriate Applications: Text-to-image GenAI image applications (Midjourney, Adobe Firefly, etc.).

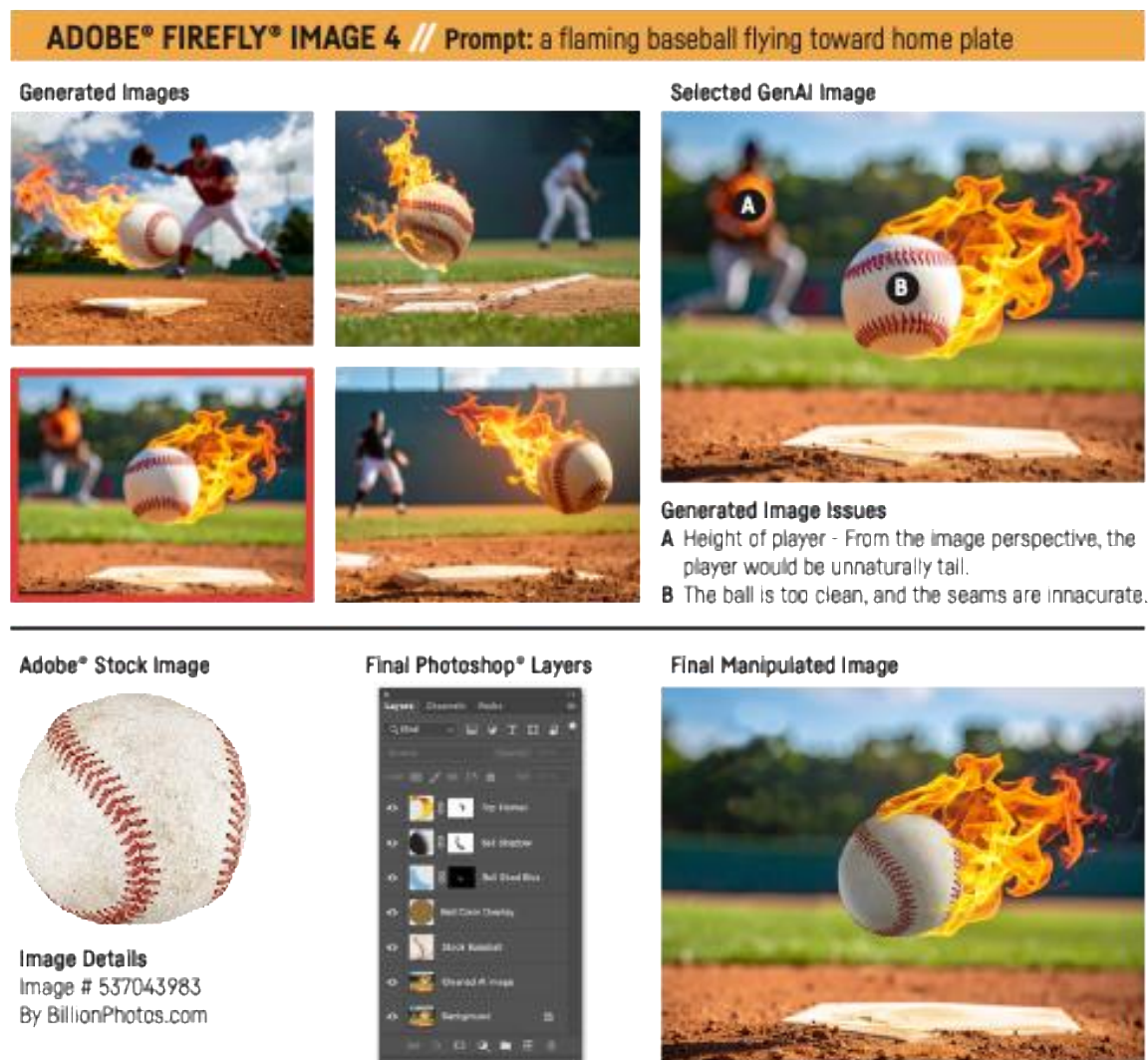


Figure 3. GenAI as a creative aid, not a creative solution. Even with the most basic imagery, there is a need for further manipulation before an image can be finished in a way that appears correct to the human eye

STEP 4: Master

This final stage will expand on prompt writing skills necessary to create video results with a GenAI application. As with still imagery, generated video will need to be edited using other methods to achieve the desired effect. Understanding this will show how GenAI should be used as a tool and not a result. During this stage, special emphasis must be placed on ethical questions surrounding GenAI-created video, such as deep fakes, personal privacy, and copyright infringement concerns.

Step 4 Goals: Use GenAI as a building block tool to enhance video creation and engrain ethical standards.

Appropriate Applications: Text-to-video GenAI applications (Runway, Midjourney, Adobe Firefly, etc.).

Even with the implementation of these steps, there must be a continuous evolution in the training around GenAI. The GenAI landscape is changing at such a rapid pace, professionals, faculty, and students must keep themselves up to date with the latest applications and trends through a willingness to embrace change (Alenezi & Alenezi, 2025).

Conclusion

While GenAI skills may start in the classroom, the real learning happens when students embrace challenges and use them as an opportunity to learn outside the formal classroom setting. For this reason, design educators need to encourage a mindset of play in discovering what these platforms can do. Educators need to embrace GenAI as a supplemental tool to enhance the creativity of their students' work. This will help destigmatize GenAI in the minds of students and encourage them to experiment and push boundaries.

As discussed, GenAI has the potential to reduce entry-level jobs. This shift requires design educators to adjust their approach to teaching design. Greater emphasis must be placed on conceptual thinking (Petrosyan, 2025). Design programs already include technical skills, but we must never lose sight of the creative problem-solving challenges, with special emphasis being placed on empathy and understanding audiences and user groups. Students need to learn how to build richer concepts by looking back through history to create new solutions. The past is full of talented designers who did not have the advantage of current creative tools. Exploring how problems were solved in the past will help students craft better solutions moving forward.

Design educators need to instill a sense of experimentation and curiosity. Exceptional designers don't lean on technology. Instead, they use technology as a tool to craft their way of thinking into something real. GenAI can help students explore ideas much faster than ever before. We must encourage this exploration and discourage stopping before ideas are fully exhausted.

Finally, design faculty need to teach students to strive for authenticity. GenAI can do incredible things, but it cannot engage on a human level. Jessa Wilcoxon, Professor and Founding Director of the School of Art and Creative Media at Millikin University, stated:

I continue to believe that authenticity is what people will pay for... I think most business owners understand that when they need something that really sells...authentic voice, authentic look, or feel still matters. That's harder to get through AI. So, really teaching students how to develop [authenticity] is critical (J. Wilcoxon, personal communication, April 9, 2025).

GenAI is not capable of creating something new; it merely assimilates what already exists. Used properly, it can be an efficient and powerful tool. The challenge for educators is to train students on how and when to ethically utilize GenAI to its fullest, without losing the humanity in design that makes it compelling and effective.

"100 years from now, the idea is still going to be more important
than all the technology in the world."

-Bill Bernbach

Co-Founder of Doyle Dane Bernbach (DDB) advertising agency, founded in 1949

Acknowledgments

I would like to thank the agency and academic professionals who took part in this study. Their insight into the practical use of GenAI was invaluable and enlightening. Also, I would like to extend my appreciation to April Bonner Addy, M.S., for her discerning feedback.

References

- Alenezi, A., & Alenezi, A. (2025). Knowledge and Teaching with Artificial Intelligence: Stem Vs. Humanities. *Comunicar*, 33(82), 116–126. <https://doi.org/10.5281/zenodo.15996228>
- American Association of Advertising Agencies. (2025, January 5). *The 4As guide to content provenance*. 4As. <https://www.aaaa.org/resource/the-4as-guide-to-content-provenance/>
- Blum, S. (2025, April 10). *CEOs are telling their employees to embrace AI—or become irrelevant*. <https://www.inc.com/sam-blum/ceos-are-telling-their-employees-to-embrace-ai-or-become-irrelevant/91174500>
- California State University (2025, January 28). *The CSU artificial intelligence (AI) strategy*. Genai.Calstate.edu. <https://genai.calstate.edu/about/csu-artificial-intelligence-ai-strategy>
- College of Education at Illinois. (2024). *Traditional AI vs. Generative AI: What's the Difference?* College of Education. <https://education.illinois.edu/about/news-events/news/article/2024/11/11/what-is-generative-ai-vs-ai>
- Crumley, B. (2025, May 12). *Employees fear the stigma of using AI at work, according to a study*. <https://www.inc.com/bruce-crumley/employees-fear-the-stigma-of-using-ai-at-work-according-to-a-study/91187736>
- Faraon, M., Granlund, V., & Rönkkö, K. (2023). Artificial intelligence practices in higher education using Bloom's Digital Taxonomy. In *2023 5th International Workshop on Artificial Intelligence and Education (WAIE)* (pp. 53-59). IEEE.
- Fleischmann, K. (2024). Generative artificial intelligence in graphic design education: A Student Perspective. *Canadian Journal of Learning and Technology*, 50(1). <https://doi.org/10.21432/cjlt28618>
- Hwang, Y., & Wu, Y. (2025, January). *Graphic design education in the era of text-to-image generation: transitioning to contents creator*. International Journal of Art & Design Education. <https://doi.org/10.1111/jade.12558>
- IBM. (2023, September 1). *AI hallucinations*. Think. www.ibm.com/think/topics/ai-hallucinations
- Jaakkola, M. (2025). Operationalizing positive-constructive pedagogy to artificial intelligence: the 3E model for scaffolding AI technology adoption. *Front. Commun.*10:1610111.
- King, B. J. (2011, August 6). *Brian King, Miami photographer: world of photography show 1988*. [Video]. YouTube. www.youtube.com/watch?v=iE4vT-8tLAW
- Li, Y., Gu, J., & Wang, L. (2020, September 27). *Research on artificial intelligence ethics in the field of art design*. Iopscience.iop.org. <https://iopscience.iop.org/article/10.1088/1742-6596/1673/1/012052>
- Matthews, B., Shannon, B., & Roxburgh, M. (2023). Destroy all humans: The dematerialisation of the designer in an age of automation and its impact on graphic design—A literature review. *International Journal of Art & Design Education*, 42(3), 367-383.
- Meggs, P., & Purvis, A. (2016). *Meggs' History of Graphic Design*. Hoboken, N.J., John Wiley & Sons. p. 85.

- Meron, Y. (2022, June 25 - July 3). Graphic design and artificial intelligence: Interdisciplinary challenges for designers in the search for research collaboration. In *Proceedings of the Design Research Society Conference (DRS2022)*, Bilbao, Spain.
- Michels, S. (2023). Teaching (with) Artificial Intelligence: The Next Twenty Years. *Journal of Political Science Education*, 20(4), 510–521.
<https://doi.org/10.1080/15512169.2023.2266848>
- Mowreader, A. (2025, June 11). *Report: Higher ed 're-norming' with tech*. Insidehighered.com.
<https://www.insidehighered.com/news/student-success/academic-life/2025/06/11/65-percent-students-use-gen-ai-chat-bot-weekly>
- Muji, S., Svensson, E., & Faraon, M. (2023). Engaging with artificial intelligence in graphic design education. In *2023 5th International Workshop on Artificial Intelligence and Education (WAIE)* (pp. 31-37). IEEE. <https://doi.org/10.1109/waie60568.2023.00013>.
- Oppenlaender, J. (2022). *The Creativity of Text-to-Image Generation*. ArXiv.
<https://doi.org/10.1145/3569219.3569352>
- O'Reilly, L. (2025, July 09). *WPP's dire warning is the last thing the ad business needs as it grapples with the impact of AI*. Business Insider. <https://www.businessinsider.com/wpp-profit-downgrade-ad-agency-market-ai-disruption-2025-7>
- Pentagram. (2024). *Performance.gov*.
<https://www.pentagram.com/news/performance-gov>
- Petrosyan, L. (2025, June 6). *The impact of the development of artificial intelligence on computer graphic design*. State Academy of Fine Arts of Armenia.
<https://orcid.org/0009-0005-1039-014X>
- SCAD. (Savannah College of Art and Design) (2024). *AI Insights 2024*. SCADask.
<https://www.scad.edu/about/industry-partnerships/scadask/ai-insights-2024>
- Syracuse University. (2025, March 26). *Types of AI: Explore key categories and uses*.
school.syracuse.edu/types-of-ai
- Wilson, M. (2024, December 5). *Pentagram partner Paula Scher unapologetically defends using generative AI*. Fastcompany.com.
<https://www.fastcompany.com/91240809/pentagram-partner-paula-scher-unapologetically-defends-using-generative-ai>
- Zailuddin, M. F. N. O., Harun, N. A. N., Rahim, A. A., Kamaruzaman, A. F., Berahim, M. H., Harun, M.H., & Ibrahim, Y. (2024). Redefining creative education: A case study analysis of AI in design courses. *Journal of Research in Innovative Teaching & Learning*, 17(2), 282-296.
<https://doi.org/10.1108/jrit-01-2024-0019>

Assessing Students' Computer Programming Skills: How Technology Teachers in Sweden Evaluate Learning in Grades 4–6

Eva-Lena Bjursten, Mälardalen University, Sweden

Lena Gumaelius, KTH Royal Institute of Technology, Sweden

Eva Hartell, KTH Royal Institute of Technology, Sweden

Abstract

This study aims to deepen the understanding of how computer programming is taught and assessed in Swedish schools by focusing on teachers' perspectives. It explores how technology teachers (teaching years 4–6, students aged 10–12) perceive their roles and responsibilities in teaching computer programming, primarily within the technology subject, and examines what computer programming content is taught and assessed. The research is based on a survey and interviews with seven experienced teachers who taught computer programming before it became mandatory. The findings reveal similar views among the teachers but also significant variation in assessment practices, categorized into four distinct personas, ranging from a strong disciplinary content and product focus to a weaker disciplinary content and process orientation. The discussion reflects upon how these variations may be influenced by teachers' backgrounds, computer programming knowledge, and unclear policy documents. The conclusions suggest that, due to this variety, Swedish students may not be equally equipped with the digital skills needed for participating in a digitalized society. To enhance equity, we argue that teachers need better preparation to effectively integrate computer programming skills across subjects. Additionally, we recommend clearer national guidelines on how to teach computer programming and how to assess this subject content in compulsory education.

Keywords

Computer programming, assessment, technology education, teacher perspective, pedagogical content knowledge

Introduction

In an increasingly digitalized society, understanding new technology is crucial. It is essential for everyone to grasp how data usage influences their daily lives and decision-making, enabling them to make informed choices as citizens. Moreover, digitalization represents the most significant technological shift affecting current competency needs (Teknikföretagen, 2020). This underscores the importance of young individuals acquiring foundational skills that will enable them to pursue future careers aligned with digitalization.

Following EU and OECD recommendations (European Union, 2006), computer programming (hereafter referred to as programming) was introduced into the Swedish national curriculum in 2018, primarily in technology and mathematics (Swedish National Agency for Education, 2017). The aim was to foster “a general understanding of programming and its implications” (Swedish National Agency for Education, 2022a, p. 8). As a result, all K–9 technology and mathematics teachers are now required to teach this content.

Programming can be described as creating instructions for a computer to solve a problem. However, in the Swedish compulsory school context, the concept also includes creativity, control and regulation, simulation and democratic dimensions (Swedish National Agency for Education, 2022b). In this article, programming is therefore understood as a combination of these perspectives.

How teachers approach this task is critical for achieving curricular objectives and equipping students for a digitalized society. Existing research underscores the recognition of programming's integration into the curriculum across various studies, although further research in this domain is warranted (Larsson, 2023; Mannila et al., 2020; Nordén et al., 2017; Nouri et al., 2020; Stigberg & Stigberg, 2019; Vinnervik, 2021).

There are strong indications that our school students' right to equal education in programming is not being fulfilled. A follow-up report on the digitalization strategy from 2022 (Swedish National Agency for Education, 2022e) revealed that over 70% of primary school teachers (years 4–6, students aged 10–12) felt uncertain about how to teach programming, highlighting significant gaps in teachers' preparedness and confidence in delivering programming education. This suggests a pressing need for enhanced teacher training and resources to ensure that all students receive high-quality education in programming.

Through this study, our objective is to deepen the understanding of how programming is taught in schools and thereby contribute to understanding what is needed for programming education to become an integrated part of school education. We have chosen to examine our research question from a teacher's perspective. Specifically, we aim to understand how teachers perceive their responsibilities and utilize their roles when teaching programming, primarily within the technology subject. This understanding can be framed as the teachers' experienced and enacted pedagogical content knowledge (ePCK), according to the PCK framework, which is frequently employed to describe teachers' capabilities and competencies in delivering effective instruction (Carlson et al., 2019). However, PCK alone does not explain how teachers' practices are shaped by curriculum structures, subject boundaries or institutional control. Therefore, in this study, we also draw on Bernstein's (2000) concepts of classification and framing to analyse how programming is positioned, regulated and enacted within the technology subject and the wider school context.

Our exploratory, descriptive study focuses on teachers' reflections on their classroom practices. Previous research has highlighted the importance of teachers having a deep understanding of subject content to teach effectively within a specific discipline (Kaya et al., 2022). Based on this, we decided to collaborate with experienced teachers who taught programming before its mandatory inclusion in the curriculum. We regard these teachers as experts, and by exploring their experiences and perceptions, we believe we can capture the most relevant ideas on how to teach programming. By investigating these aspects, we hope to identify the necessary components for integrating programming education effectively into school curricula.

The overarching research question for this study is as follows:

How do teachers of the technology subject perceive what students in grades 4–6 should learn about programming?

More specifically, we seek to understand this research question by examining how teachers reflect on their ePCK - that is, how they implement teaching and assessment practices for programming in the classroom.

Background

Pedagogical Content Knowledge

Pedagogical content knowledge (PCK), introduced by Shulman in the 1980s (Shulman, 1987, 2013), is a framework for understanding teachers' ability to teach a specific subject area. It highlights that classroom practice depends on both pedagogical competence and subject expertise, as well as how teachers apply this knowledge. PCK develops through experience and is shaped by individual and contextual factors (Hubbard, 2018). The framework has been particularly influential in science education and has been continuously refined to also to be used in technology education (eg. Doyle et al., 2019; Hume et al., 2019).

Efforts have been made to develop and update the framework by engaging active researchers in discussions about the framework and its applicability in different summits (Carlston et al., 2019; Gess-Newsome, 2015). The latest model, published in 2019 (Carlson et al., 2019) is called the RCM model which comprises three realms: personal PCK (pPCK), an individual teacher's knowledge and beliefs about teaching specific content; enacted PCK (ePCK), this knowledge in action; and collective PCK (cPCK), the shared professional knowledge found in curricula, research, and teaching communities.

In this study, we focus on how teachers reflect on their classroom practices—descriptions of their ePCK—and how they draw on their pPCK in specific situations. By comparing multiple teachers' accounts, we aim to contribute to understanding their cPCK. Additionally, by asking teachers to relate their reflections to national guidance documents (Swedish National Agency for Education, 2017), we explore how such documents shape the way pPCK is enacted in teaching.

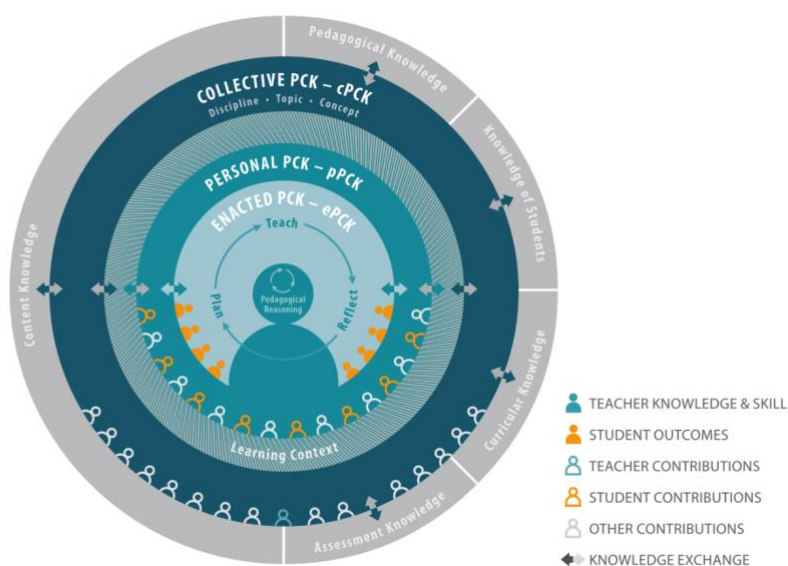


Figure 1. The refined consensus model of PCK (Carlson et al., 2019, p. 84)

Description of the Integration of New Subject Content in the Curriculum

In 2017, programming was introduced into the Swedish compulsory school curriculum as part of the national digitalisation strategy (Nordén et al., 2017). Rather than being defined as a separate subject, it was embedded within existing ones, including technology.

To understand how this new content is valued, organised, and integrated, we draw on Basil Bernstein's theoretical framework. Bernstein (2000) examined how new knowledge domains are transformed when incorporated into curricula and how their status and boundaries are negotiated. His concepts therefore offer a useful foundation for analysing how programming is positioned, classified, and integrated within the technology subject.

Building on Bernstein's work, Ashwin (2009) illustrates how classification helps illuminate how new knowledge is treated in relation to existing disciplinary structures. Bernstein's construct of classification refers to the boundaries between categories of knowledge and can be understood as follows:

1. Strong classification: In this scenario, the new knowledge area is classified as strong, meaning it is included in the curriculum as a standalone content area independent of existing disciplines.
2. Weak classification: The new knowledge area may be integrated as a subset of a well-defined discipline, resulting in weak classification as part of a broader discipline.
3. Non-disciplinary classification: The knowledge area may be regarded as non-disciplinary, serving as a competency that can be developed through project-based courses focused on various knowledge areas. This classification is inherently weak.

Looking at how programming is classified in higher education, we can see several different examples of how it aligns with Bernstein's three classification categories. Programming is clearly strongly classified when it exists as its own discipline in higher education, as seen in educational programs such as software engineering. Conversely, it can also be weakly classified when treated as a tool for solving problems within other knowledge areas. Finally, programming may equally fit with a non-disciplinary classification, whereby students are expected to develop programming skills through project-based courses without being offered foundational courses in the subject.

How programming is classified influences how different stakeholders, policymakers, curriculum designers, teachers, and students, treat and value the content. Understanding these dynamics helps reveal potential tensions and can guide efforts such as teacher training, professional development, and other interventions to support successful integration into school education.

Assessment Practices

Various methods exist to assess individual learning and foster understanding. Formative and summative assessments serve distinct but complementary purposes in education. Formative assessment is an ongoing process that provides real-time feedback to students and teachers, allowing for adjustments in teaching and learning strategies to enhance understanding and performance (Black & Wiliam, 2009). It is primarily diagnostic and developmental, helping to identify areas of strength and weakness, involving teachers as well as learners in the process with the purpose of adapting what happens next to better meet learners' needs based on

evidence of learning. Feedback is an integral part of formative assessment, and it needs to be forward-looking providing descriptions on where to go next. Kluger and DeNisi's (1996) review of effective feedback suggests that what seem to matter most is how the learner responds to it.

Summative assessment, on the other hand, evaluates student learning at the end of an instructional period, providing a comprehensive measure of achievement against predefined standards. In Sweden, it is the teachers' responsibility to award the grades to students. It ensures that the learning objectives stipulated in the curriculum have been met (Swedish National Agency for Education, 2011).

By continuing exploring ways to improve the quality of assessment, some researchers suggest that collaboration among teachers is a promising approach (e.g. Harrison, 2009; Hartell, 2015). Collaborative assessment, in which teachers collaborate to construct and assess students' tasks, as proposed by Allal (2013), has been found to enhance both teachers' performance and assessment practices (Thornberg & Jönsson, 2015).

Programming assessment

Assessing programming in compulsory school remains a major challenge. Formative assessment practices such as feedback can support students' motivation and learning (Azmi et al., 2017). Rubrics are frequently recommended for programming assessment (Björklund & Nordlöf, 2023; Brennan & Resnick, 2012) as they help teachers evaluate diverse student solutions (Jönsson & Svingby, 2007; Kilday et al., 2012). However, premade rubrics may cause misalignment with curriculum intentions if teachers adapt them too freely (Sadler, 2009).

In Sweden, summative assessment in the technology subject relies on teachers' own judgments, as no national tests exist for this subject. Such assessments are usually based on classroom activities, with tests being infrequent and of varying quality (Hartell et al., 2018). When it comes to programming, some instruments have been developed. For example, Mannila et al. (2020) created a test to identify students' understanding and misconceptions, but these do not assess the quality of students' self-created programs.

Research shows that programming assessment often occurs ad hoc and focuses mainly on whether a program works, rather than on conceptual understanding or problem-solving processes (Dagienė et al., 2023). Tools such as ProMAT (Hartmann et al., 2022) demonstrate that conceptual knowledge can be assessed, but these tools remain tied to specific environments like Scratch and xLogo. This reflects a broader issue: much programming research relies on Scratch, limiting generalizability (Zhang & Nouri, 2019). Thus, researchers argue for assessment approaches that are conceptually grounded rather than language-specific.

Teachers' assessment practices vary widely. Neutens et al. (2022) found that functionality is often prioritized, while abstraction and testing receive less attention. Swedish teachers similarly emphasize either product-oriented criteria (functional programs) or process-oriented criteria (reasoning, persistence), though the ability to explain code is valued across contexts (Björklund & Nordlöf, 2023). Overall, assessment remains highly individual and teacher-dependent (Dagienė et al., 2023; Hartmann et al., 2022; Zhang & Nouri, 2019).

Although computational thinking is internationally influential (Zhang & Nouri, 2019), the concept is not defined in Swedish policy documents. The curriculum mentions the related

notion of “datalogiskt tänkande” but does not specify its meaning or how it should be interpreted in teaching (Swedish National Agency for Education, 2022b). This study therefore focuses on assessing students’ programming knowledge and conceptual understanding as framed in the Swedish curriculum, where programming encompasses problem-solving, creativity, control and regulation, simulation, and democratic dimensions (Swedish National Agency for Education, 2022b).

Steering Documents Guiding Swedish Middle-school Teachers in Programming Education

The Swedish national curriculum consists of three parts: core values and mission, overarching goals and guidelines, and subject syllabuses outlining objectives, core content, and grading criteria (Swedish National Agency for Education, 2022a). These directives serve as the foundation for teachers’ planning, instruction, and assessment but do not contain specifics on how to enact in classroom practices. Instead, teachers are trusted to adapt teaching to their local context. Neither do the Swedish curricula specify detailed content. However, recent national discussions have highlighted a move towards a more knowledge-rich curriculum, inspired by international developments such as in England, emphasising stronger subject content and cognitive foundations for learning (SOU 2025:19, 2025).

To support teachers, the National Agency for Education provides subject-specific materials, including guidance on digital inclusion and clarifications for interpreting the technology syllabus (Swedish National Agency for Education, 2022b, 2022c, 2022d). While these resources offer some support for understanding grading criteria, they still leave considerable room for interpretation, granting teachers substantial autonomy in their professional judgement.

Programming in the Swedish Curriculum

Programming as content has been integrated into both the mathematics and technology syllabuses in Swedish schools since 2018 (Nordén et al., 2017). In the technology subject, the overarching goal is for students to develop an understanding of technological development and its historical context while fostering technological awareness. This knowledge equips students to critically engage with technology, relate its use to issues such as sustainable development, and apply it responsibly. Within this framework, programming is intended to be integrated.

For years 4-6, the technology syllabus specifies three core content areas:

- Technology, people, society and the environment
Students study technological systems (e.g., water, sewage, recycling) and consider their impacts and trade-offs.
- Technological solutions
Students learn about components and systems—such as bicycles or electrical circuits—and how these interact to achieve functionality.
- Working methods for developing technological solutions
Students engage in need identification, proposing ideas, designing, constructing, testing, and documenting solutions using sketches, models, or written descriptions.
Programming is included here as a method for controlling constructions or objects (Swedish National Agency for Education, 2022a).

Grading Criteria for Technology (Grade 6)

The grading criteria for technology, like other subjects, are divided into three levels: E, C and A. These correspond to the Swedish national grading scale (Swedish National Agency for Education, 2022a, pp. 277-278), where E = pass, C = good and A = excellent. For example, to achieve an A, the student is expected to perform as follows

The pupil gives examples of technological solutions and describes, in a well-developed manner, some of their advantages and disadvantages for the individual and the environment and how they have changed over time.

The pupil examines technological solutions and describes, in a well-developed manner, how some components work together to achieve purpose and function.

The pupil performs simple technology development and design work in a well-organized manner. In the work, the pupil formulates and chooses alternative courses of action that lead to progress. The pupil creates documentation that sets out the intention of the solution well.

However, the criteria do not explicitly mention programming in any of the criteria available for E, C, and A. Despite its omission from the text on grading procedures, programming is considered an integral part of the process in technology development and construction work. Therefore, it may be suggested that the third grading criterion should be applied to assess students' programming tasks. This lack of guidance in terms of assessing programming in technology also applies to mathematics.

In mathematics, programming is introduced through visual programming environments to support logical thinking and problem-solving (Swedish National Agency for Education, 2022a). The support material in mathematics offers further guidance on integrating programming, emphasizing the development and application of algorithms in mathematical contexts, such as calculating averages or creating rule-based movements (Swedish National Agency for Education, 2022c). While programming in mathematics focuses on logical and problem-solving skills in technology, programming is approached within a broader context, connecting it to technological systems and their role in society.

There is no doubt that the recent introduction of programming to Swedish schools has posed challenges for teachers in terms of assessment (Vinnervik, 2021), which confirms even earlier results from Hartell (2012) showing that technology teachers are often left to their own devices, and their teaching practices rely solely on their own experiences.

Method

This study is situated within an interpretivist paradigm, assuming that teachers' knowledge and practices are shaped by their experiences, perceptions, and interactions with curricular and institutional structures. Our epistemological stance is constructivist, recognising that understanding is co-constructed through teachers' reflections on their programming instruction. While the PCK framework guides our focus on enacted knowledge, Bernstein's concepts of classification and framing serve as lenses for analysing how teachers interpret and enact the curriculum in their contexts. Together, these perspectives support an exploratory,

descriptive approach aimed at deepening understanding of how programming is taught in practice.

Participants

The empirical data are based on interviews and survey responses from seven teachers who consented to being part of the study. All possess prior teaching experience of teaching 10–12-year-olds in programming in technology education, both before and after the official/explicit introduction of programming into the Swedish Curriculum in 2018. Hence, here we consider them as experienced in teaching programming in years 4–6. Their backgrounds show a variety of educational experiences, and all but one has a teacher certificate. Please note that all names are fictitious.

Table 1. Background information regarding the participants

Informant	Higher education in programming
Camilla	7.5 ECTS*
Henric	None, self-taught and short course
Irene	None, self-taught
Jack**	36 ECTS in games programming
Kate	Short courses
Liam	Self-taught and short course
Magnus ***	Short courses

* European Credit Transfer System

** No teacher certificates

*** Former teacher, now teacher trainer at a science center

Survey

The initial data for this study were derived from a survey in which participants were asked to underline the parts of the grading criteria in the Swedish technology syllabus they considered relevant for assessing programming skills, as outlined in the central content “Control of the pupils’ own constructions or other objects with programming” (Swedish National Agency for Education, 2022a, p. 275).

Follow-up interviews were conducted to gain an even deeper understanding of the participants’ views regarding assessment.

Interviews

Seven semi-structured interviews were conducted (Bryman, 2014) by the first author via an online conference system. The interviews were recorded and transcribed verbatim. The interviews aimed to capture multifaceted answers about programming assessment in the technology subject, allowing the participants to articulate their perspectives, methods, and experiences.

Analysis

The data analysis proceeded in three phases. First, we examined teachers’ pPCK by examining how the participating teachers interpreted the use of assessment criteria in the technology subject to evaluate students’ programming skills. This was done by looking at the text segments they had underlined and by analyzing the interviews. Second, we investigated their ePCK by

asking the participants about how they practice their pPCK. Third, we explored the potential for cPCK by comparing the interviews during an open-coded analysis in which we aimed to identify emerging themes. This third process revealed two distinct thematic areas: Programming is the focus vs. programming is the means and Product is the focus vs. process is the focus. These themes provided a structured lens for detecting and understanding how the teachers viewed programming and how its role in education varied. Finally, the identified themes were compared with the existing literature to identify relevant frameworks for deeper analysis. Bernstein's framework, as developed by Ashwin (2009), was particularly useful for categorizing the themes and understanding differences in teachers' assessment practices. Based on the frameworks, a matrix was developed to map the teachers' varied positions along the extremes of the two thematic areas.

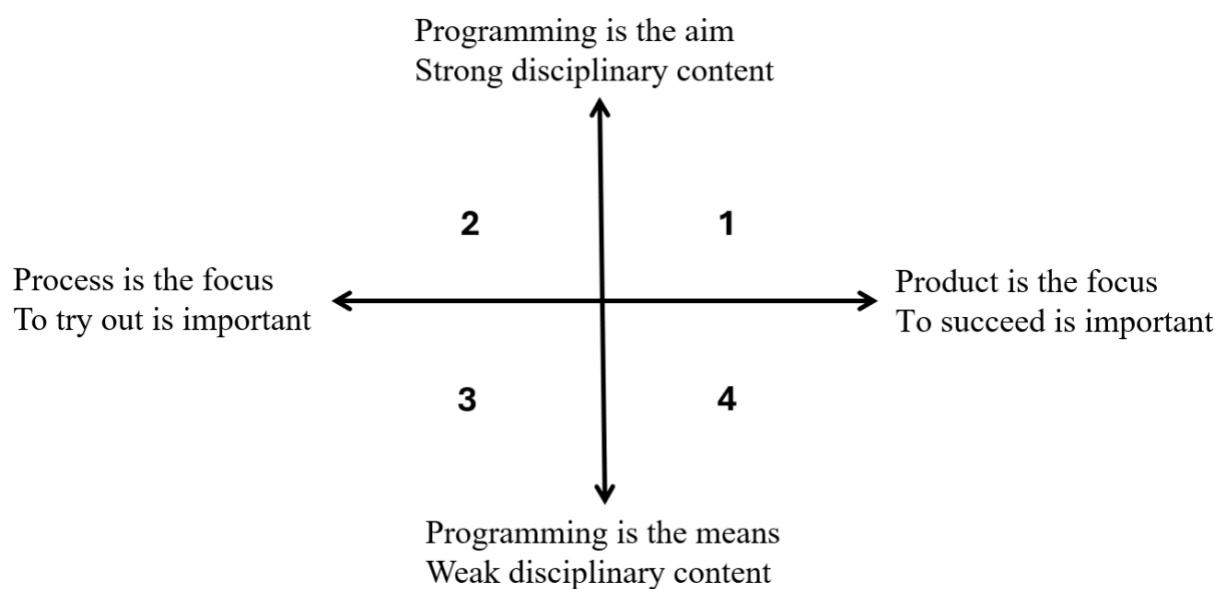


Figure 2. Matrix mapping teachers' various positions in the two thematic areas

The authors compared and discussed the findings and analysis process to reach a consensus.

Results

Teachers' pPCK for Assessing Programming Skills

The participants were asked to underline which grading criteria could be used to assess programming (see example in Figure 3). Liam and Camilla underlined all or almost all the grading criteria. Irene underlined only small portions of the text from all three grading criteria, signalling that not all parts could be used. Kate underlined snippets of the first and third grading criteria and underlined the second grading criterion in full. Magnus, Henric, and Jack all underlined the second and third parts of the grading criteria, while excluding the first grading criteria. In summary, the participants did not agree upon how and if grading criteria one and three could be used, but they all agreed upon the relevance of using grading criteria two for assessing programming skills.

Participant	1 st Grading criteria	2 nd Grading criteria	3 rd Grading criteria
Camilla	The pupil gives examples of technological solutions and describes, in a well-developed manner, some of their advantages and disadvantages for the individual and the environment and how they have changed over time.	The pupil examines technological solutions and describes, in a well-developed manner, how some components work together to achieve purpose and function.	The pupil performs simple technology development and design work in a well-organized manner. In the work, the pupil formulates and chooses alternative courses of action that lead to progress. The pupil creates documentation that sets out the intention of the solution well.

Figure 3. Illustrative example of one participant's underlined parts of the grading criteria considered relevant for assessing computer programming skills (Camilla)

Description of Teachers' ePCK when Assessing Programming

The participants' underlined sections of the grading criteria served as a foundation for the subsequent interviews focusing on assessment. They were asked to further explain how they interpreted the grading criteria to be suitable or not for assessing programming tasks in technology in their daily practice.

The pupil gives examples of technological solutions and describes, in a well-developed manner, some of their advantages and disadvantages for the individual and the environment and how they have changed over time.

The participants shared their thoughts on this grading criterion. Liam noted that some aspects of the criterion are well-suited for evaluating programming projects. He referred to the emphasis on technical solutions and the ability to investigate and describe them. Liam stressed that students' enthusiasm and their ability to articulate their project's goals and functionalities play an important role in the assessment of their programming projects. Liam discussed the relevance of this criterion for his robot war competition, in which students build and program their own robots to compete against each other on a large round mat. The goal is to push the opposing robot off the mat, and the last robot remaining on the mat wins. To participate, students must program their robots to use sensors that detect when they reach the edge of the mat, prompting the robot to reverse to avoid falling off. Liam clearly saw how he could use the first grading criterion to assess programming exercises, explaining, "The technical solutions aspect aligns perfectly with our robot war and classic car projects. These projects inherently involve controlling objects through programming, and it's crucial for students to demonstrate a well-developed understanding of how these components interact. This is essential, as it reflects their ability to build a strong offense and defence in our competitive events. Students often realize this during the competitions when they evaluate their work. Some may say, 'I should have tried something different.' It becomes clear to them why they are not performing at a certain level."

Camilla mentioned that when her students design smartwatches or MP3 players, she can assess with the first grading criterion, as the students reflect on various choices concerning technical solutions. This includes considering their impact on individuals, society, and the environment, as well as recognizing the historical evolution of technology. She explained that using prebuilt blocks results in a pass grade, but when students incorporate their own variables, this raises their level of achievement. Students are given the opportunity to present and discuss the smartwatches or MP3 players they have programmed, which helps Camilla assess them against the first grading criterion. During these discussions, students reflect on the advantages and disadvantages of having a single device that performs multiple functions. In this way, she leverages what the students have created as a foundation for deeper discussions.

The pupil examines technological solutions and describes, in a well-developed manner, how some components work together to achieve purpose and function.

When discussing this grading criterion, the participants consistently emphasized that programming is highly relevant for assessing technological understanding in programming. They particularly highlighted the connections between components within a program and the interactions between an artifact and its corresponding software. Several informants provided evidence supporting this perspective. Jack simply stated that students explore how the different parts in a program come together, while Kate underscored the importance of students understanding the synergy between programming and artifact construction, particularly in the context of LEGO robotics and Micro:bit. Irene believed that she could assess whether the students could describe, in a well-developed manner, how various components interact to achieve specific purposes and functions through programming with Micro:bit. She continued by explaining that this involves connecting different LEDs, making them blink, and lighting up in a certain order.

The pupil performs simple technology development and design work in a well-organized manner. In the work, the pupil formulates and chooses alternative courses of action that lead to progress. The pupil creates documentation that sets out the intention of the solution well.

When addressing this grading criterion, Camilla said that her students formulate and choose action alternatives that advance their programming work. She also mentioned that students sometimes require assistance with individual steps, but she encourages them to seek help and learn through collaboration. Henric described his perspective on how he views a well-crafted technology development project by a student compared to a simpler approach:

"Some students tend to rush their work, thinking they're finished in just 10 minutes. I encourage them to spend the next two lessons adding extra features to their games to make them unique. I provide examples, but some find it dull and just change the ball's colour and declare it 'done.' However, with one full lesson and a three-quarter lesson remaining, it's crucial to use the available time wisely. /.../ I think the most important thing is that the students dare to start." (Camilla).

In addition to students initiating and developing their own ideas, Henric emphasized the importance of simplifying and adapting advanced concepts. He highlighted that students should not only generate ideas for improvement but also demonstrate the ability to refine and adapt complex concepts to make them more accessible. Furthermore, he underscored the value of students' vision and their capacity to identify opportunities. Henric also pointed out that one of

the key attributes of programming is that it enables students to articulate and, at times, even present their vision.

To assess the final aspect of the third criterion - students' ability to document their work - Henric evaluates how they write documentation to explain their project's process and functionality. This includes writing game instructions when sharing a game created in Scratch. By allowing students to read each other's instructions and test play their games, they become more aware of how to write clear and effective instructions, ultimately improving their ability to structure and optimize their code.

The third criterion gives the opportunity to assess a technological development process in which students are expected to begin with a need, investigate, propose solutions, construct, and test, using sketches and physical as well as digital models. Jack described this, stating that through the developing phases in technology development and construction work that his students undertake, they get to work with the entire chain. Most of his students' work in the technology subject is centred on programming projects, where they apply their programming skills to develop solutions to various technical challenges.

Regarding the last part of the third criterion, which involves students creating documentation of their work, Liam emphasized its importance. Students take pride in showcasing their work, and Liam takes photos and videos and showcases these for the parents. Students also express a desire to preserve their robot creations for the spring open house, but this may not always be feasible due to other classes needing the material. Consequently, documentation of their work becomes vital for the benefit of others. Additionally, this approach allows students to document their work independently using their personal mobile devices.

In addition to their reflections on the individual grading criteria, the participants expressed more general views on the assessment of students' programming projects. For example, Henric noted that "programming itself isn't a significant part of the assessment," and he mentioned that the curriculum does not specify assessment criteria for programming. However, he believed that the iterative process of refinement should be considered in the evaluation, as it encourages students to experiment and learn through trial and error. Furthermore, Kate's students are in the fifth grade and are not subject to formal grading in terms of summative grades, which begin in year 6 (12-year-olds). Consequently, she does not need to assess them as rigorously as she would if they were in the sixth grade, where grading is mandatory. As a result, her evaluation is more of a pass or not pass nature, based on whether the student has fulfilled the task or not.

On the other hand, Irene, who also teaches fifth-grade students, evaluates them according to the three criteria, and does not use the binary distinction of *pass* or *not pass*.

Exploring the Participants' cPCK

In the thematic analysis of the interviews, two distinct thematic areas that all the teachers discussed and related to were identified. The first concerns how teachers perceive programming as a subject discipline. Specifically, we noted differences in whether the teacher viewed programming as an independent subject with its own terminology and language or as a tool to be used in the context of other subjects. From the literature, we reference Bernstein's

pedagogical device approach, as introduced earlier, which describes how a new subject area can be integrated into schools and their curricula.

The second thematic area concerns assessment practices. We observed clear differences between the teachers who emphasized the final product and those who focused more on the process. When compared to the literature, we see that a focus on the product resembles summative assessment, while a focus on the process is more akin to formative assessment (see Assessment Practices).

We viewed the teachers' different responses in those areas as points along a continuum, where one end represents one extreme in the thematic area, and the other end represents the opposite extreme. The teachers who discussed programming as if students needed to prepare for a technical university program were placed at one end of the continuum for the first theme. In contrast, the teachers who expressed that they teach, use, and assess programming as a tool that students need to master to succeed in other subject disciplines were placed at the other end. The teachers who viewed the product (i.e., the program that students created) as the most important aspect to assess were placed at one end of the continuum for the second theme. Conversely, the teachers who believed that the process by which students engaged in programming was the most crucial aspect of assessment were placed at the other end.

Through this analysis, we identified four distinct personas, each situated in a quadrant of a matrix. Each teacher is placed in one of the quadrants. All these personas were visible in this study and encapsulate the diversity of pedagogical approaches among technology teachers in relation to programming education.

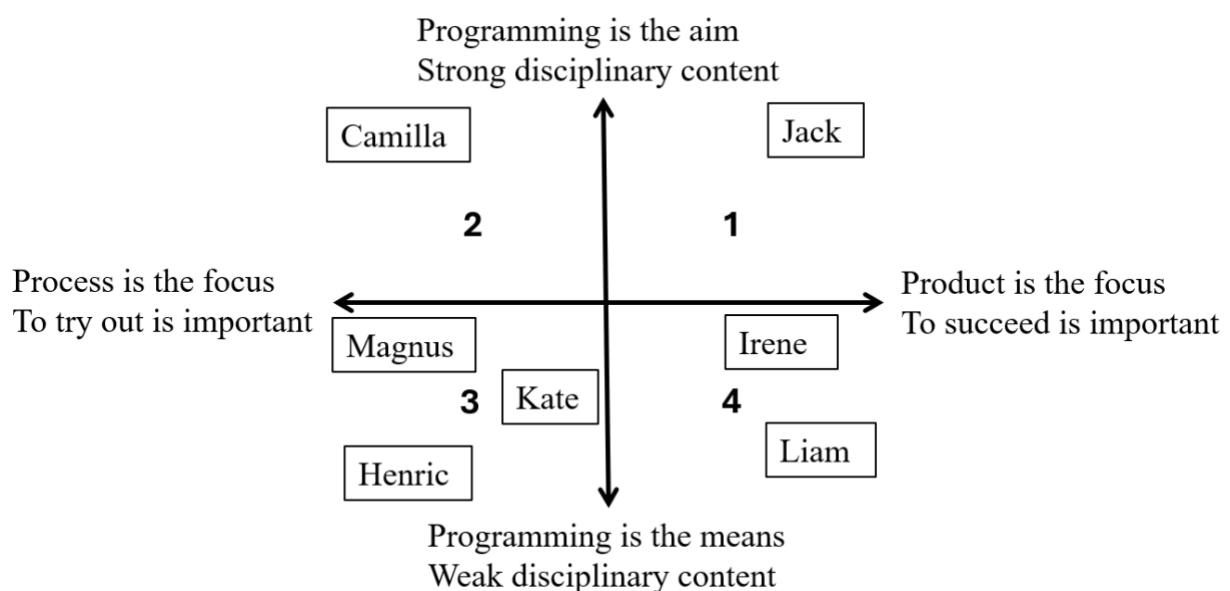


Figure 4. Visualization of how we describe the four distinct personas identified in the study, which depict how technology teachers approach programming instruction

Persona 1: Strong Disciplinary Content, Product Focus

In quadrant one, the teacher views knowledge of programming as a subject area of computer science as a goal of their teaching. The teacher also sees it as important for the student to

successfully complete their task and thus be able to master the entire process and present a well-functioning product. When assessing programming, the outcome is important, meaning that the quality of the finished program is considered.

Teacher Jack described how a student who has succeeded/done well and is considered to be in the upper right corner of the quadrant behaves:

"... I have this code, and, in this way, it works ... if the student can explain their own solution, they usually can also explain another solution and understand why it works" (Jack).

According to the same practice, a student close to the origin in the matrix would show rather poor knowledge in the discipline of computer science and would not have succeeded in creating a well-functioning product.

Persona 2: Strong Disciplinary Content, Process Focus

In this quadrant, the teacher focuses on the student learning the basics of programming and thus considers the student's computer science knowledge. However, the focus is not primarily on how the final product works; instead, it is more important that the student has tried different solutions and can demonstrate mastery of coding at various levels.

Teacher Camilla provided an example of how she assesses her students during programming tasks:

"... then I can guide them a bit to try that first, because I know there is a greater chance of success ... then I can facilitate, but they have still shown that they have some sort of idea. Now I want this to happen ..." (provide context to make it clear that they are actually discussing the theoretical subject matter) (Camilla).

This quote also shows that this assessment practice is more formative than summative, as it is very important for Camilla to coach the students during the process. A student who receives a high grade can demonstrate that they have good knowledge of computer science and are willing to try several different methods and solutions.

Persona 3: Weak Disciplinary Content, Process Focus

A teacher whose practice falls into this quadrant focuses on student testing and practice. It is important for the student to use the equipment and the programming environment provided. The process is crucial; thus, it is important for the student to dare to test how coding works. How is assessment done here?

Henric explains how he assesses his students:

"... Students try and retry. This idea that you get to try and then you sit down and think about what went wrong and do it again" (Henric).

Henric also circulates through the classroom, and if students need help, which is quite common, as they often get stuck on some details, he seizes the opportunity to look at the students' code. Additionally, he play-tests their games and asks the students about their programs.

Another example comes from Kate, who emphasized that the actual code and coding proficiency are not her primary focus in assessment. Instead, she evaluates students based on their holistic development, problem-solving skills, ability to enhance their projects, and overall growth and creativity.

A student who receives high grades and is in the lower left corner dares to test and is engaged in and enthusiastic about the task, while a student who does not receive such good grades is not active in the class. Programming and coding are used as a means of activity. This assessment is mainly formative and takes place in the classroom during programming activities.

Persona 4: Weak Disciplinary Content, Product Focus

The fourth quadrant represents the teachers who assess the student's final product. The most important thing is not that the program has good quality coding, but that it truly does what it is intended to do. This assessment practice has a summative focus, and during the class, the teacher tries to support students in achieving a functioning product.

Liam expresses his assessment practice as follows:

"... a lot of what fits in is when we actually build and create something, not just clicking in code.org. Then, I would feel that we haven't done enough" (Liam).

Irene also expresses this with the following statement:

"It's important for students to understand how to connect these components and explain why they've done it in a particular sequence." (Irene)

A student who receives a high grade has managed to get a program to work so that it can control, for example, their own construction. How this has been accomplished is not so important. A student who fails is considered to have failed if they do not produce a functioning product. Even if they have knowledge of coding and have made attempts and experiments, this is not considered in the assessment.

Discussion

Through the PCK framework, we recognize that a teacher's subject knowledge, pedagogical approaches, and understanding of curriculum guidelines and the school context all play a crucial role in how a subject is taught.

In this study, we interviewed seven teachers with expertise in programming to explore how their perspectives on teaching programming in the classroom (ePCK) have evolved over their years of experience. While many aspects of their teaching practices are similar—for instance, all the participating teachers align their instruction with the technology subject curriculum and assessment criteria—their insights showcased the multifaceted nature of assessment, highlighting creativity, problem-solving, and collaboration as pivotal factors in evaluating students' programming achievements. Our findings also revealed that, despite their expertise, they expressed uncertainty about what and how to teach and assess programming. This became particularly evident when examining how they assess students' programming competencies in practice.

The results section first presents teachers' personal PCK (pPCK), followed by a reflection on their enacted PCK (ePCK), aiming to capture how programming instruction and assessment are conducted in the classroom.

It is important to note that we did not directly observe teachers' ePCK in practice; rather, our findings are based on their self-reported experiences of their ePCK.

In the subsequent section, where we discuss the four different personas, we highlight the variations in their teaching approaches. Our analysis suggests that, despite their competence and experience, these teachers demonstrate significant differences in their instructional methods, values, and objectives for programming education. This variation indicates that there is little to no shared collective pedagogical content knowledge (cPCK) among them. By applying Bernstein's theoretical framework (Ashwin, 2009) alongside our understanding of formative and summative assessment (Black & Wiliam, 2009; Swedish National Agency for Education, 2011), we can interpret these differences more clearly. This, in turn, allows us to reflect on the underlying reasons why teachers hold such diverse perspectives on how programming should be taught.

Weak Versus Strong Subject Content

As mentioned, incorporating new subject content into school curricula is not easy. We observe that teachers perceive programming as anything from a relatively weak subject area to well-established and robust disciplinary content. Digitalization is a societal change of unprecedented magnitude, which means there is no prior experience to draw upon in the face of this paradigm shift. By introducing programming as a relatively weak subject content, used merely as a tool within various school subjects, rather than as a discipline that needs to be thoroughly learned, both theoretically and practically, there is a significant risk. Schools may fail to achieve their purpose of providing students with equal opportunities for future career choices. This approach could potentially undermine the development of essential programming skills that are crucial for students' success in technology-related fields. We perceive a risk that students who do not learn the fundamentals of programming from home or are self-taught through their extracurricular activities will find it much harder to both progress in a profession where programming knowledge is a prerequisite and make critical democratic societal decisions. We believe that a deeper understanding of programming and coding is necessary to comprehend today's society and societal development.

Formative Versus Summative Assessment

We observed that formative and summative assessment in programming education often translate into a focus on either the process or the product. Formative assessment emphasizes the learning journey, in which teachers provide feedback on students' ability to understand, find, and apply algorithms to develop a functional program. In contrast, summative assessment evaluates the final product, assessing how well the completed program solves the intended problem (Bjursten et al., 2022).

In this study, the participating teachers demonstrated distinct approaches to formative and summative assessment. Ideally, a balanced assessment strategy incorporating both perspectives would provide a more comprehensive evaluation of students' programming skills. Achieving this balance likely requires strong subject knowledge and a clear understanding of

the skills students should acquire in programming. This aligns with the findings of Björklund and Nordlöf (2023), who note that teachers tend to emphasize either the process or the product when assessing programming.

Moreover, the broader assessment culture within the technology subject in schools may influence how teachers approach assessment in programming. Understanding these contextual factors could provide valuable insights into the variations in assessment practices observed in this study.

We identified four distinct teacher profiles or personas, suggesting that students' experiences and knowledge acquisition in programming education vary significantly, depending on their teacher's persona. We argue that it is crucial to reflect on which persona educators should ideally align with when teaching programming in the technology subject for grades 4–6. Such reflection could inform the development of professional development programs tailored to support technology teachers in enhancing their instructional approaches to programming.

What, then, do we believe is the reason behind these relatively large differences?

Diverse Teacher Backgrounds

One of the teachers, representing persona one, Jack, has a background as a software developer before transitioning to teaching technology. As a result, Jack possesses a strong knowledge of computer science. It is unsurprising that this teacher has adopted an approach that emphasizes the importance of students learning the fundamentals of programming as a subject area. It is also understandable that this teacher believes that students can learn both the basics of programming and produce a well-functioning product. Furthermore, we observe that a teacher representing persona two, Camilla, who has a high level of knowledge of computer science and programming, also described her teaching practice as one in which students are encouraged to learn and demonstrate their understanding of the basics of programming. In contrast, the other teachers, lacking the same depth of subject knowledge but having taken short courses in programming, described their teaching practice in quadrants three or four. Thus, they do not prioritize ensuring that students acquire the foundational knowledge needed for learning programming later in their educational journey.

Unclear Policy Documents

Another reason for the disparate views among teachers regarding their practices may be the lack of clarity in the current policy documents. For the technology subject, the curriculum strictly states that students should use programming to control construction. Neither the curriculum nor the supplementary material for technology specifies that students should learn programming (Swedish National Agency for Education, 2022a, 2022d). This ambiguity could be interpreted as suggesting that the curriculum implies that teaching practice should align with persona four, wherein students should be able to use some form of coding to develop a solution without specifying how this should be done. In contrast, the mathematics curriculum describes how aspects of coding practice should be taught, leading teachers who teach both mathematics and technology to prefer quadrant two, whereby it is essential for students to test their knowledge acquired in mathematics in a different context (Swedish National Agency for Education, 2022a, 2022c). Unclear steering documents run counter to the principles of a knowledge-rich curriculum, which is desirable for deep thinking and learning complex skills. In

such curricula, clear expectations about what students should learn are crucial for ensuring equitable teaching (Vanhees et al., 2025). This literature also highlights the importance of coherence, both vertical and horizontal: that is, how knowledge for understanding programming is built progressively over time, and how different subjects contribute to a coherent and cumulative understanding of programming.

Limited Programming Competence Among Teachers

We know that approximately 70% of teachers teaching technology express a need for professional development (Swedish National Agency for Education, 2022e). This likely indicates a lack of knowledge about how to program, making it difficult for them to move their practice to quadrants one or two. This may also be the case for our participants, even though they were selected for this study. Through this study, we have reason to believe that a relatively large group of teachers in Sweden find themselves in the teaching practice described in quadrant three, where students have the opportunity to test programming and where curiosity and engagement are the focus of assessment.

Vulnerability in Technology Education

When it comes to technology education, due to the subject's relatively small size, there is often only one technology teacher within a larger teaching environment (Bjursten, Nilsson & Jonsson, 2023). As a result, technology teachers frequently find themselves isolated in their specific practice, with limited opportunities to engage in the collaborative approaches that are commonly advocated for developing a shared teaching culture within a school. This pattern was identified by Hartell (2015) and is, unfortunately, reaffirmed a decade later in recent national data (IVA, 2025). According to the IVA report, many technology teachers still lack fundamental prerequisites for high-quality teaching, including adequate material resources, reasonable group sizes, and sufficient planning time, and they also report limited support from school leadership (IVA, 2025, p. 7).

Conclusion

This study investigated teachers' personal pedagogical content knowledge (pPCK) and their reflections on their enacted pedagogical content knowledge (ePCK) in the context of programming instruction within the technology subject. By conducting a survey, followed by interviews with experienced teachers, we explored how programming is assessed and interpreted within the existing curriculum.

The findings reveal notable variations in how teachers describe their assessment practices, illustrating diverse interpretations of how programming can be assessed. This variation highlights a broader discussion on how collective PCK (cPCK) in programming should be established and integrated in primary education (years 4–6).

Further thematic analysis identified two theme areas influencing teachers' assessment practices: the extent to which they prioritize computer programming as a process for problem-solving versus a product as an end goal and their expectations regarding students' subject content knowledge. The analysis is presented in a matrix with four quadrants representing four personas. Across the study, teachers' assessment practices spanned all four personas: 1) strong disciplinary content and product focus; 2) strong disciplinary content and process focus; 3) weak disciplinary content and process focus; and 4) weak disciplinary content and product

focus. This matrix illustrates the different pedagogical approaches taken by teachers, resulting in varying student experiences of programming education.

A critical concern arising from this study is whether Swedish students are equally prepared to engage in a digitalized society. The findings suggest that there are discrepancies in programming education, meaning that students may not receive equal opportunities to develop the necessary digital competencies. Several factors may contribute to this inequality. First, programming remains a relatively new subject in Swedish primary education, and curriculum documents lack clear guidance on how it should be implemented. Second, teachers' backgrounds seem to significantly influence their assessment practices—those with prior experience in programming tend to approach both instruction and assessment differently from those without such expertise. These combined factors indicate that cPCK for programming education has yet to be established, which may have implications for the equity and consistency of digital education in Sweden.

There are several possibilities for strengthening programming as a subject area in schools. One approach is, of course, to ensure that programming is included as a strong subject area in the form of a separate subject in which students learn to program and then use this knowledge in other school subjects. Another approach is to ensure that well-defined subject modules exist in various school subjects. These could be integrated into subjects such as mathematics and technology, as is done today. If these subject modules were well linked with a progressive approach between them, relatively strong subject content could be achieved.

Ultimately, for programming education to contribute to digital equity, it is crucial to reconsider how teachers are trained in programming. A more interdisciplinary approach, integrating both technology and mathematics, could better equip teachers to provide high-quality programming instruction while ensuring equal learning opportunities for all students. Without such measures, the risk remains that students' access to digital competencies will continue to be shaped by individual teachers' interpretations and prior experiences rather than by a standardized and equitable national curriculum.

References

- Allal, L. (2013). Teachers' professional judgement in assessment: a cognitive act and a socially situated practice. *Assessment in Education: Principles, Policy & Practice*, 20(1), 20-34. <https://doi.org/10.1080/0969594X.2012.736364>
- Ashwin, P. (2009). *Analysing teaching-learning interactions in higher education*. Continuum Publishing Corporation.
- Azmi, N. A., Mohd-Yusof, K., & Phang, F. A. (2017). Impact of Effective Assessment towards Students' Motivation in Computer Programming Course. 2017 7th World Engineering Education Forum (WEEF), Kuala Lumpur, Malaysia.
- Bernstein, B. (2000). *Pedagogy, symbolic control, and identity: Theory, research, critique* (Vol. 5). Rowman & Littlefield.
- Bjursten, E.-L., Hartell, E., & Gumaelius, L. (2022, 7-10 Dec 2022). Assessment Practices in Computer Programming [Conference presentation]. 11th Biennial International Design and Technology Teacher's Association Research Conference (DATTArc). Southern Cross University, Gold Coast Campus, QLD, Australia.

- Bjursten, E.-L., Nilsson, T., & Jonsson, G. (2023). Factors influencing Swedish grades 4–6 technology teachers' choice of teaching and learning material in programming education. *International Journal of Technology and Design Education*.
<https://doi.org/10.1007/s10798-023-09860-8>
- Björklund, L., & Nordlöf, C. (2023). Product or Process Criteria?: What Teachers Value When Assessing Programming. In J. Hallström & M. J. de Vries (Eds.), *Programming and Computational Thinking in Technology Education: Swedish and International Perspectives*. Brill. https://doi.org/10.1163/9789004687912_016
- Black, P., & Wiliam, D. (2009). Developing the theory of formative assessment. *Educational Assessment, Evaluation and Accountability*, 21(1), 5-31.
<https://doi.org/10.1007/s11092-008-9068-5>
- Brennan, K., & Resnick, M. (2012). New frameworks for studying and assessing the development of computational thinking. Proceedings of the 2012 annual meeting of the American Educational Research Association, Vancouver, Canada.
- Bryman, A. (2014). *Samhällsvetenskapliga metoder [Social Research Methods]* (6th ed.). Liber AB.
- Carlson, J., Daehler, K. R., Alonzo, A. C., Barendsen, E., Berry, A., Borowski, A., Carpendale, J., Kam Ho Chan, K., Cooper, R., Friedrichsen, P., Gess-Newsome, J., Henze-Rietveld, I., Hume, A., Kirschner, S., Liepertz, S., Loughran, J., Mavhunga, E., Neumann, K., Nilsson, P., Wilson, C. D. (2019). The refined consensus model of pedagogical content knowledge in science education. In A. Hume, R. Cooper, & A. Borowski (Eds.), *Repositioning pedagogical content knowledge in teachers' knowledge for teaching science* (pp. 77-94).
<https://doi.org/10.1007/978-981-13-5898-2>
- Dagienė, V., Gülbahar, Y., Grgurina, N., López-Pernas, S., Saqr, M., Apiola, M., & Stupurienė, G. (2023). Computing Education Research in Schools. In *Past, Present and Future of Computing Education Research: A Global Perspective* (pp. 481-520). Springer.
- Doyle, A., Seery, N., Gumaelius, L., Canty, D., & Hartell, E. (2019). Reconceptualising PCK research in D&T education: Proposing a methodological framework to investigate enacted practice. *International Journal of Technology and Design Education*, 29(3), 473-491. <https://doi.org/10.1007/s10798-018-9456-1>
- European Union. (2006). Recommendation of the European Parliament and of the Council of 18 December 2006 on key competences for lifelong learning. <https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:394:0010:0018:en:PDF>
- Hartell, E. (2012). The inefficient loneliness: A descriptive study about the complexity of assessment for learning in primary technology education KTH Royal Institute of Technology.
- Hartell, E. (2015). *Assidere necesse est: Necessities and complexities regarding teachers' assessment practices, in technology education* KTH Royal Institute of Technology.
- Hartell, E., Isaksson Persson, H., Bartholomew, S., & Strimel, G. (2018). Investigating the Potential for RGT and ACJ towards deeper insights of Teacher Assessment Practices. The 36th Pupils' Attitudes Towards Technology Conference in Athlone, Ireland. 18–21 June, 2018,
- Hartmann, M., Edelsbrunner, P., Hielscher, M., Paparo, G., Honegger, B. D., & Marinus, E. (2022). Programming concepts and misconceptions in grade 5 and 6 children: Developing and testing a new assessment tool. *Atti del 5° Convegno sulle didattiche disciplinari*, 328-333.

- Hubbard, A. (2018). Pedagogical content knowledge in computing education: A review of the research literature. *Computer Science Education*, 28(2), 117-135. <https://doi.org/10.1080/08993408.2018.1509580>
- Hume, A., Cooper, R., & Borowski, A. (2019). *Repositioning pedagogical content knowledge in teachers' knowledge for teaching science*. Springer. <https://doi.org/10.1007/978-981-13-5898-2>
- IVA. (2025). Det bygger på oss- Tekniklärares syn på sina förutsättningar att undervisa i grundskolan [It's all about us – Technology teachers' views on their ability to teach in compulsory school]. <https://www.iva.se/contentassets/4391de43acf443bba3ef7cb8ba26f371/iva-rapport-det-bygger-pa-oss-202509.pdf>
- Jönsson, A., & Svingby, G. (2007). The Use of Scoring Rubrics: Reliability, Validity and Educational Consequences. *Educational Research Review*, 2(2), 130-144. <https://doi.org/10.1016/j.edurev.2007.05.002>
- Kaya, Z., Kaya, O. N., Aydemir, S., & Ebenezer, J. (2022). Knowledge of student learning difficulties as a plausible conceptual change pathway between content knowledge and pedagogical content knowledge. *Research in Science Education*, 52(2), 691-723. <https://doi.org/10.1007/s11165-020-09971-5>
- Kilday, C. R., Kinzie, M. B., Mashburn, A. J., & Whittaker, J. V. (2012). Accuracy of teacher judgments of preschoolers' math skills. *Journal of Psychoeducational Assessment*, 30(2), 148-159. <https://doi.org/10.1177/0734282911412722>
- Kluger, A. N., & DeNisi, A. (1996). The effects of feedback interventions on performance: A historical review, a meta-analysis, and a preliminary feedback intervention theory. *Psychological bulletin*, 119(2), 254-284.
- Larsson, A. (2023). *Metaphor in Mind: Programming Teachers' Knowledge and Beliefs in Action* Linköping University Electronic Press. <https://doi.org/10.3384/978910752381>
- Mannila, L., Heintz, F., Kjällander, S., & Åkerfeldt, A. (2020). Programming in primary education: Towards a research based assessment framework. Proceedings of the 15th Workshop on Primary and Secondary Computing Education, virtual event Germany.
- Neutens, T., Coolsaet, K., & Wyffels, F. (2022). Assessment of code, which aspects do teachers consider and how are they valued? *ACM Transactions on Computing Education (TOCE)*, 22(4), 1-27.
- Nordén, L.-Å., Heintz, F., Mannila, L., Parnes, P., & Regnell, B. (2017). Introducing Programming and Digital Competence in Swedish K–9 Education. In V. Dagienė & A. Hellas (Eds.), *10th International Conference on Informatics in Schools: Situation, Evolution, and Perspective, ISSEP 2017* (pp. 1-12). Springer Nature. <https://doi.org/10.1007/978-3-319-71483-7>
- Nouri, J., Zhang, L., Mannila, L., & Norén, E. (2020). Development of computational thinking, digital competence and 21st century skills when learning programming in K-9. *Education Inquiry*, 11(1), 1-17. <https://doi.org/10.1080/20004508.2019.1627844>
- Sadler, D. R. (2009). Indeterminacy in the use of preset criteria for assessment and grading. *Assessment & Evaluation in Higher Education*, 34(2), 159-179. <https://doi.org/10.1080/02602930801956059>
- Shulman, L. S. (1987). Knowledge and Teaching: Foundations of the New Reform. *Harvard Educational Review*, 57(1), 1-22. <https://doi.org/10.17763/haer.57.1.j463w79r56455411>
- Shulman, L. S. (2013). Those who Understand: Knowledge Growth in Teaching. *Journal of Education*, 193(3), 1-11. <https://doi.org/10.1177/002205741319300302>

- SOU 2025:19. (2025). Kunskap för alla – nya läroplaner med fokus på undervisning och lärande [Knowledge for all – new curricula with a focus on teaching and learning]. (SOU 2025:19). Retrieved from <https://www.regeringen.se/rattsliga-dokument/statens-offentliga-utredningar/2025/02/sou-202519/>
- Stigberg, H., & Stigberg, S. (2019). Teaching programming and mathematics in practice: A case study from a Swedish primary school. *Policy Futures in Education*, 1478210319894785. <https://doi-org/10.1177/1478210319894785>
- Swedish National Agency for Education. (2011). *Kunskapsbedömning - Vad, hur och varför?* [Knowledge assessment - What, how and why?]. <https://www.skolverket.se/getFile?file=2666>
- Swedish National Agency for Education. (2017). Läroplan för grundskolan, förskoleklassen och fritidshemmet 2011 Reviderad 2017 [Curriculum for the compulsory school, preschool class and school-age educate 2011 (revised 2017)] <https://www.skolverket.se/publikationsserier/styrdokument/2017/laroplan-for-grundskolan-forskoleklassen-och-fritidshemmet-2011-reviderad-2017?id=3813>
- Swedish National Agency for Education. (2022a). *Curriculum for the compulsory school, preschool class and school-age educate*. Retrieved from <https://www.skolverket.se/sok-publikationer/publikationsserier/styrdokument/2024/curriculum-for-compulsory-school-preschool-class-and-school-age-educare---lgr22>
- Swedish National Agency for Education. (2022b). Få syn på digitaliseringen på grundskolenivå – Ett kommentarmaterial till läroplanerna förförskoleklass, fritidshem och grundskoleutbildning [Recognizing Digitalization at the Compulsory School Level – Commentary on the Curricula for Preschool Class, After-School Center, and Compulsory School Education]. Retrieved from <https://www.skolverket.se/getFile?file=11627>
- Swedish National Agency for Education. (2022c). *Kommentarmaterial till kursplanen i matematik* [Supplementary material to the mathematics curriculum]. Retrieved from <https://www.skolverket.se/sok-publikationer/publikationsserier/kommentarmaterial/2022/kommentarmaterial-till-kursplanen-i-matematik---grundskolan>
- Swedish National Agency for Education. (2022d). *Kommentarmaterial till kursplanen i teknik* [Supplementary material to the technology curriculum]. Retrieved from <https://www.skolverket.se/sok-publikationer/publikationsserier/kommentarmaterial/2022/kommentarmaterial-till-kursplanen-i-teknik---grundskolan>
- Swedish National Agency for Education. (2022e). Skolverkets uppföljning av digitaliseringsstrategin 2021 [The National Agency for Education's follow-up of digitalization strategy] (RAPPORT 2022:4). Statens Skolverk. <https://www.skolverket.se/publikationsserier/rapporter/2022/skolverkets-uppfoljning-av-digitaliseringsstrategin-2021>
- Teknikföretagen. (2020). Framtidsspaning - Så påverkar teknikskiftena behoven av ingenjörskompeten [Anticipating the Future: The Impact of Technological Shifts on Engineering Competence Needs]. <https://www.teknikforetagen.se/globalassets/rapporter--publikationer/kompetensforsorjning/framtidsspaning---sa-paverkar-teknikskiftena-behoven-av-ingenjorskompetens.pdf>

- Thornberg, P., & Jönsson, A. (2015). Sambedömning för ökad likvärdighet? [Co-assessment for greater equity?]. *Educare - Vetenskapliga Skrifter*(2), 179-205.
<https://conferences.lnu.se/index.php/PFS/article/view/1401>
- Vanhees, C., Nijlunsing, J., Muijs, D., Crato, N., Wils, M., Wiliam, D., Surma, T., & Kirschner, P. A. (2025). The role of knowledge-rich curricula in promoting deep thinking and complex skill acquisition. *Learning and Individual Differences*, 121, 102729.
- Vinnervik, P. (2021). När lärare formar ett nytt ämnesinnehåll - Intentioner, förutsättningar och utmaningar med att införa programmering i skolan [Teachers as curriculum makers : intentions, settings and challenges associated with integrating programming into schools] [Doctorial dissertation, Umeå Universitet]. <http://www.diva-portal.org/smash/record.jsf?pid=diva2%3A1589572&dswid=5480>
- Zhang, L., & Nouri, J. (2019). A systematic review of learning computational thinking through Scratch in K-9. *Computers & Education*, 141, 103607.

Designing for Entrepreneurship: STEM-Based Approaches in Primary Education

Cemre Saraçlar, Independent Researcher, Türkiye

Ahmet Oğuz Akçay, Eskisehir Osmangazi University, Türkiye

Engin Karahan, Middle East Technical University, Türkiye

Abstract

This study aims to enhance primary school students' entrepreneurial skills by integrating STEM education. Employing a qualitative action research design, the study involved 19 fourth-grade students (aged 9–10) selected via convenience sampling. Over a six-week period totaling 18 instructional hours, researchers implemented two STEM-based activities aligned with the study's objectives. Data were gathered from multiple sources, including video recordings, e-portfolios, student journals, researcher journals, and student-generated artifacts. The research was guided by a framework encompassing 22 entrepreneurial skills, categorized into three domains: knowledge, skills, and attitudes. Findings indicate that while students did not demonstrate complete competence in all areas, particularly within the entrepreneurial aptitude domain, they showed notable development in their understanding, practical skills, and attitudes related to entrepreneurship.

Keywords

Entrepreneurial Skills, Engineering-Design, STEM Education, Action Research, Primary Education

Background

To effectively compete in the global arena, students must possess comprehensive 21st-century skills (Cansoy, 2018; Duman & Aybek, 2003; Yalçın, 2018; Yüksel, 2019). These skills, including critical thinking, entrepreneurship, problem-solving, collaboration development, initiative-taking, and communication, are essential for success in today's world. As unemployment increases, individuals must be able to adapt to rapid advancements in science and technology. Entrepreneurship skills have gained significant importance, and incorporating entrepreneurship education into the school curriculum can foster career awareness (Raposo & Paco, 2011). Further research and pilot studies are necessary to determine the most effective learning methodology. While the school curriculum in different countries incorporates entrepreneurship skills, there is a lack of specific details for primary schools. Scholars propose analyzing national methodologies and adapting those to local contexts to acquire 21st-century skills (Ekici et al., 2017; Gelen, 2017). Consequently, understanding how entrepreneurship education is conceptualized and practiced in various educational systems provides valuable insights for developing effective and contextually relevant approaches. This allows for successful applications while avoiding ineffective activities or programs. Varied interpretations of entrepreneurship education led to diverse implementation approaches in European countries (EACEA, 2016). The extent of entrepreneurship varies based on socio-cultural environments (Kelly, 2020; Sawyer, 2012).

Conceptual Framework

Entrepreneurship in Primary School

Teaching entrepreneurial skills at all levels of education, particularly from primary school, is crucial for cultivating entrepreneurial individuals who can meet the demands of a rapidly changing and evolving world (Yurtseven, 2020). Entrepreneurship education in primary school focuses more on encouraging basic skills such as creativity, curiosity, problem solving, communication, and teamwork, considering that students are not developmentally ready to understand abstract economic concepts (Lackéus, 2015). Integrating entrepreneurship skills into primary school curricula aims to enhance students' career awareness (Herdem & Ünal, 2018; Raposo & Paço, 2011). Field trips, observations, and expert meetings can boost career awareness (Selanik Ay & Acar, 2016). Primary school students should learn foundational entrepreneurial elements, including favorable attitudes, essential abilities, hands-on learning, exploring personal interests, and developing entrepreneurial behavior and skills (Barba-Sanchez & Atienza-Sahuquillo, 2016). Entrepreneurship is considered not only as a process that produces economic output, but also as a multidimensional mental structure involving creativity, recognizing opportunities, risk assessment, and innovative problem solving (Lackéus, 2015). The development of entrepreneurial skills at the primary school level plays a crucial role in helping students acquire fundamental skills, such as problem-solving, creativity, communication, and collaboration, at an early age (Ministry of National Education [MoNE], 2018). Academic research examines the factors that influence teaching entrepreneurial skills to students. Deveci and Çepni (2014) suggest that creating suitable environments for skill acquisition fosters entrepreneurial development. While some studies suggest entrepreneurship has an inherent element, others present contrasting findings. Yurtseven and Ergün (2018) emphasize that the primary goal of entrepreneurship education is to acquire or enhance entrepreneurial competencies in cases where they are lacking. Yurtseven (2020) classified content related to primary school students' entrepreneurial skills under the headings of knowledge, skills, and attitudes (see Figure 1 for the list). Individuals with entrepreneurial aptitude are crucial for innovative thinking and transforming concepts into tangible results, such as creating original merchandise. Effective communication skills are also essential for interacting with relevant individuals or institutions. In this respect, entrepreneurship education is considered a process that should be initiated at the primary school level to enable students to gain career awareness and develop innovative thinking skills (Deveci & Çepni, 2014; Hardie et al., 2020; Yurtseven, 2020).

Entrepreneurship and STEM Education

The significance of production and innovation has increased in our dynamic global landscape, driven by heightened consumption. Technological advancements have increased global interconnectedness, making changes in one country have significant implications for others. To remain competitive, countries must adapt. Ağca and Yumuşakipek (2015) assert that innovation is driven by knowledge, technology, and technological advancements. Countries at the forefront of global competition incorporate STEM education into their curricula. STEM education effectively responds to evolving demands. Education must continually adapt to sustain its strength in the face of technological advancements, product variations, changing consumption patterns, evolving production methods, and shifting scientific disciplines. Karahan et al. (2014) found that high-quality STEM education provides students with STEM literacy and essential 21st-century competencies, including problem-solving, critical thinking, and

teamwork. Recent research indicates that STEM education is crucial to the economy (Tekbiyık & Çakmakcı, 2018).

Entrepreneurship, as defined in various sources, involves multiple subdimensions and requires interdisciplinary collaboration (Kelly, 2020; Yüksel, 2019). According to Vesper and Gartner (1997), the duration of entrepreneurship education is crucial for acquiring and developing entrepreneurial skills (Tarhan, 2019a). The existence of sub-dimensions of entrepreneurial skills may necessitate that these skills be taught in an integrated manner. Teaching these skills within the school, if there is no specific course dedicated to this subject, necessitates an activity framework integrated into the course content. A well-planned activity process will be valuable in terms of developing these skills. Entrepreneurial skills influence work principles in STEM activities and contribute to the value of products. Entrepreneurship cultivates creativity, management, planning, problem-solving, innovation, and risk-taking. It also addresses economic implications and marketing strategies. Presenting a case study to students and designing a product to solve the problem, determining the market value of this product, and preparing a user manual for the product are activities that are expected to be effective in developing these skills. Aydoğdu et al. (2020) emphasize the importance of cultivating entrepreneurship skills for appreciating product value in STEM activities and effectively executing marketing strategies.

Integrating entrepreneurship skills into STEM education through interdisciplinary approaches enhances individual development and product quality. STEM education fosters career awareness by integrating knowledge and proficiencies from various disciplines in practical endeavors. Herdem and Ünal (2018) found that career awareness is integrated as an intermediate discipline in primary school education, and STEM education is crucial for developing this awareness in STEM fields. Entrepreneurship requires innovative thought processes. Promoting innovation is vital for economic growth, and STEM education, the foundation for innovation, can achieve this.

Innovation manifests in creative and unconventional thinking, as highlighted by Kelly (2020). Kuhn (1991) emphasized the need for paradigm shifts to disrupt the status quo. For innovation to occur, it is necessary to step outside the box and think outside the lines. The comfort that individuals/societies find in the standard hinders the realization of innovations. Deveci and Çepni (2015) identified novel idea generation as a fundamental entrepreneurial trait. McDaniel (2002) defined it as transforming novel concepts into marketable products or services through entrepreneurial efforts. Researchers focus on cultivating novel concepts and pursuing innovation. Entrepreneurship, involving sharing and launching novel ideas and products, is central to STEM studies, highlighting their synergy. Dinçer (2014) suggests that allocating resources to STEM skills can position nations in the global economy, influenced by sustainability and innovation enabled by science-oriented education, which directly addresses entrepreneurship education.

Several studies have focused on transmitting entrepreneurial skills to subsequent cohorts, emphasizing educators' entrepreneurial competencies and pedagogical expertise in fostering entrepreneurship abilities. Hassi (2016) highlighted the significance of curriculum design in early skill development. Seikkula-Leino et al. (2010) found that teachers play a crucial role in students' entrepreneurial skills. However, the goal and application guidance lacked clarity.

Yurtseven and Ergün (2018) suggested strategies like drama, brainstorming, project management, research-based learning, and problem-based learning to enhance teachers' entrepreneurial competencies. Tarhan (2021) emphasized the impact of inspiring entrepreneurs and using entrepreneurial narratives for career advancement. Floris and Pillitu (2019) advocated for a problem-oriented approach to entrepreneurship education in primary schools, involving policymakers and local stakeholders. Primary school studies are considered a strategic investment in early education. The integration of STEM education with entrepreneurial skills is important, particularly in primary education, in terms of its potential to support students' ability to generate innovative solutions to real-life problems.

Objectives

This research aims to develop STEM activity modules to enhance primary school students' entrepreneurship skills. The study evaluates the effectiveness of the modules. The activities were part of the "Let's Build Simple Electrical Circuits" and "Light and Sound Technology" instructional units. The research modified the Science and Mathematics curricular units to align with STEM education and implemented them in an extracurricular setting. Yüksel (2019) argues that an interdisciplinary approach is advantageous for acquiring entrepreneurial skills. The research inquiry examines the impact of STEM activities on the development of entrepreneurial aptitude among fourth-grade students (aged 9–10). The research questions were:

- How do STEM-focused activities affect 4th-grade students' entrepreneurship knowledge?
- How do STEM-focused activities affect 4th-grade students' entrepreneurship skills?
- How do STEM-focused activities affect 4th-grade students' entrepreneurship attitudes?

Methods

The primary objective of this study was to enhance the entrepreneurial skills of primary school students. The research methodology employed was action research, utilizing qualitative research designs. Due to the requirement of prolonged implementation in real-world contexts, the researchers concluded that prioritizing local concerns would yield more significant advantages (Aksoy, 2003; Yıldırım & Şimşek, 2018). The study specifically focused on developing entrepreneurship skills among primary school students. This study observed the development of students' entrepreneurial skills within the context of the problem statement presented throughout the research process.

Action Research Process

Diagnosis

The existing literature lacks a clear definition of entrepreneurship knowledge and skills for primary school students (Yurtseven, 2020). While the curriculum for 21st-century skills includes entrepreneurship skills, specific primary school-level sub-dimensions are lacking. This stage is the initial research phase, commonly referred to as the diagnosis stage.

Identification

After the diagnosis, specialists discussed the prevailing issue. To understand the problem, they systematically reviewed relevant literature from various sources. The investigation into entrepreneurship skills revealed that most studies focused on engineering and business

students (Çetinkaya Bozkurt & Alparslan, 2013; Dünder & Ağca, 2007; İşcan & Kaygın, 2011; Karslı, 2018; Keleş et al., 2012). Recent research has focused on entrepreneurship skills in education (Selanik Ay & Acar, 2016; Tarhan, 2019b; Yılmaz & Sünbül, 2009). Integrating entrepreneurship skills into primary school education is a relatively recent development, prompting research on the acquisition of these skills (Akbayrak, 2019; Karakılıç, 2020; Tarhan, 2021; Yurtseven, 2020; Yurtseven & Ergün, 2018). However, there is a lack of comprehensive empirical data on specific sub-dimensions of entrepreneurial skills.

Development

To address the problem of increasing national demands and a lagging economy, educational institutions must equip students with practical skills for real-world scenarios. Ememe et al. (2013) found that students lacked readiness for life, hindering their employment prospects. Including entrepreneurship skills in the curriculum can address this issue. Recent graduates who establish businesses often lack essential entrepreneurial skills, which can lead to the failure of their enterprises. A structured curriculum can cultivate entrepreneurship skills. Tarhan (2019a) emphasizes the need for individuals to acquire entrepreneurial skills to create new employment opportunities. Instruction in entrepreneurship skills should begin in preschool, fostering creativity and collaboration.

The literature on entrepreneurship studies equips students with skills and knowledge to succeed in real-life challenges, just as STEM studies do. Kuratko (2005) emphasizes the importance of technology in entrepreneurship. An early 2000s study highlighted the need for adopting the STEM approach in education to prepare students for entrepreneurial endeavors in the 21st century. STEM skills reinforce this necessity. The Turkish Ministry of National Education's 2018 guidelines for 4th-grade science textbooks include activities titled 'Science, Engineering, and Entrepreneurship', which equip students with real-world skills and allow them to showcase their designs at the annual science fair. The curriculum's focus on 21st-century skills equips students with the competencies to navigate contemporary life and critically evaluate their outcomes.

Development of an Action Plan

Researchers employed STEM-based activity modules with fourth-grade students to develop entrepreneurship skills, utilizing two Science units that integrated technology, engineering, and mathematics. Students solved a problem scenario involving a natural disaster and created two potential solutions as products. The first product resolved the issue, while the second was a district map on which they placed the product. Table 1 presents the distribution of activity modules and outlines the skills emphasized within the modular scope during action research.

Table 1. Skills Targeted in the Modular Scope during the Action Research Process

Purposes	Technology Skills	Entrepreneur Skills	Engineering Skills
Module 1: Understand and visualize the problem situation.	Creative Communicator Global Collaboration Digital Citizen	Creativity and Innovation Management Skills and Leadership Planning	Analyze and Interpret Data
Module 2: Identifies the environment where the problem occurs and the weather conditions that cause the problem, and creates a graph accordingly	Global Collaboration Digital Citizen	Creativity and Innovation Problem Solving	Information gathering, evaluation, and communication
Module 3: Sound technologies, inventors, and the periods in which they lived are researched. Research is presented on a poster	Computational Thinking Digital Citizenship	Creativity Leadership Planning	Information Gathering, Evaluation, and Communication
Module 4: Research what can be done to prevent inconvenience to the public in case of the collapse of electric poles, and seek expert opinions	Empowered Learner Digital Citizenship Knowledge Constructor	Innovation Creativity Problem Solving	Creating Explanations and Designing Solutions Analyzing and interpreting data Planning and Executing Investigations
Module 5: The generated draft product drawings are compared with the information on sound technologies discovered (considering the economic efficiency and lifespan of the products), and a decision is made on the best idea.	Creative Communicator Digital Citizenship Knowledge Constructor	Problem Solving Risk Taking Innovation Planning Creativity Management	Information Gathering, Evaluation, and Communication Analyzing and Interpreting Data Planning Investigations and Conducting

Module 6: The product is created.	Empowered Learner Digital Citizenship Knowledge Constructor	Innovation Creativity Problem Solving Planning Taking Risk Management	Creating Descriptions and Designing Solutions Analyzing and Interpreting Data Planning Investigations and Conducting
Module 7: The user manual of the product is written.	Digital Citizenship Knowledge Constructor	Innovation Creativity Planning Management	Developing and Using Models Analyzing and Interpreting Data Planning and Conducting Investigations
Module 8: A city map is created, indicating the usage of the product based on all available information	Knowledge Constructor Empowered Learner Computational Thinking	Taking Risk Creativity Planning Management Problem Solving Innovation	Developing and Using Models Analyzing and Interpreting Data Planning and Conducting Investigations Information Gathering, Evaluation, and Communication Creating explanations and designing solutions

Implementation and Evaluation

As part of the action process, students were required to create two STEM products to address a problem in their immediate surroundings. The observation of entrepreneurship skills development was intended to be conducted through the students' creation of STEM products. On July 3, 2020, a landslide disaster in the Uzumlu district of Erzincan caused power outages by collapsing electricity poles. The students were tasked with analyzing the socioeconomic status of the local population and their familiarity with Uzumlu in their product design. The students formed groups and conceptualized and developed their products using computer software on a collaborative platform. In the initial STEM activity, "I am a Little Engineer," the groups strategically positioned their products on the Uzumlu map to monitor power outages. The following section presents the STEM activities and the respective activities of the groups.

I am a Little Engineer: Based on the primary education curriculum, specifically the unit on Lighting and Sound Technologies, students learned about a power outage caused by a landslide and its impact on the community. They were tasked with developing products that use lighting

and sound technologies to address the issue. Four groups strategically chose to use these technologies to reach a wider audience. They incorporated devices such as alarms, sirens, and lamps into their products and positioned them in fixed locations.

I am Planning My District: The “I am Planning My District” activity encouraged students to use the Uzumlu district map to plan their products. They applied mathematical skills to calculate expenses and understand how to distribute their products effectively within the community. Students provided a rationale for their product placement on the map. The cost was determined by multiplying the unit price by the quantity of products ordered. This calculation informed their decision to increase or decrease the quantity of products to be ordered.

Participants

The study involved the participation of fourth-grade students who volunteered for the research. The study recruited participants in groups of four, consisting of a total of 19 students from two different classrooms within the same school. The participants were selected utilizing a convenience sampling method. To facilitate convenient access for students and parents, the researcher employed this approach, as it allowed her to continue her research within the confines of her affiliated institution. Participants were assigned to groups labelled S1, S2, S3, up to S19. Group members decided the group names after they were assigned to their groups.

Table 2. Group Names and Students

Group Name	Students
Small Builders	S1, S2, S3, S4, S5, S6
Myth Team	S7, S8, S9, S10
Engineer Stars	S11, S12, S13, S14
The Best Engineers of the World	S16, S17, S18, S19

Data Collection Tools

The data was gathered via various methods, including focus group interviews, observations, e-portfolios, student journals, and researcher journals. The subsequent sections provide comprehensive explanations of each instrument used for data collection.

Focus Group Interview

The study used a group interview method focusing on a specific topic. Focus group interviews typically follow seven stages (Yıldırım & Şimşek, 2018).

1. Review research purpose and method.
2. Develop interview questions based on research problems.
3. Plan location and technology.
4. Pilot test the process.
5. Invite participants.
6. Conduct the study.
7. Organize and analyze data.

Participants in groups in Table 2 were interviewed four days a week. The interviews assessed students' knowledge, skills, and attitudes related to their ongoing activities. During the "I am a little Engineer" activity, students discussed the local community's needs and designed a product. They researched and developed a preliminary product draft. During the "I Plan My District" activity, groups discussed marketing strategies for their products. Students learned communication, technological proficiency, keyword identification, and problem-solving skills. Despite challenges with peers or unfamiliar software, they overcame them through learning.

Student Journals

According to Ören (2014), using student journals allows researchers to assess and comprehend the evolution of students' achievements, experiences, reflections, and dispositions toward the instructional content over time. Students must provide written responses in their journals following the conclusion of after-school activity sessions. These responses should address their perceptions of the activity, the knowledge they acquired, the stage of the activity that had the most significant impact on them, and the specific role they assumed in the distribution of tasks.

Researcher Journals

It is essential to promptly document actions, observations, and noteworthy aspects to ensure the study plan's progress. Çelik et al. (2020) posit that qualitative researchers have the opportunity to utilize research journals as a means to articulate and critically evaluate their ideas comprehensively. Utilizing the researcher's journals facilitated the retrospective examination and correlation of activities undertaken at the commencement and culmination of each procedural phase.

E-Portfolio

E-portfolios are educational tools that monitor students' progress and mitigate risks due to their digital nature. Soland et al. (2013) found that active e-portfolio use enhances self-awareness and fosters collaboration, learning to learn, communication, and application skills. Ravitz et al. (2020) emphasized the importance of active technology engagement for acquiring 21st-century skills. This study documented artifacts in students' e-portfolios, including product drafts, posters, city models, final products, and user manuals throughout the implementation process.

Observations

The documentation of observations was crucial for reporting the implementation process and student outcomes in the action research study. The researcher used video and audio recorders to enhance the detail of student interactions (Yıldırım & Şimşek, 2018). Weekly video recordings were made and transcribed for analysis.

Data Analysis

Acquiring entrepreneurial skills through the STEM approach requires a systematic and well-organized framework. The framework is presented in Figure 1. The research data were analyzed using a descriptive approach, as outlined in the framework. The categorization of entrepreneurship content involved three key components: knowledge, skills, and attitudes (Yurtseven, 2020). Figure 1 shows the classification of entrepreneurship based on knowledge, skills, and attitudes.

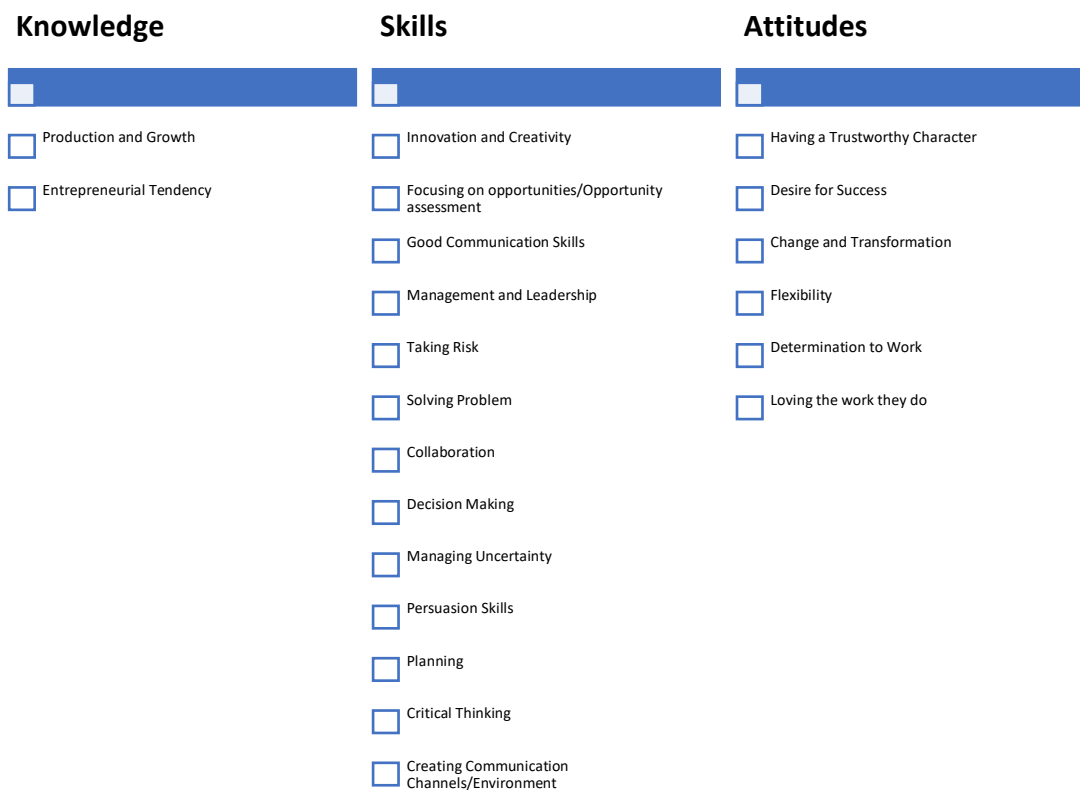


Figure 1. Classification of Entrepreneurship in Terms of Knowledge, Skills, and Attitudes (Yurtseven, 2020)

All procedures conducted in this action research study involving human subjects complied with ethical norms. The study was approved by the Eskişehir Osmangazi University Ethics Committee (Approval number: 2021-09). Informed consent was obtained to ensure that each of the fourth-grade participants voluntarily chose to participate in the research. Additionally, permission to publish research findings, including student-generated artifacts and identifiable data, has been obtained from both the study participants and their parental guardians. The data collection process, which took place outside the classroom, was conducted in the presence of the students' legal guardians.

Results

Knowledge

Production and Growth

The participants emphasized Production and Growth, and the researcher observed students' progress in this area. At this point, students adopted the perspective of the intended audience to address the problem. They adapted their knowledge to the problem's context and proposed potential solutions. For instance, they suggested creating two distinct designs to meet the needs of those facing the issue. The researcher detailed the situation in their scholarly journal.

After evaluating the products, they discussed their advantages and disadvantages. They suggested producing two products to offer the public options. (Researcher Journal)

The students suggested implementing the designs they created, considering cost and usability factors. They asserted that the applicable designs could be implemented in various regions. S7 emphasized extending the warning system's implementation from a limited neighborhood to diverse neighborhoods for the dissemination of widespread information. They also advocated for adopting the system in various cities. S7's statement is presented as follows:

This is not very expensive, but it is slightly above average. It is for use between neighborhoods, but for large neighborhoods, such as this area, it can be used to connect to another far-away neighborhood. Someone living in another neighborhood can hear the sound but cannot see the light. This promotion should be conveyed to every province in Türkiye and exported. (S7)

Entrepreneurial Tendency

The findings examined student progress in acquiring knowledge about entrepreneurial activities. Students designed individual products and grouped to determine the most exemplary one. Their goal was to create a cost-effective product accessible to a wide audience. Affordability and broader accessibility were key considerations. S16 designed a product while balancing profit maximization with environmental impact, utilizing their entrepreneurial skills. Their statements suggest this perspective.

Using a brighter light rather than a red light will be cheaper than my suggestion. Let us try changing the red to something else. (S16)

The subsequent statement represents the decision made by S16 regarding the proposition to manufacture goods utilizing recycled materials.

Yes, it is possible. We can help the environment and reduce our carbon footprint together. (S16)

Skills

Innovation and Creativity

The study found an increase in students' aptitude for innovation and creativity. S3 presented their independently developed sound and light warning system to peers and the researcher during the study's initial phase. S4's product, "I am a little engineer," was well-received by most of its target audience; however, S6 and S1 identified areas for further enhancement. The Little Builders team's claims focus on originality and imagination.

When the light is green, the risk is minimal. The siren emits a soft sound. When it is yellow, the threat is moderate. The sounds are slightly louder. I have marked three distinct siren tones in red for maximum coverage. (S3)

S5 aimed to raise awareness of the disaster by utilizing existing products, such as a minaret, rather than building new infrastructure for a warning system. The following statements are based on S5's principles.

We installed streetlights and erected a single iron rod outside town, hundreds of meters away. The rod's camera detects oncoming floods, visible from anywhere in the city. A

cable connects the ground to the rod, delivering the latest news to the mosques and streetlights. (S5)

Focusing on Opportunities/Opportunity Assessment

Students' focusing skills, crucial for entrepreneurship, were developed through STEM activities. S8 discussed assessing water wastage, specifically identifying unnecessary consumption, to address the entrepreneur's issue of thirst during a STEM career study. The student's argument aligns with this approach.

I think the restroom, Ms. Teacher. When you flush, a lot of water goes down the drain. (S8)

S12 discovered a solution to the aforementioned real-world dilemma:

Our mothers, for instance, often loaded the washer with too little laundry. Wasted water. (S12)

The Small Builders group members noticed they could effectively expand their target market by assessing their products and diversifying their offerings.

After evaluating the products, the Little Builders group discussed their pros and cons by watching a video where S2 explained her product design for the "I am a Little Engineer" activity. The company claimed that they could produce two products for greater variety. (Researcher Journal)

S19 and S18 collaborated to solve a problem and presented their product to the team. S19 also identified ways to ensure equitable access to their products for marginalized individuals.

Although it was designed with deaf people in mind, we will also add vibrations for the visually impaired. (S19)

To highlight the extent of individuals' reliance on their mobile devices, S17 proposed integrating vibration functionality into their product design. Presented here is the statement of S17:

We set it to vibrate on the phone, so it falls out of their hand even if they cannot see it, since we know it will not fall out of their hands. (S17)

Communication Skills

The study revealed a significant enhancement in the communication skills of the students. The Small Builders group members have conducted an assessment of S1's communication abilities and have documented the following observations:

It was noted that S1 was tense and rude to a few friends while conducting weather research and creating the graph. (Researcher Journal)

Notably, S1 mellowed during subsequent dates, and after viewing the video of S2 introducing his product, he suggested that his friend give the presentation because of his superior communication skills. (Researcher Journal)

S12 expressed their perspective on the significance of effective communication. Presented here is the explanation of S12:

Not only is there something similar, but it is also beautiful, can be accomplished without stuttering, and requires no explanation. There is a 98% chance of success if we take these steps. (S12)

Management and Leadership

The evaluation of students encompassed an assessment of their advancements in management and leadership. The subsequent discourse comprises S4's communication to his team members concerning leadership and the recommended course of action they should adopt.

Hopefully, I will do it; we will both do it; of course, we will take turns. First, you will share some info, and then I will share mine. I will respond first if a question is posed to both of us. (S4)

Furthermore, the research journals have verified that S3 allocated distinct responsibilities to each group member to create the poster.

S3 coordinated the poster study by determining who would write what, where, and how on the shared page. He was viewed as a leader due to his independent work style, which was generally well-received. The typical works of the students are listed below. (Researcher Journal)

Taking Risk

Students' risk-taking capability was monitored. The Myth Team group considered revisiting problem-solving and product-design methodologies and presenting an alternative design if their product did not meet expectations. They also considered scenarios where their product might not be included, lack aesthetic appeal, or fail to meet expectations. Students shared their perspectives on their risk-taking tendencies.

We need to apply and notify them of floods, I believe. (S9)

S5 assumed the task of composing the guide. Upon careful examination of the mandatory software, S5 developed a sense of apprehension regarding their ability to fulfil the assignment successfully. The following statement is pertinent to the discussion at hand.

S5 of the Small Builders team offered to write up the instructions. He was concerned about this problem after learning about the Canva program and suggested delegating the work. (Researcher Journal)

S5 used Canva to create the user manual and shared it with friends before the six-day meeting with the Small Builders organization. The following is the researcher's recorded interview observations.

S5 consulted friends about the product's components and purposes before creating the user manual in Canva. Despite solving his problem, he took a chance by writing the manual himself. (Researcher Journal)

Problem solving

The progress of the students was monitored about their problem-solving skills. S3 successfully resolved the issue by devising a solution involving a loud alarm system accompanied by flashing lights. In this matter, please consider the subsequent statement wherein S3 delineates the artifact he has created:

When green, the threat is minimal. The siren emits a soft sound. Yellow indicates a moderate threat. Medium sounds are slightly louder. I will color-code three siren sounds in red for universal recognition. (S3)

S6 discussed their intention to incorporate provisions for individuals with disabilities during the development of their inaugural product.

This idea came to me because I mentioned that some people have trouble hearing or seeing, and others prefer to listen to music through headphones. (S6)

S2 elucidated the product's layout in the accompanying video clip. Figure 2 shows the students' design of their product.

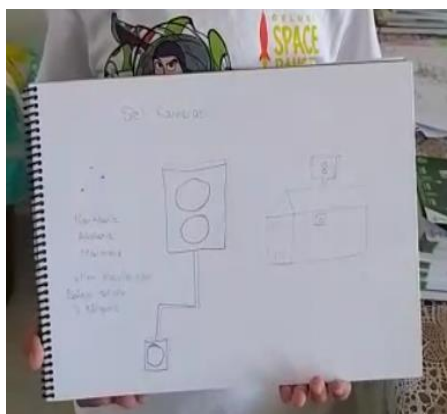


Figure 2. Student Product Design

S11 demonstrated considerable effort in overcoming the challenges encountered in his academic pursuits despite the lack of recognition from his educators and peers for his problem-solving skills throughout the academic term.

Collaboration

The participating students' progress was assessed on their teamwork skills. The first member of the Small Builders crew successfully overcame obstacles through collaborative effort. S16, a member of the "Best Engineers in the World" group, actively sought feedback from authoritative entities about his designed product. Here is S16's statement on the matter:

Teacher, I have created a product that protects against any natural disaster, not just floods. I even consulted my dad's co-workers, and they shared their thoughts.

The researcher demonstrated Canva, a software tool, to the participants. They designed a group logo using a shared computer. The text below presents a statement.

Students in The Best Engineers in the World used Canva for their project. She demonstrated the program, and students worked on their own devices, showing each other their screens and collaborating on a logo. (Researcher Journal)

Figure 3 shows the logo prepared by the The Best Engineer of the World group.



Figure 3. The Best Engineer of the World group logo study

Managing Uncertainty

When determining the cost and profit of the product, member S17 employed their expertise in managing uncertainty to make informed estimations. S17 puts forth the following claims:

If a high-quality speaker costs 700 lira, then a pleasant vibration device should not cost less than 500... 16,800 lira. I will cross out the nearby locations. (S17)

The presentation delivered by the Small Builders group was characterized by a pervasive sense of uncertainty, which can be attributed to their inadequate level of preparation. The following is the transcript of the group's conversation:

When the floods come, we have a vehicle to get the word out. (S6)

To explain, the user guide must first be displayed. Let him (S5) show. (S4)

Decision Making

The researchers observed the students' decision-making skills. They established a friendly environment for discussion, thanks to their positive relationships, and collaboratively reached decisions on their designs. Despite design preferences, they developed a cost-effective collective design. The Engineer Stars group investigated the advantages and disadvantages of solar energy. After evaluating the information, they decided to use solar energy as a viable option due to its affordability. The results are presented below.

The Engineer Stars group chose the solar panel due to its environmental friendliness and cost-effectiveness, as learned from the engineer's knowledge of energy conversion. (Researcher Journal)

The Small Builders group has acquired many product designs. They must decide which one to showcase effectively. Here is the researcher's journal statement about decision-making.

The Small Builders group calculated the cost of their products to determine an affordable price by comparing it with others. (Researcher Journal)

Persuasion Skills

Students' progress in Persuasion Skills was monitored. S10 and S7 disagreed on the product name. The findings are a direct result of the inquiry in this domain.

S10 and S7 competed for the product name. S10, like S7, dominated and forced him to agree to his name. (Researcher Journal)

Creating a Communication Channel/Environment

The analysis focused on students' ability to establish a medium of exchange for measuring growth. Researchers found S17 inclined to communicate ideas to a broader audience and had already identified suitable channels for dissemination. S17's statement declares their capability in this area.

I will explain. I bought these items online. People will benefit from using this product. I plan to draw attention to myself by acting like a used car salesman. (S17)

Since participants lacked cell phone access, the researcher created a Google Classroom class called "4-Entrepreneurs" for communication. Below is the data collected from this line of communication.

Students enjoyed interacting with the researcher and frequently used the app, as evidenced by comments in the Google Classroom. (Researcher Journal)

Planning

S6 presented a comprehensive overview to all cohorts, detailing the materials planned for the Little Builders group's product design, as well as relevant applications and methods of use.

We installed streetlights and erected a single iron rod outside town, with a camera mounted to record the flood. The camera will be visible from anywhere in the city due to its widespread presence. A cable transmits information from the ground up to the mosques and lamps. (S6)

Attitudes

Having a Trustworthy Character

The study examined students' growth in cultivating a dependable character. Adherence to obligations and self-assured conduct were significant factors contributing to reliability. The data is presented below.

S7's concern about missing a previous lesson demonstrates her responsibility. She never missed another lesson, and her family supported her. (Researcher Journal)

Desire for Success

Students' development was observed within the context of the Desire for Success attitude. S16 effectively communicated with stakeholders to ensure the product's success. The interview results are presented below.

S16 from The Best Engineers of the World group explained that his designed system warns of floods and other natural events. He consulted his father's friends and AFAD members for ideas. (Researcher Journal)

Change and Transformation

The researchers monitored students' receptiveness to change and ability to transform. S13 proposed altering his colleagues' designs to achieve the highest quality and practicality. Here is his comprehensive statement:

What if most people do not understand? What are your plans? This is not an option. An app could send a signal. What if this were a phone feature? Nobody might install the app. (S13)

S6 incorporated design elements from S2 and S3 to create a novel product that caters to a broader audience at an affordable price. The statement is presented below in its appropriate context.

In the Small Builders group, member S6 created something new by fusing the concepts of two earlier products, S2 and S3. (Researcher Journal)

One team member, S8, suggested that the Change and Transformation mindset framework allows for price modifications for specific products. S8's relevant statement is:

This is the most cost-effective option for powering it, and it can be done anywhere. A large battery pack could power it, depending on the price. There is likely at least one nearby. If the noise level is acceptable, take it one neighborhood at a time. We can adjust the price if it is not satisfactory.

Flexibility

The researchers observed a significant improvement in students' ability to adapt to novel situations effectively. They worked with people outside their social circle, demonstrating flexibility and independence. The following statements are presented within this context.

Although he was part of the Best Engineers in the World team, S5 from the Small Builders team had no trouble expressing his ideas. (Researcher Journal)

Participants in the focus group became more willing to participate in interviews. They managed to schedule interviews autonomously without the researcher's help. The conclusion follows.

Student members of the Engineer Stars group stated that they planned to continue working independently of the researcher. (Researcher Journal)

Self-confidence

The students' progress was assessed based on their self-confidence levels. The findings are presented in the following sections. S7's self-assurance was evident in their presentation, as noted by S16. S16's perspective on S7 is elaborated on in the following discourse.

The seventh member of S7 has the most assurance. Your assurance and clear explanation impress me. (S16)

S19 and S18, despite their lack of verbal communication, effectively collaborated to conceive a product, articulate its features to practitioners, and counter objections. These statements were uttered in this context.

Only S19 and S18 answered our questions. They claimed they planned to meet without the researcher, but when that failed, they brainstormed a product. Surprisingly, two students made such a breakthrough, given their silence throughout the research. (Researcher Journal)

Determination to Work

The students' development was observed in relation to their Work Perseverance attitude. S13 and S11 have provided the following statements and observations regarding.

Teacher, I shared my study idea with my father, an engineer. We examined it, including the electrical demolition video. (Researcher Journal)

S6 expressed a desire to learn about his friend's program and develop it. S6's commitment to employment is as follows. S11 and S12 were interviewed to gather information for their product presentations. S11 was enthusiastic about contributing to the presentation. The observation statement is provided below.

S11 prepared a new presentation for the meeting, which S11 and S12 attended. S14 will create the user guide and add it to the presentation. S11 wants more responsibility and realizes it. (Researcher Journal)

The following presentation showcases the product designs in Figure 4 created by the team designated as S11:



Figure 4. A slide from the Presentation of the Engineer Stars Group

It was discovered that S8 believed that he could surmount challenges by adopting a resolute work ethic.

Loving the work they do

The study examined students' development in relation to their attitude toward their chosen pursuits. The results are presented below. The students' anticipation and enthusiasm for

activity-based learning heightened their excitement and interest in the subject. Their statements suggested that students were motivated to work on their projects rather than attend their courses. However, since this was not feasible, they worked on their projects only during the designated time. The students' expressions of enthusiasm are presented as follows.

The students were excited about the study and insisted to the researcher, "Take us from all courses; let us work." (Researcher Journal)

At the start of the online interview with the Engineer Stars group, only S14 participated. The remaining members joined the interview later. Here is the statement about their chosen occupation.

S14 said the other group members did not participate in the live lessons and doubted they would do so again. The students apologized for being late and joined the lesson. S14 suggested they have found the work enjoyable. (Researcher Journal)

Students interviewed an electrical engineer for career development and a young entrepreneur. The observation statement is provided below.

After interviewing the entrepreneur and engineer, their interest and seriousness in the study increased. (Researcher Journal)

S1, a member of the Small Builders group, found joy in his work and was pleased to share his knowledge with his peers.

Critical thinking

The analysis focused on students' cognitive development regarding their critical thinking skill. Students expressed positive and negative remarks during the design process. The findings are elaborated in the subsequent section.

Some of S3's friends liked the final product, but others (including S1, S4, and S6) pointed out flaws. (Researcher Journal)

S7 proposed reinforcing electricity poles to enhance their structural integrity and reduce the risk of collapse. They also suggested developing a specialized product for this purpose. The following section presents the results of a comprehensive analysis in this field.

S7 suggested fortifying the poles from below, but S10 deemed it absurd. (Researcher Journal)

The team from Small Builders developed a method to notify the public of a large-scale power outage, which they incorporated into their product. However, one acquaintance, S1, expressed strong disapproval of the plan. The findings are presented here.

S1 criticized the plan to cut power to homes while issuing warnings to the public through lights and visual cues. They argued it is illogical to further victimize the public by cutting electricity access. (Researcher Journal)

The Engineer Stars group proposed a mobile app to alert the public about an impending flood. However, S13 argued that implementing this option was not practical for the residents. The details are in the next section.

Some users may not be able to download the app, so it would be more cost-effective and accessible if the feature were part of the phone's default configuration. (Researcher Journal)

Upon the conclusion of their presentation, the Engineers Stars group was subjected to the subsequent critique from S17:

Teacher, I think it sounds false because of how much it costs. (S17)

Coping skills/crisis management

The students' resilience in overcoming challenges has garnered attention. While the literature on entrepreneurship does not explicitly cover struggle and crisis management skills, these qualities are evident in the efforts of entrepreneurs. S16 designed a product to document and inform about various natural disasters, beyond floods. She presented her concept at the AFAD, receiving feedback that its implementation was unfeasible. S16 intends to develop an additional product related to the research, but prioritizes realizing this design. The outcomes of this capability are presented below:

AFAD members stated that it was impossible to produce the product due to specific issues, but S16 insisted that a screen could reflect natural events and take precautions. The student was upset but vowed to improve the product if he consulted others and found solutions. (Researcher Journal)

On the presentation day, the Myth Team group failed to show the S10 video. S10 said there was a brief delay loading it. This statement fits this competency.

After figuring out why S10's presentation would not open, he could complete it. (Researcher Journal)

Discussion

Knowledge

The concept of the invention is observed despite the absence of explicit references in Hisrich and Peters (1989) and OECD (2015). Nations must prioritize the development of successive cohorts deeply ingrained with this guiding principle to achieve equilibrium between production and consumption, thereby exerting a substantial influence on the future trajectory (TUSIAD, 2017). Uçak and Erdem (2020) emphasized the relationship between production and economic advancement, noting that nations achieve growth through heightened output. This viewpoint can be traced back to the Industrial Revolution. The marketing process is crucial for product growth and development. Entrepreneurial talents are indispensable. The study's findings indicate that knowledge acquisition and development in production and growth can be attributed to STEM activities.

Successful entrepreneurs possess specific skills, including adequate capital, thorough feasibility studies, access to financial resources, constructive competition, and investing in profitable

areas. Etemand (2004) emphasized the importance of international orientation, global thinking, and business financing for entrepreneurs. Students demonstrated an understanding of environmental impacts and recycling practices, as well as market dynamics through price research, innovation fostering, and effective communication, as shown in their posters. They also showed familiarity with entrepreneurship. Previous research on primary school entrepreneurship education has focused on basic concepts, identification, and advertising strategies. Evidence suggests that students may be predisposed to certain entrepreneurial practices due to their participation in STEM activities.

Skill

The study found that students displayed behaviors and expressions within the Innovative and Creative skills domain. This skill is listed in various entrepreneurship skills tables, including those of Akyürek and Şahin (2013), Etemand (2004), Hisrich and Peters (1989), and Morris (1998). TUSIAD (2017) emphasizes the importance of these skills, noting their increasing demand. Jacobs (1989) suggests that creativity can solve problems. The study observed that students demonstrated their innovative and creative skills, especially in the later stages of the intervention, which was likely due to the STEM activities. The inherent characteristics of STEM education enhance creativity, and engaging in STEM-based activities improves entrepreneurial skills.

Entrepreneurship requires the ability to focus on opportunities. For an entrepreneurial movement to thrive, individuals must acknowledge their limitations and see them as opportunities. Çetinkaya-Bozkurt and Alparslan (2013) defined an entrepreneur as someone who seizes opportunities, emphasizing the importance of this aptitude. Students were allowed to explore their skills and demonstrate their abilities in the research. Tekbıyık and Çakmakçı (2018) emphasized the importance of recognizing and developing students' skills by incorporating STEM applications. It is crucial to cultivate self-confidence in primary school students by providing opportunities for self-discovery and knowledge sharing. Students demonstrated a proactive approach to knowledge dissemination and a heightened ability to identify details in product design, transforming them into opportunities. This enables students to acquire and develop the aptitude to focus on prospects in E-STEM endeavors.

Studies identify cooperation as a skill, but communication skills are inconsistent (Akgündüz et al., 2015; TUSIAD, 2017; Uçak & Erdem, 2020). Effective communication is crucial for establishing and sustaining cooperation. Students with communication difficulties disengage from research due to ineffective collaboration. Effective communication is essential for group planning and decision-making. Jacobs (1989) found a comprehensive overlap among the aspects of skill teaching. Observing a student's expression reveals multiple skills. Cultivating effective communication, a key entrepreneurial competency, can be facilitated through STEM activities.

Çetinkaya Bozkurt and Alparslan (2013), Morris (1998) and TUSIAD (2017) lack management and leadership skills in their analyses. The report by TUSIAD (2017) suggests enhancing administrative practices in response to rapid technological advancements, increased information accessibility, and information overload. Uçak and Erdem (2020) argue that individuals should lead change within themselves. Jacobs (1989) suggests students can assume leadership roles in cooperative learning environments, especially in project-based studies.

Students demonstrated leadership qualities across various academic disciplines in multiple studies. Implementing activity-based studies with diverse courses and content develops students' self-assurance, highlights leadership abilities, and fosters entrepreneurship. STEM activities facilitate leadership skill development.

Risk-taking skills, though not part of 21st-century skills, are often discussed in entrepreneurial literature. Scholars (e.g., Ağca & Yumuşakipek, 2015; Yılmaz & Sünbül, 2009) define entrepreneurs as risk-takers. Hisrich and Peters (1989) emphasized the importance of risk-taking for students to gain new knowledge and face setbacks, while TUSIAD (2017) underscored the importance of risk-taking in STEM to promote innovation. In this study, students' risk-taking abilities were identified and found to improve over time.

Entrepreneurship skills include identifying and analyzing problems, generating viable solutions, and understanding students' cognitive processes. Problem-solving is a primary subcomponent of engineering skills, and integrating it into the curriculum is crucial for developing competent individuals. The Organization for Economic Cooperation and Development emphasizes the importance of engaging students in real-life problem-solving scenarios to foster entrepreneurial skills. Research indicates that students with enhanced problem-solving skills, a subset of entrepreneurial skills, tend to exhibit better performance in STEM activities that involve real-life problems. Collaboration between industry, educational institutions, and educators is essential for adequate STEM studies and addressing STEM-related challenges. STEM activities facilitate the development of collaborative working skills.

In the literature, tolerance for uncertainty is described as the ability to cope with situations where information is incomplete or unclear, rather than as having little uncertainty. Comprehensive explanations of this skill in relation to uncertainty were unavailable. Research findings suggest that students' recent acquisition of market sensitivity and inadequate planning contribute to the emergence of uncertainty. However, students effectively navigate and address these uncertainties. STEM activities enhance the skill to handle ambiguity and unpredictability effectively.

Çetinkaya Bozkurt and Alparslan (2013) and Hisrich and Peters (1989) include decision-making skills in their statements. Gencer et al. (2019) emphasize their importance in engineering abilities, while Uçak and Erdem (2020) highlight their commonality in technology skills. Research shows that students use decision-making skills during problem-solving and facilitate cooperation in collaborative tasks. Therefore, engaging in STEM activities is crucial for acquiring and enhancing decision-making skills.

The OECD's 2015 publication mentions planning skills, while the ISTE (2016) categorizes them as "Organizing Information," involving resource allocation and strategic information management. STEM activities aim to develop products, so students must plan and execute product creation consistently. Integrating a STEM product into society requires qualification to align with societal needs. Students must strategically organize each phase of conceptualization, design, and production for public consumption. Yurtseven's (2020) research suggests that primary school students can develop planning skills if supported explicitly. Ağca and Yumuşakipek (2015) argue that planning helps businesses maintain focus on objectives. Empirical evidence suggests that students who plan and execute projects consider the societal benefits. STEM activities enhance entrepreneurial planning skills.

Students' critical thinking skills were evident in their development of different perspectives throughout the design process, their ability to offer suggestions, and their willingness to express opposing views. Participants demonstrated the cognitive aspects of critical thinking by evaluating technical proposals based on both logical reasoning and social impacts. Critical thinking is a crucial 21st-century skill supporting STEM education. Yurtseven (2020) suggested engaging in activities and using training tools to acquire critical thinking skills. Empirical evidence shows a positive correlation between directing attention to potential avenues and critical thinking. Developing critical thinking involves continuous inquiry and reflection, enabling individuals to discern and seize opportunities. However, as Willingham (2007) argues, critical thinking is not a generic skill that can be taught in isolation; it is deeply tied to domain-specific knowledge and requires sustained practice to be effectively applied.

Ethemand (2004) emphasized the ability to create communication channels. The International Society for Technology in Education's (ISTE, 2016) student standards, titled Creative Communicator, emphasize choosing suitable communication channels and seamlessly incorporating products into appropriate platforms. Students need appropriate communication channels for designing and presenting products in STEM and entrepreneurship activities online. Research has found that engaging in STEM activities can enhance essential skills in communication technologies, which are crucial in contemporary society.

The concept of tackle is evident in Tarhan's (2019a) study. Students feel despair when creating, finalizing, valuing, and defending products compared to others. They need skills to manage this process effectively. Struggle skills include persistence in decision-making, emotional intelligence, and problem-solving. Akyürek and Şahin (2013) and Ethemand (2004) identified and included these three skills in their list of entrepreneurship skills.

Attitude

Upon careful observation during the study process, it became apparent that behaviors and expressions associated with a dependable character closely resemble those of a responsible individual. While entrepreneurship is not explicitly mentioned in the literature, it is plausible that entrepreneurship encompasses responsible and reliable attitudes. Two conceptual frameworks were used to examine this topic. Several studies (Ercan & Sünbül, 2009; Gencer et al., 2019; Jacobs, 1989; Uçak & Erdem, 2020; Uştu, 2019) focused on responsibility but neglected reliability. Jacobs (1989) argued that children develop responsibility and independence as they fulfil their obligations. The study's findings supported this assertion. S11 earned the trust of his peers and educators through conscientious duty. Analysis revealed that STEM activities foster a dependable character.

The absence of the desire for success was observed in Morris's (1998) work and the OECD's (2015) findings. Ercan and Sünbül (2009) discussed the importance of taking risks for success. Evaluating this disposition alone is imprudent. Individuals aspire to professional success, but circumstances play a significant role. Success following a risk-taking endeavor requires perseverance and persistence despite setbacks and failures. It also involves emotional challenges. The research found that students experienced various emotions and situations during the 9-week study, but their primary goal was optimal outcomes for their presentation. Based on these rationales, STEM activities can cultivate students' inclination towards achieving success.

The change and transformation aspect of attitude is not included in Ethemand (2004) or the OECD (2015). Morris (1998) found that this attitude was the most effective in implementing initiatives. Technological advancements require significant skill changes, as indicated by TÜSİAD (2017) and Uçak and Erdem (2020). Yılmaz and Sünbül (2009) found that recognizing change leads to identifying opportunities. Due to the COVID-19 pandemic, the planned in-person research was initially adapted to an online action research methodology. The research found that students adapted to the change and enhanced their attitude.

The literature on entrepreneurial skills does not emphasize flexibility. Uştu (2019) observed this attitude in collaborative work, where diverse perspectives are accepted. Adopting a flexible mindset and adaptive behavior is crucial in a collaborative professional setting. Uçak and Erdem (2020) found that flexible behavior depends on adapting to innovations. Students showed a disposition towards adaptability and cognitive abilities in both scenarios. Based on the research, engaging in STEM activities facilitates the development of a flexible mindset.

Self-confidence, defined as a key entrepreneurial trait by Yılmaz and Sünbül (2009) and a blend of self-confidence and respect by Ethemand (2004), is essential for developing students' entrepreneurial characteristics, as evidenced by increased self-confidence and positive attitudes toward STEM activities (Yurtseven & Ergün, 2018). Perseverance, identified as a critical entrepreneurial attribute (Hisrich & Peters, 1989; Yurtseven & Ergün, 2018; Yurtseven, 2020), is demonstrated by students' determination and commitment in STEM participation. While Hisrich & Peters (1989) discussed job satisfaction, Yılmaz and Sünbül (2009) emphasized performing duties with ardor and resoluteness. Students' enjoyment of academic tasks and independent interviews suggests a clear link between positive attitudes toward STEM activities and the development of entrepreneurial skills such as self-confidence, perseverance, and work satisfaction.

Implications

While we acknowledge the need for caution regarding the complexity of entrepreneurial practices at the primary level, our findings suggest a critical distinction between skill internalization and explicit demonstration. We argue that while the students may not have fully presented these skills in a conventional or professional manner, we frame these results as exploratory evidence that cognitive acquisition of these skills often precedes the ability to fully articulate or showcase them. Recognizing this developmental trajectory allows us to appreciate the structural impact of the applied pedagogical strategies. STEM-based action research interventions in primary school classrooms are an effective strategy for fostering foundational entrepreneurial skills early in students' development. Specifically, the success of utilizing authentic contextually relevant scenarios indicates that educators should incorporate place-based cases to enhance student engagement and the practical application of skills such as problem-solving and risk-taking. It is also advisable that engineers engage in collaborative research to thoroughly explore the subject matter. Ultimately, these findings advocate for a curriculum shift that merges technical STEM literacy with entrepreneurial competencies to better equip young learners for future economic and innovative demands.

References

- Ağca, V., & Yumuşakipek, H. D. (2015). Günümüzde girişimcilik trendini yükselten güçler. In E. Kaygın, & B. Güven, (Eds.). *Girişimcilik temel kavramlar, girişimcilik türleri, girişimcilikte*

- güncel konular* [Basic concepts of entrepreneurship, types of entrepreneurship, current issues in entrepreneurship] (pp. 11-29). Siyah İnci Akademi.
- Akbayrak, K. (2019). *An action research on the acquisition of entrepreneurship skills of 4th-grade gifted students by the creative drama method* [Unpublished master's thesis]. Recep Tayyip Erdoğan Üniversitesi.
- Akgündüz, D., Aydeniz, M., Çakmakçı, G., Çavaş, B., Çorlu, M. S., Öner, T., & Özdemir, S. (2015). *STEM eğitimi Türkiye raporu* [STEM education Türkiye report]. Scala Basım.
- Aksoy, D. N. (2003). Action research: A method for improving and changing educational practices. *Educational Administration in Theory & Practice*, 36(36), 474–489. <https://dergipark.org.tr/tr/pub/kuey/issue/10361/126837>
- Akyürek, Ç., & Şahin, Ç. (2013). Evaluation of elementary teachers' entrepreneurship skills. *EKEV Akademi Dergisi*, 57, 51-68.
- Barba-Sánchez, V., & Atienza-Sahuquillo, C. (2016). The development of entrepreneurship at school: The Spanish experience. *Education+ Training*, 58(7/8), 783-796.
- Cansoy, R. (2018). 21st century skills according to international frameworks and building them within the education system. *İnsan ve Toplum Bilimleri Dergisi*, 4(7). <https://doi.org/10.3112/3134.00000003-2768-9939>
- Çelik, H., Başer Baykal, N., & Kılıç Memur, H. N. (2020). Qualitative data analysis and fundamental principles. *Journal of Qualitative Research in Education*, 8(1), 379-406. <https://doi.org/10.14689/issn.2148-2624.1.8c.1s.16m>
- Çetinkaya Bozkurt, Ö., & Alparslan, A. M. (2013). Characteristics, must be included entrepreneurs and entrepreneurship education: Opinions of entrepreneurs and students. *Journal of Entrepreneurship and Development*, 8(1), 7-28.
- Deveci, İ., & Çepni, S. (2014). Entrepreneurship in science teacher education. *Journal of Turkish Science Education*, 11(2), 161–188.
- Deveci, İ., & Çepni, S. (2015). Development of entrepreneurship scale towards student teachers: A validity and reliability study. *International Journal of Human Sciences*, 12(2), 92–112. <https://www.j-humansciences.com/ojs/index.php/IJHS/article/view/3240>
- Dinçer, H. (2014). STEM eğitimi ve işgücü: Bilgi ekonomisinin olmazsa olmazı [STEM education and workforce: A must for the knowledge economy]. *TÜSİAD Görüş Dergisi*, 85. <http://www.tusiadstem.com/kesfet/makaleler/4-stem-egitimi-ve-isgucue-bilgiekonomisinin-olmazsa-olmazi>
- Duman, B. & Aybek, B. (2003). A comparison of the approaches of process-based and interdisciplinary instruction. *Muğla Üniversitesi Sosyal Bilimler Enstitüsü Dergisi*, 11, 1-12.
- Dündar, S., & Ağca, V. (2007). Entrepreneurial characteristics of Afyon Kocatepe University undergraduate students: An empirical study. *Hacettepe University Journal of Economics and Administrative Sciences*, 25(1), 121-142.
- EACEA (2016). *Entrepreneurship education at school in Europe: Eurydice report* (Report No. EC-02-16-104-EN-N). European Union. https://publications.europa.eu/resource/ellar/74a7d356-dc53-11e5-8fea-01aa75ed71a1.0001.02/DOC_1
- Ekici, G., Abide, Ö. F., Canbolat, Y., & Öztürk, A. (2017). Analysis of resources on 21st century skills. *Journal of Research in Education and Teaching*, 1(6), 124-134.
- Ememe, O. N., Ezech, S. C., & Ekemezie, C. A. (2013). The role of head-teacher in the development of entrepreneurship education in primary schools. *Academic Research International*, 4(1), 242-249.

- Etemand, H. (2004). International entrepreneurship as a dynamic adaptive system. *Journal of International Entrepreneurship*, 2(1-2), 5–59.
- Floris, M., & Pillitu, D. (2019). Improving entrepreneurship education in primary schools: A pioneer project. *International Journal of Educational Management*, 33(6), 1148–1169.
- Gelen, İ. (2017). P21- 21st century skill frameworks in curriculum and instruction: USA Practices. *The Journal of Interdisciplinary Educational Research*, 1(2), 15–29.
- Gencer, A. S., Doğan, H., Bilen, K., & Can, B. (2019). Integrated STEM education models. *PAU Journal of Education*, 45, 38–55.
- Hardie, B., Highfield, C., & Lee, K. (2020). Entrepreneurship education today for students' unknown futures. *Journal of Pedagogical Research*, 4(3), 401-417.
- Hassi, A. (2016). Effectiveness of early entrepreneurship education at the primary school level: Evidence from a field research in Morocco. *Citizenship, Social and Economics Education*, 15(2), 83–103.
- Herdem, K., & Ünal, İ. (2018). Analysis of studies about STEM education: A meta-synthesis study. *Journal of Educational Science*, 48(48), 145–163.
<https://doi.org/10.15285/maruaebed.381417>
- Hisrich, R. D., & Peters, M. P. (1989). *Entrepreneurship: Starting, developing, and managing a new enterprise*. Irwin McGraw-Hill.
- International Society for Technology in Education [ISTE]. (2016). *ISTE standards for students: A practical guide for learning with technology*. Author.
- İşcan, Ö. F., & Kaygın, E. (2011). An investigation to determine the entrepreneurship tendency of university students as potential entrepreneurs. *Organizasyon ve Yönetim Bilimleri Dergisi*, 3(2), 275-286.
- Jacobs, H. H. (1989). Design options for an integrated curriculum. In H.H. Jacobs (Ed.), *Interdisciplinary curriculum: design and implementation* (pp. 13–24). ASCD. <https://files.eric.ed.gov/fulltext/ED316506.pdf>
- Karahan, E., Guzey, S., & Moore, T. (2014). Saving pelicans: A STEM integrations unit. *Science Scope*, 38(3), 1-9.
- Karakılçık, N. (2020). *The description of the students' entrepreneurship skills in the science learning environment outside of the school* [Unpublished master's thesis]. Çukurova Üniversitesi.
- Karslı, H. O. (2018). *Investigating the relationship between personality traits and entrepreneurial intention in terms of proactive personality dimension* [Unpublished master's thesis]. Hacettepe Üniversitesi.
- Keleş, H. N., Özkan, T. K., Doğaner, M., & Altunoğlu A. E. (2012). A research on determining the levels of entrepreneurship of students with an associate's degree. *International Journal of Economic and Administrative Studies*, 5(9), 108-118.
- Kelly, R. (2020). *Collaborative creativity: Educating for creative development, innovation and entrepreneurship*. Brush Education.
- Kuhn, T. (1991). *The structure of scientific revolutions*. Alan.
- Kuratko, D. F. (2005). The emergence of entrepreneurship education: Development, trends, and challenges. *Entrepreneurship Theory and Practice*, 29(5), 577–591.
<https://doi.org/10.1111/j.1540-6520.2005.00099.x>
- Lackéus, M. (2015). *Entrepreneurship in education: What, why, when, how*. OECD.
https://www.oecd.org/content/dam/oecd/en/publications/reports/2015/10/entrepreneurship-in-education_c5ab9450/cccac96a-en.pdf
- McDaniel, B. A. (2002). *Entrepreneurship and innovation: An economic approach*. M.E. Sharpe.

- Morris, M. H. (1998). The entrepreneurial individual. In *Entrepreneurial intensity*. Quorum Books.
- OECD. (2015). *Skills and competences for entrepreneurship*.
<http://www.oecd.org/cfe/leed/skills-for-entrepreneurship.htm>
- Ören, F. (2014). Fen Bilimlerinde alternatif ölçme-değerlendirme [Alternative assessment and evaluation in science]. In Ş. Anagün & N. Duban (Eds.), *Teaching Science* (pp. 277-340). Anı.
- Raposo, M., & Paço, A. (2011). Entrepreneurship education: Relationship between education and entrepreneurial activity. *Psicothema*, 23(3), 453–457.
- Ravitz, J., Bakhshaei, M., Hardy, A., & Seylar, J. (2020). *Assessing classroom technology use for 21st century skills: A research-based rubric*. International Society for Technology in Education (ISTE).
https://uocsweb03.uocslive.com/ISTE/ISTE2020/PROGRAM_SESSION_MODEL/HANDOUTS/113588516/ISTE_2020_Ravitz_et_al_21CTLRubric_Paper.pdf
- Sawyer, G. (2012). *Entrepreneurship and tax policy* [Doctoral dissertation]. Georgetown University.
- Seikkula-Leino, J., Ruskovaara, E., Ikavalko, M., Mattila, J., & Rytikola, T. (2010). Promoting entrepreneurship education: The role of the teacher? *Education+ Training*, 52(2), 117-127.
- Selanik Ay, T., & Acar, Ş. (2016). Views of classroom teachers about the acquisition of entrepreneurial skills. *Electronic Journal of Social Sciences*, 15(58), 960-976.
<https://doi.org/10.17755/esosder.03138>
- Soland, J., Hamilton, L. S., & Stecher, B. M. (2013). *Measuring 21st century competencies: Guidance for educators*. Asia Society Global Cities Education Network.
https://www.researchgate.net/publication/267269458_Measuring_21st-century_competencies_Guidance_for_educator
- Tarhan, M. (2019a). *Girişimcilik pedagojisine giriş* [Introduction to entrepreneurship pedagogy]. Pegem Akademi.
- Tarhan, M. (2019b). An assessment of the future of entrepreneurship education in Turkey within the framework of the 2023 education vision of the Ministry of National Education. *Bolu Abant İzzet Baysal Üniversitesi Eğitim Fakültesi Dergisi*, 19(2), 667-682.
- Tarhan, M. (2021). An evaluation on self-life stories of entrepreneurs in the context of gaining to entrepreneurship skills. *Bolu Abant İzzet Baysal Üniversitesi Eğitim Fakültesi Dergisi*, 21(1), 74-86. <https://doi.org/10.17240/aibuefd.2021.21.60703-815358>
- Tekbiyık, A., & Çakmakcı, G. (2018). *Fen bilimleri öğretimi ve STEM etkinlikleri* [Science teaching and STEM activities]. Nobel.
- TUSIAD (2017). The STEM Need in Turkey for 2023
<https://tusiad.org/tr/yayinlar/raporlar/item/9735-2023-e-dog-ru-tu-rkiye-de-stem-gereksinimi>
- Uçak, S., & Erdem, H. H. (2020). On the skills of 21st century and philosophy of education in terms of searching a new aspect in education. *Usak University Journal of Educational Research*, 6(1), 76-93.
- Uştı, H. (2019). *Preparing and implementing successful STEM / STEAM activities in primary schools: A participatory action research with primary school teachers* [Unpublished doctoral dissertation]. Necmettin Erbakan Üniversitesi.
- Vesper, K. H., & Gartner, W. B. (1997). Measuring progress in entrepreneurship education. *Journal of Business Venturing*, 12(5), 403–421.

- Willingham, D. T. (2007). Critical thinking: Why is it so hard to teach? *American Educator*, 31(2), 8–19. https://www.aft.org/sites/default/files/periodicals/Crit_Thinking.pdf
- Yalçın, S. (2018). 21st century skills and tools and approaches that are used to measure these skills. *Ankara University Journal of Faculty of Educational Sciences*, 51(1), 183-201. <https://doi.org/10.30964/auebfd.405860>
- Yıldırım, A., & Şimşek, H. (2018). *Sosyal bilimlerde nitel araştırma yöntemleri* [Qualitative research methods in the social sciences]. Seçkin.
- Yılmaz, E., & Sünbül, A., M. (2009). Developing scale of university students' entrepreneurship. *The Journal of Selcuk University Social Sciences Institute*, 21, 195-203.
- Yüksel, F. (2019). *The effects on the learning outputs of STEM applications for outdoor educational secondary school science courses* [Unpublished master's thesis]. Ondokuz Mayıs Üniversitesi.
- Yurtseven, R. (2020). Entrepreneurship education in primary school: Purpose, content, and teaching process. *International Journal of Science and Education*, 3(2), 135-153. <https://doi.org/10.47477/ubed.836675>
- Yurtseven, R., & Ergün, M. (2018). Teacher opinions on improving the entrepreneurial skills of primary school students. *International Journal of Social Science Research*, 7(1), 118-140.

A repurposed geometric reasoning model for Engineering Graphics and Design: a conceptual paper

Vernon Candiotes, University of Pretoria, South Africa

Willem Rauscher, University of Pretoria, South Africa

Sonja van Putten, University of Pretoria, South Africa

Abstract

Engineering Graphics and Design is a South African school subject which is foundational to fields such as mechanical, electrical, and civil engineering. However, persistent shortcomings in this subject's instruction have been documented in the South African National Senior Certificate examiners' reports over the past decade. These issues stem primarily from ineffective instructional strategies and a lack of structured reasoning development. These methodological deficiencies may influence the development of learners' visuospatial reasoning skills and conceptual understanding. The situation is exacerbated by the fact that no model for developing such conceptual understanding and reasoning currently exists in the Engineering Graphics and Design field. The need for such a model prompted our search for a suitable model for the structured development of visuospatial reasoning skills, culminating in this conceptual paper. We address the gap by demonstrating how the van Hiele model of geometric reasoning can be particularised to suit the needs for the development of visuospatial reasoning skills in this subject. Our methodology involved the extraction of nine cognitive descriptors from the relevant literature dealing with the van Hiele model. We explain how these descriptors align with Engineering Graphics and Design reasoning requirements. The proposed model offers both diagnostic capabilities for assessing student reasoning levels and instructional guidance for systematic skill development. It is recommended that empirical studies be conducted to test the usability of this repurposed model both in teaching and in the evaluation of the levels of reasoning in assessments.

Keywords

Engineering Graphics and Design; van Hiele model for geometric reasoning; visuospatial reasoning; orthographic and isometric drawing

Background

Engineering Graphics and Design (EGD) is an elective subject offered to Grades 10- 12 learners in South African schools. In this subject, the language of the field is introduced complete with its own operational symbols, lines, and grammatical rules (Bertoline et al., 2011). This language enables verbal and non-verbal communication, allowing technical ideas to be conveyed with clarity. For many EGD learners, essential reasoning skills are poorly developed or lacking (Khoza, 2014; Ramatsetse et al., 2023; Sotsaka & Singh-Pillay, 2020). Information obtained from the South African National Senior Certificate (NSC) examiners' reports for EGD, indicates that Grade 12 learners make certain persistent errors (Department of Basic Education, 2021, 2022). These reports include the following: the inability to read and interpret engineering drawings; difficulty in analysing and planning;

displaying poor knowledge of EGD conventions; poor analysis of question data and requirements; poor planning; poor transfer of Grades 10 and 11 knowledge; inability to calculate simple volumes and areas; misconceptions with orthographic projections; inability to construct and rotate solid geometry figures; inability to convert orthographic multiviews to isometric views; poor execution of assembly drawings; incorrect hatching of sectioned views; and poor visualisation abilities in navigating between 2D and 3D spaces. The teaching and learning of visuospatial reasoning (VSR) is a thread which lies across most of the problematic areas that have been highlighted in these examiners' reports of the last 11 years.

VSR is also referred to as spatial intelligence, spatial thinking, spatial cognition and spatial expertise (Hegarty, 2010). The domain of spatial reasoning ability is contentious as much research has been conducted on it, yet defined attributes appear fragmented, and a single definition does not yet exist (Seery et al., 2015). Newcombe and Shipley (2014, p. 2) argue against the notion of a unitary approach to VSR and state that, "Sadly, the truth is that a hundred years or so of work with existing tests and statistical techniques has not arrived at a cohesive view of the structure of spatial intellect".

The 2021 Department of Basic Education report alludes to problems with teacher competence, as evidenced by an analysis of Grade 12 final examinations. It may well be that the problems lie within the schooling system itself. Hurrell (2021) contends that schooling systems that focus more on procedural knowledge than conceptual knowledge are prone to encourage superficial learning, which negatively impacts the transfer of learning.

Research by Makgato (2016) on preservice EGD teachers found that they are generally underprepared in terms of their VSR ability. Potter et al. (2009) conducted longitudinal studies on EGD over a period of two decades and found that most first-year university students experienced difficulties with VSR.

A similar situation exists in other parts of the world where preservice teachers were found not to know the basic concepts well enough to understand complex concepts and to teach at the correct level (Cunningham & Roberts, 2010). Globally, spatial training is historically missing from most curricula (Taylor & Hutton, 2013; Uttal et al., 2013; Potter et al., 2009). As an unintended consequence, many students in STEM fields who display low levels of spatial ability are dropping out of tertiary education (de Rosa & Fontaine, 2018). As a compounding factor, the White Paper on Post-school Education and Training presented by the Department of Higher Education and Training (2013) hints at current lecturer shortcomings, especially in STEM subjects.

Although considerable progress has been made to increase enrolment in STEM fields, drop-out rates are undermining attempts to retain and grow student numbers in such programmes (Pinxten et al., 2015). To curtail the drop-out trend in STEM fields, it is vital to employ strategies for the early detection of at-risk students regarding spatial ability (Potter et al., 2009; Khoza, 2014; Pinxten et al., 2015). Battista (2007, 2011) argues for the need to understand students' thought processes in order to provide them with a meaningful education. It is essential to identify the cognitive processes that underlie geometry processes in learners in order to determine the nature of the difficulty they are experiencing (Duval, 2006; Lithner, 2000; Battista, 2007; Makina & Wessels, 2009). Scaffolding the

development of students' spatial abilities has become a crucial concern in spatial ability research (Buckley, 2018; Luh & Chen, 2013; Gal & Linchevski, 2010; Uttal et al., 2013). However, Taylor and Hutton (2013) argue that efforts towards developing spatial ability should focus on the teaching process rather than modified or additional content.

Conceptual knowledge in EGD involves VSR skills. Research findings suggest that it is common for teachers of EGD to lack the teaching skills required for learners to develop such skills (Khoza, 2014; Perez Carrion & Serrano, 2012; Singh-Pillay & Sotsaka, 2016). Teachers are often unable to master certain spatial and geometric concepts themselves and may therefore, by default, impart the same misconceptions to their learners (Kell et al., 2013; Khoza, 2017; Verdine et al., 2017). In addition, EGD teachers often experience difficulties with certain subject content and lack the understanding to plan effective teaching and learning experiences (Khoza, 2017; Marunić & Glazar, 2014). Documented research shows that teachers' own spatial skills influence their pedagogical choices: weaker spatial abilities lead to reduced use of spatial tools like sketching, manipulatives, diagrams, and gestures in teaching, and are often accompanied by increased spatial anxiety, particularly with regard to the manipulation of 2D and 3D objects that may limit students' learning opportunities (Atit & Rocha, 2021).

Interest in the efficacy of pedagogical practices in Science, Technology, Engineering, and Mathematics (STEM) education is on the increase due to the significant correlation between STEM students' performance and spatial reasoning skills (Carbonell Carrera et al. 2011; Cheng & Mix, 2014; Harle & Towns, 2011; Marunić & Glazar, 2014; Sorby, 2009; Uttal & Cohen, 2012). Studies by Delahunty et al. (2020) and Wai et al. (2009) on the conceptualisation of STEM problems confirm Tversky's (2005) belief that advanced spatial skills utilise VSR processes that generate substantial mental representations of problems for successful problem solving. Delahunty et al. (2016) caution that the etiological relationship between STEM success and spatial reasoning ability is not yet well understood. Nevertheless, McLain (2022) states that the unique pedagogical approaches and instructional strategies of Design and Technology education can be of value to a broad and balanced curriculum.

As a subject, Engineering Graphics and Design is not the sole proprietor of spatial reasoning: substantial research links spatial reasoning skills to mathematics and STEM teaching and learning across grades. Lowrie and colleagues conducted large-scale intervention studies demonstrating that spatial training programs significantly improve both spatial reasoning and mathematics performance in primary school students (Lowrie, Logan, & Ramful, 2016; Lowrie, Logan, Harris, & Hegarty, 2018). Importantly, these improvements extended beyond geometry and measurement tasks to include number and algebra problems, suggesting that the development of spatial reasoning skills supports a wider range of mathematical thinking. There is therefore a sound argument based on empirical support for the development of explicit instructional frameworks in spatially demanding disciplines like Engineering Graphics and Design.

Teachers' spatial abilities significantly influence instructional approaches. Nationally representative data reveal substantial variation in spatial skills across teacher types: secondary STEM teachers possess spatial skills 0.8 standard deviations higher than preschool and primary teachers, with differences persisting after controlling for intelligence

and gender (Atit, Miller, Newcombe, & Uttal, 2018). Compared to the general population, 79% of secondary STEM teachers demonstrated above-average spatial skills, versus only 47% of preschool and primary teachers. These disparities are concerning given that spatial skills are fundamental to STEM learning from early educational levels (Atit & Rocha, 2021). These findings have direct implications for Engineering Graphics and Design teacher preparation. Professional development addressing teachers' own spatial reasoning, combined with pedagogical frameworks supporting systematic spatial instruction, may be essential for ensuring effective instruction. The adapted van Hiele model provides such a framework, enabling teachers to diagnose students' conceptual understanding, identify misconceptions, and design appropriately sequenced instruction.

The design of effective instructional systems must be grounded in a clear understanding of the interrelatedness of cognitive processes that support effective VSR (National Research Council, 2006). The interrelatedness of spatial factors and their numerous implications for teaching and learning in STEM places a responsibility on teachers to understand VSR on a deeper level (Delahunty et al., 2016). Several researchers mention a gap between understanding the complex cognitive involvement with VSR tasks and the absence of a tailored framework to classify the different cognitive processes (Buckley & Seery, 2016; Newcombe & Shipley, 2014; Pittalis & Christou, 2010; Seery et al., 2015).

But what is VSR actually? Sir Francis Galton (1883) is credited for the conceptualisation of the construct of spatial reasoning ability using mental imagery studies as early as 1880 (Mohler, 2008). In Thorndike's (1921) work, "mechanical intelligence" was defined as the ability to visualise relationships among objects and to comprehend various functions of the physical world. Thurstone (1938) suggested a "space" factor as a mental ability to process spatial and/or visual images. He was among the first to propose that intelligence is not a singular factor and demonstrated his ideas through his Multiple Factors theory. Thurstone (1950) used abstract terms to propose three factors central to spatiality, S1, S2 and S3. Mental rotation (S1) is the ability to maintain recognition of objects when a change in their orientation occurs. Spatial visualisation (S2) is defined as the ability to recognise the components of objects being displaced from their original position. Spatial perception (S3) relates to spatial orientation by manipulating one's own body orientation. These definitions were subsequently replaced with terms that most people could relate to. In general terms, spatial visualisation is the capacity to visualise objects in space and to be perceptive of the internal and external relationships which allow them to be transformed and manipulated. Spatial reasoning skills are mental functions to reason about spatial relationships in imagined and real spaces and manipulate and organise mental images (Newcombe & Shipley, 2014; Uttal et al., 2013).

Hendel (2021) posits that hierarchical teaching and learning models such as those devised by Bloom et al (1956), Gagne (1985), Van Hiele (1986), Anderson and Krathwohl (2001) and Marzano (2001), have led to educational improvement across the globe. However, a tailored framework for geometric reasoning in EGD has remained elusive. The literature in this regard points to several obstacles in STEM education and, in particular, to EGD, where research is needed to provide effective teaching and learning. The purpose of this article is to demonstrate how the framework gap can be filled by particularising a version of the van Hiele model for geometric reasoning for use in EGD. Therefore, the question that

would guide our research was framed as follows: how can a proven framework for geometric reasoning skills be repurposed for use in EGD?

Understanding concepts in Engineering Graphics and Design

In educational research, concepts represent organising principles that structure understanding within a domain, distinct from procedural knowledge. In mathematics, concepts such as "equivalence" or "function" represent fundamental organising ideas, whereas procedures represent specific solution steps. Similarly, in science, concepts like "energy transformation" provide frameworks for organising and interpreting phenomena. Thus, conceptual understanding involves the "why" of an organisational principle, whereas procedural knowledge refers to the "how" or the steps in implementing such a principle.

Within Engineering Graphics and Design, concepts represent fundamental principles underpinning spatial reasoning, projection systems, and technical communication. Nabutola et al. (2018) identified ten fundamental concepts through multi-institutional collaboration: Visualising in 2D and 3D, Mapping between 2D and 3D, Planar Graphical Elements, Sectional Views, Methodologies for Object Representation, Projection Theory, Parallel Projection Methodologies, Drawing Conventions, Dimensioning, and Solid Modelling Constructs.

Consider projection theory as an example. This concept deals with the principles governing how three-dimensional objects are systematically represented in two dimensions, not merely procedural steps for creating views. Conceptual understanding includes grasping geometric relationships between projection planes, understanding *why* views align in specific configurations, and recognising how dimensional information transfers between views. Students with strong conceptual understanding can explain *why* projections work and they can flexibly apply principles to a variety of contexts, whereas procedural knowledge enables correct execution, i.e. *how* to do it, without understanding underlying geometric principles.

The distinction between conceptual and procedural knowledge has significant instructional implications. Nabutola et al. (2018) prove that building on poor conceptual foundations leads to misconceptions and academic problems. Misconceptions—systematic errors in understanding, rather than random errors—persist and compound as students encounter more complex material. Students commonly exhibit specific misconceptions about core concepts, like view orientation, projection layout conventions, or alignment relationships (Nabutola et al., 2018).

The van Hiele model adaptation provides a developmental framework for conceptual progression in geometric reasoning. Just as the original model describes how geometric thinking develops through increasingly sophisticated conceptual levels, the adapted model provides teachers with structured approaches for supporting students' progression from informal spatial intuitions through formal conceptual frameworks.

Filling the framework gap

Delahunty et al. (2016) state that the interrelatedness of spatial reasoning ability factors has numerous implications for STEM education. Yet, two years later, when Buckley (2018) conducted intensive research on the factors that encompass our understanding of spatial reasoning ability, he found that a single, suitable framework still did not exist. Both STEM

teachers and students generally find VSR to be problematic (Clark & Ernst, 2012; McLaren, 2008; Metraglia et al., 2015; Ruckpaul et al., 2015). Frameworks specific to the effective teaching and learning of EGD with VSR as the central construct are lacking.

In our search for an appropriate theoretical framework, we considered the Structure of Observed Learning Outcomes (SOLO) of Biggs and Collis (1982), the Six-Stage Theory of Dienes (1960) and the Actions, Processes, Objects, and Schemas (APOS) theory (Dubinsky, & McDonald, 2001). Biggs and Collis (1982) created the SOLO model which facilitates the teaching and learning of geometry through a structured framework of assessment of learners' geometry insight at different levels. The SOLO model advocates progression from surface-level understanding (identification of shapes and their basic properties) to deeper, more complex reasoning (analysis of relationships for applying existing schemas in new contexts), without defining cognitive milestones.

The Six-Stage Theory of Dienes (1960) focuses on the progression of thinking using concrete manipulatives which gradually makes way for abstract thinking. This theory lacks a structure of hierarchical cognitive levels of thinking and does not provide learning/teaching phases.

The APOS Theory (Dubinsky & McDonald, 2001) focuses on learners' mental structures of action, reasoning processes, and schemas to explain how mathematical concepts are understood. In learning geometry, learners progress from performing actions such as constructing shapes to generating schemas for complex geometric relationships. However, APOS is more appropriate for developing general mathematical concepts rather than geometry-specific thinking.

In contrast, the van Hiele model does provide a hierarchical cognitive structure to describe the development of geometry-specific thinking, thus remedying what may be seen as shortcomings in the models we discuss above. In this regard, Braithwaite (2022) argues that the van Hiele model may be immutable in terms of other, non-geometry mathematical areas, which, in turn, may be conducive to cognitive rigidity. Braithwaite (2022) emphasises the dependence in geometric proof on such skills as visualisation, which he deemed to be less useful in other mathematical areas. However, the van Hiele model has proven its usefulness in geometry education by virtue of its structured hierarchical framework, in which cognitive skills are acquired through a scaffolded teaching and learning process (Karakuş & Peker, 2015).

The van Hiele model characterises students' learning of geometry on hierarchical levels of reasoning (Fuys et al., 1988). The model also proposes five learning phases to improve students' acquisition of reasoning levels by arranging the learning environment according to their prior learning and ability to acquire new levels of reasoning (Karakuş & Peker, 2015). Content that builds onto previous-level cognitive acquisitions can be strategically integrated into the learner's prior body of knowledge by taking cognisance of foundational concepts that should already be acquired. Most studies based on the van Hiele model have only considered the learner-centred part of the model that focuses on cognitive diagnostics (Slavin, 2018).

Guided by Slavin's (2018) thoughts on van Hiele's five learning phases, it is our contention that the teacher-centred part of the van Hiele model is just as important, and efforts to

focus purely on diagnostics will not necessarily lead to practices of improved teaching and learning. The van Hiele developed the hierarchical levels to separate different cognitive skills and to demonstrate how instructional strategies should be designed for learners to progress through the levels. The process allows students to cycle and re-cycle through the learning phases to address the non-acquired conceptual skills until they achieve competence.

The five instructional/learning phases suggested by the van Hiele model should incorporate the following cognition areas through the hierarchy of cognitive levels of reasoning:

1. Recognise and differentiate between 2D shapes and 3D objects according to their order of governing properties.
2. Use the principles of both informal and formal inductive and deductive reasoning to relate figure properties within same objects and across different 2D and 3D views of the same object.
3. Identify and distinguish between the necessary and sufficient conditions for a concept to form meaningful definitions towards formal arguments to justify a reasoning path.
4. Apply critical, logical reasoning through theorems, axioms, and definitions in the context of EGD's axiomatic systems.
5. Apply logical reasoning in structuring figure properties and manipulating intrinsic characteristics of relations to derive further information from given data (transition pieces with branches of interpenetration require such reasoning).
6. Acquire technical language through which the properties of concepts can be described.
7. Forge new relationships between concepts while maintaining, refining and renewing existing concepts. For students to progress through the levels of reasoning, conceptual understanding of such re-arrangements must occur.

The van Hiele model has not been particularised for EGD or any other STEM fields besides mathematics. Usiskin (1982) states that cognitive development in geometry can be accelerated through the van Hiele levels by purposeful instruction, exploration, and reflection. Jaime and Gutierrez (1995) noted, "the van Hiele model of mathematical reasoning has become a proven descriptor of the progress of learners' reasoning in geometry and is a valid framework for the design of teaching sequences in school geometry" (p. 592). Pittalis and Christou (2010) argue that not enough research has been conducted to understand VSR phenomena from an integrated visuospatial and geometry perspective in subjects where learners have to switch mentally between 2D and 3D transformation of objects. EGD is such a subject.

The appropriateness of adapting the van Hiele model for Engineering Graphics and Design is further supported by research demonstrating that spatial and geometric understanding develops through hierarchical levels of increasingly sophisticated conceptual frameworks. Lowrie and colleagues' implementation of the ELPSA (Experience-Language-Pictorial-Symbolic-Application) pedagogical framework for spatial reasoning instruction is similar to the van Hiele model, with both frameworks recognizing that learners progress from concrete, experience-based understanding through increasingly abstract and formalised

reasoning (Lowrie & Patahuddin, 2015; Lowrie et al., 2018). The ELPSA framework begins with experiential, hands-on engagement, progresses through language development and pictorial representation, advances to symbolic manipulation, and culminates in flexible application—a developmental sequence that parallels the van Hiele levels' progression from visual recognition through informal and formal description to relational reasoning. Similarly, research on engineering graphics concept development demonstrates that students' understanding progresses from recognition of surface features through increasingly sophisticated grasp of underlying geometric and projection principles (Nabutola et al., 2018), further supporting the applicability of hierarchical models like van Hiele to engineering graphics domains.

The van Hiele model of geometric reasoning

A husband-and-wife team from the Netherlands, Pierre van Hiele and Dina van Hiele–Geldof postulated a theory in 1957 for the teaching and learning of geometry, based on their research on how learners progress through learning geometry concepts. In the 1960s, education specialists in the Soviet Union redesigned the geometry national curriculum. The results were so good that they caught the eye of American researchers like Usiskin (1982) and Senk (1985). Their work changed the teaching of geometry on an international scale.

Pierre and Dina van Hiele believed that most of the problems experienced by learners are situated in instructional practices rather than in the cognitive processes utilised for geometry reasoning (Pegg, 2020). The model consists of five hierarchical levels of cognitive reasoning (Pegg & Davey, 1998), which they numbered from 0 to 4. The American version of the model has the levels labelled from 1 to 5. Pierre van Hiele stated that "the levels are situated not in the subject matter but in the thinking of man" (Van Hiele, 1986, p. 41). Henceforth, the levels are referred to as VH1 through to VH5. Each level is defined by cognitive descriptors of how learners reason as they progress in a linear order from Level 1 to Level 5. Figure 1 represents the hierarchical structure of the van Hiele model's five cognitive levels of reasoning.

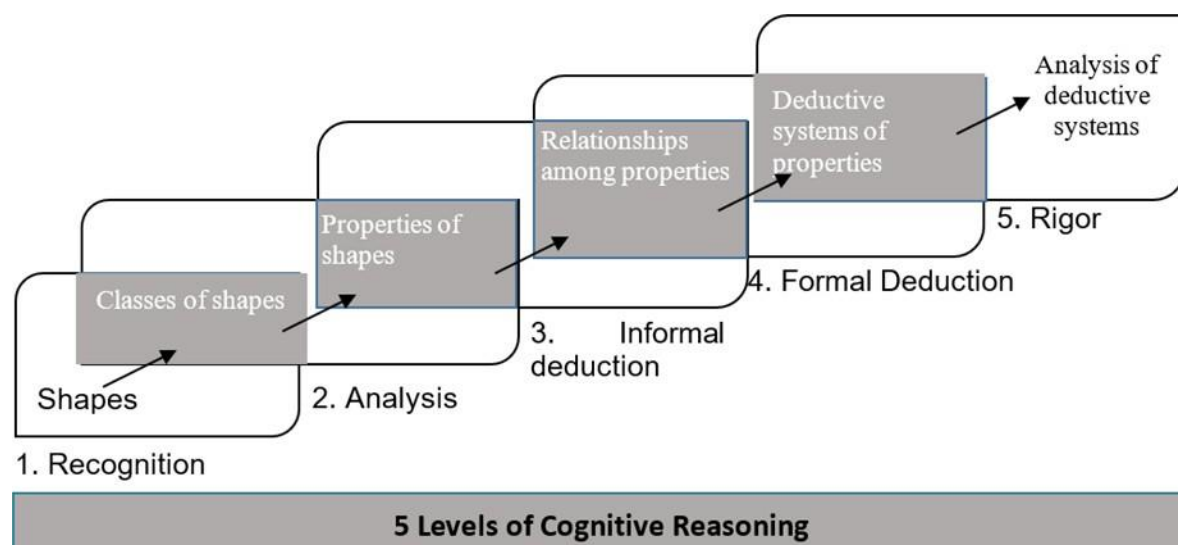


Figure 1: Van Hiele's five levels of cognitive reasoning

Five levels of cognitive reasoning

VH1: Recognition

Figures are visually recognised by their global characteristics (Abdullah & Zakaria, 2013; Gutierrez, 1992). Figures such as squares, triangles and parallelograms are recognised according to their shape, but learners are not yet able to identify figure-properties explicitly (Burger & Shaughnessy, 1986). This level is characterised by learners' ability to observe shapes, take them apart, and rebuild or manipulate them somehow. The focus is on the classification of shapes by exploring their similarities and differences, physically and mentally (van de Walle et al., 2019). In the area of EGD, competency on this level is an assumption because shape recognition is foundational to the field. Since reasoning on Level 1 is intrinsic to visuospatial reasoning of any kind, this level is not included in our application of this model to EGD.

VH2: Analysis

Learners start to consider classing shapes by analysing the properties of figures and learning to describe them appropriately by their technical terminology but are still unable to interrelate the properties within a figure or a figure with other figures (Haviger & Vojkůvková, 2015; Watan & Sugiman, 2018). Learners focus on one class of shapes and can reason that rectangles are rectangles because they have four sides, with opposites being parallel and four 90° angles, their opposite sides equal lengths, and diagonals being equal in length (Curran, 2015). Size and orientation are not considered at this level. Learners begin to grasp those shapes that belong to a certain class, such as cubes, and share corresponding properties. For example, the six congruent faces of cubes are all squares (van de Walle et al., 2019).

VH3: Informal deduction

Learners move beyond just considering figure properties, but also the sufficiency of necessary conditions that allow them to find the relationships between properties of specific shapes (Curran, 2015; Feza & Webb, 2005). Learners apply short deduction steps to arrange the properties of figures logically, and they can grasp such concepts as class inclusions and other interrelationships between figures (de Villiers, 2010; Gutierrez, 1992). Many learners experience difficulty with geometry because of their inability to move beyond VH3 (Haviger & Vojkůvková, 2015). When learners no longer focus only on one particular shape and start to identify other object properties, relationships between various properties of an object and related objects start to make sense. According to van de Walle et al. (2019, p.505), "If all four angles are right angles, the shape must be a rectangle. If it is a square, all angles are right angles. If it is a square, it must be a rectangle." When learners start to engage in if-then reasoning, they are able to use a minimum set of defining attributes to classify shapes. The ability to engage in informal logical reasoning is a signature attribute of Level 3 reasoning. Because they comprehend various properties of shapes, they can ask "Why?" or "What if?" (Pusey, 2003).

VH4: Formal deduction

Learners on this level display a high level of VSR (Gutierrez, 1992). Learners start to comprehend the significance of deductive reasoning, as evidenced by the development of longer sequential statements and start to function with axioms, proofs and theorems. Learners can now analyse informal arguments and the structures of systems inclusive of

their axioms. Geometric truth emerges as they begin to use definitions, theorems and corollaries (Ndlovu & Mji, 2012; van de Walle, et al., 2019). Learners can now reason beyond just the properties and utilise networks of relations to derive further information from information that was given through logical thinking rather than intuition most of the time (van Putten, 2008).

VH5: Rigor

Learners move beyond reasoning within one axiomatic system and start to compare and contrast various axiomatic systems. On the most advanced level of the van Hiele hierarchy, axiomatic systems are no longer just the deductions within a system, but the actual axiomatic system becomes the focal point of interest (Frazee, 2018). Researchers such as Usiskin (1982) state that Level 5 cannot be tested as it provides theoretical value only and falls outside the ambit of school geometry. For this reason, Level 5 is excluded from our application of this model to EGD.

The model's strength lies in its hierarchical structure, where each level builds upon previous ones, and its dual focus on diagnosis and instruction. Students must master lower levels before progressing to higher ones, though development is not necessarily linear (Patkin & Barkai, 2014).

Demonstration of the particularisation process

As an example of this process, we selected a simple machine casting which is represented in Figure 2. In this figure, three 2D orthographic multiviews (front, right and top views, on the lefthand side of the figure) and a 3D isometric view are presented on the right in Figure 2. In this example the three orthographic multiviews are used to create the 3D isometric view.

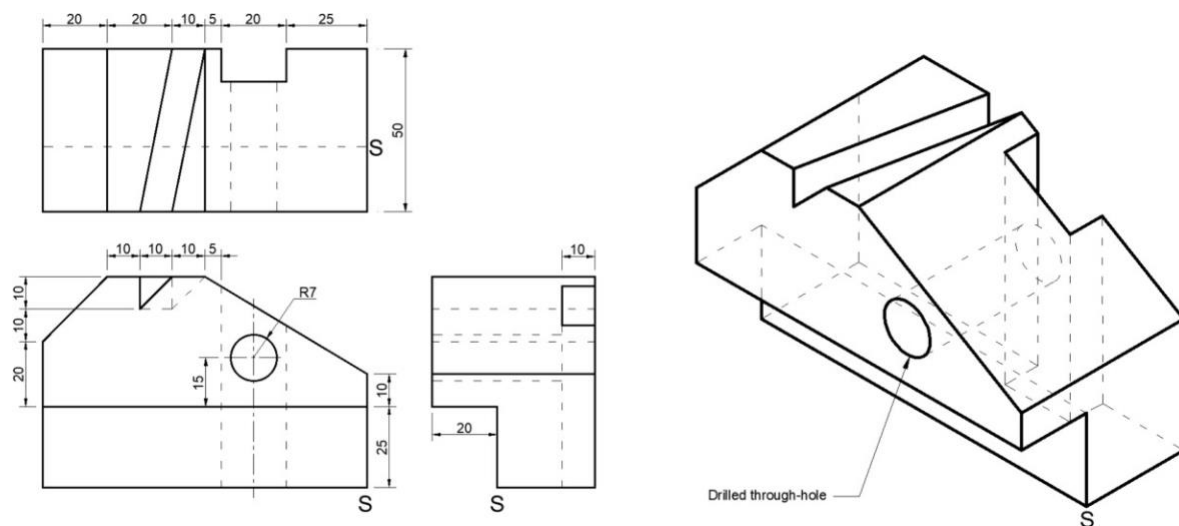


Figure 2: Multiviews and Isometric view of a machine casting

This exercise involves only van Hiele Levels 2, 3, and 4. According to van der Sandt (2007), learners should be functional on Level 3 when they exit the primary school system. As explained in our description of Level 1 earlier, we have excluded the reasoning type of van Hiele Level 1 because the cognitive descriptors of VH2, VH3, and VH4 are more suitable for

demonstrating the relationship between EGD and van Hiele. Level 5 is also excluded as it falls outside the ambit of school curricula.

We conducted a wide search of the literature on van Hiele's model of geometric reasoning and extracted nine cognitive descriptors that were found to be appropriate according to our experience with EGD reasoning. These nine cognitive descriptors are listed in Table 1. We identified three cognitive descriptors on VH 2 (Analysis) which align with the reasoning in creating the isometric view shown in Figure 2. On VH3 (Informal deduction), we identified an additional three cognitive descriptors which apply to reasoning associated with creating an isometric view from three orthographic multiviews. Three cognitive descriptors were identified on VH4 which aligns with associating 2D views with corresponding 3D views.

Table 1: Van Hiele cognitive descriptors for geometric reasoning

Van Hiele descriptors for geometry
VH2: Analysis
Can differentiate between types of shapes (Van de Walle, et al., 2019).
Classify types of shapes according to governing properties (Patkin & Barkai, (2014).
Reasoning is mostly inductive (Curran, 2015).
VH3: Informal deduction
Recognise the importance of properties, and the relationships between them. Can recognise a square as also being a rectangle by definition (De Villiers, 2010).
Can order geometric properties and connect them deductively through logical arguments (Karakuş & Peker, 2015).
Learners can distinguish between necessary and sufficient conditions for a concept. They can form meaningful definitions and give informal arguments to justify their reasoning (Bleeker et al., 2013).
VH4: Formal deduction
Grasps the significance of deduction. Can reason formally within the context of a mathematical system (axiomatic), complete with undefined terms, axioms, and underlying logical systems with definitions and theorems (Pegg, 2020).
Properties are structured to derive further information from given data. Uses logic more than intuition (Burger, & Shaughnessy, 1986).
Manipulate intrinsic characteristics of relations (Haviger & Vojkůvková, 2015).

Using Figure 3, we demonstrate how the nine cognitive descriptors of Table 1 pertain to the reasoning types when an isometric view is created from the orthographic views depicted in Figure 3. Some net-shapes were coded in shades of grey on both the orthographic views and the isometric view to show how net-shapes align across different views. Alphabetical characters were used to trace coordinates of the same type across different views.

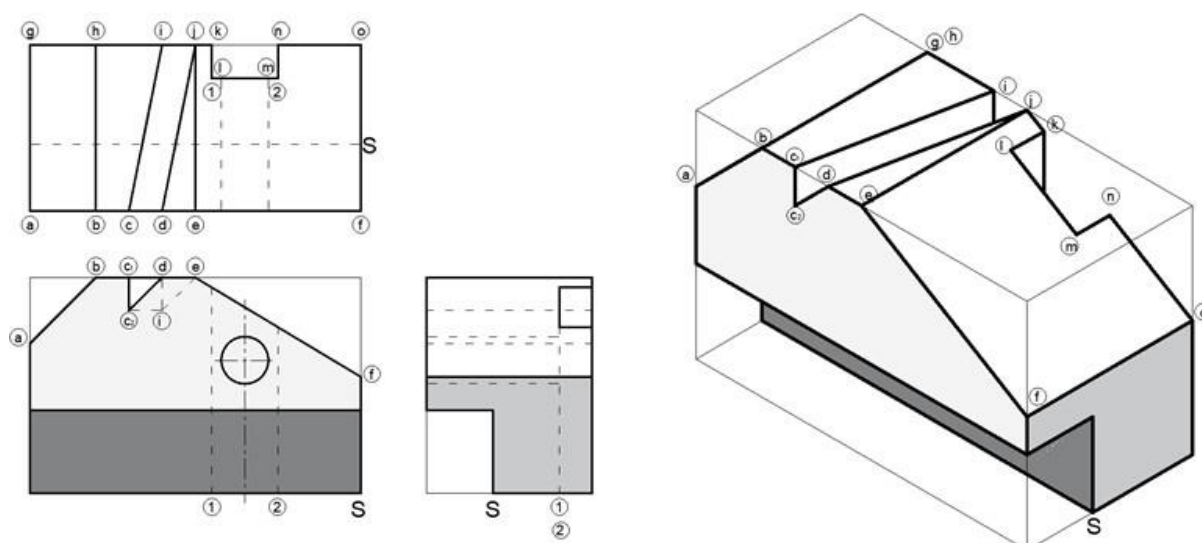


Figure 3: Orthographic and isometric views

The three van Hiele levels of geometric reasoning are used in EGD reasoning in the following manner when converting multiple 2D views of an object to one single 3D view. The cognitive descriptors of Table 1 appear in brackets where they apply: **VH2: Analysis**

Analysis of the given graphical data by identifying the orthographic net-shapes (Cognitive descriptor 1) according to their governing properties (Cognitive descriptor 2). Note: True net-shapes can be identified from the three orthographic multiviews in Figure 2, taking cognisance that slanted nets are not true shapes. At this level, reasoning is mainly inductive (Cognitive descriptor 3) due to the heuristic behaviour of “rule-inference”.

VH3: Informal deduction

In order to differentiate the different net-shapes from each other, EGD practitioners must recognise the importance of properties, and the relationships between them (Cognitive descriptor 4). They must be able to recognise a square as also being a rectangle by definition. By understanding how orthographic views relate to one another and an associated isometric view, they have to order geometric properties and connect them deductively through logical arguments (Cognitive descriptor 5). EGD practitioners must distinguish between necessary and sufficient conditions for a concept. They can form meaningful definitions and give informal arguments to justify their reasoning (Cognitive descriptor 6). This reasoning is essential to distinguish isometric and non-isometric lines from the given orthographic views as such differences require different techniques for creating isometric drawings.

VH4: Formal deduction

EGD practitioners should grasp the significance of deduction. They reason formally within the context of a mathematical system (the axiomatic rules of orthographic and isometric projection), complete with undefined terms, axioms, and underlying logical systems with definitions and theorems (Cognitive descriptor 7). In order to find the coordinates of slanted lines in the isometric view, orthographic properties can be structured to derive further information from given data by using logic more than intuition (Cognitive descriptor 8). When determining the position and extent of details that are obscured (the groove at the back), EGD

practitioners have to manipulate the intrinsic characteristics of relations to find the extents of the groove geometry purely through mental manipulations (Cognitive descriptor 9).

In summary

By virtue of the nature of EGD content, drawing tasks are traditionally quantitatively assessed at the hand of rubrics and are sometimes accompanied by short notes from the assessor. Rubric scores may well point to areas of poor performance but do not provide comprehensive information on the acquisition or non-acquisition of essential levels of cognitive reasoning.

Application of the van Hiele model across the world has been instrumental in ameliorating reasoning deficiencies in geometry by way of the model's dualistic utility. First, in a diagnostic sense, it measures reasoning on a hierarchy of cognitive competence and second, it provides learning phases for learners to cycle through content until the required cognitive skills for a particular level are acquired.

The international research on spatial reasoning interventions points to the broader applicability of structured developmental frameworks across diverse educational contexts. Research from Australia (Lowrie et al., 2018), the United States (Atit et al., 2018; Atit & Rocha, 2021; Nabutola et al., 2018), and other nations demonstrates consistent relationships between spatial reasoning and STEM performance, suggesting that fundamental spatial-mathematical connections transcend cultural and curricular differences. Lowrie's large-scale classroom interventions in Australian primary and secondary schools, involving over 800 students across multiple institutions, demonstrated that spatial training embedded within pedagogical frameworks produces substantial gains that transfer to mathematics performance across geometry, measurement, and number domains. Similarly, multi-institutional research in the United States spanning over 800 engineering students across four universities established that students hold misconceptions about fundamental engineering graphics concepts, with identifiable conceptual gaps (Nabutola et al., 2018). The consistency of findings across international contexts—regarding both the importance of spatial reasoning for STEM learning and the prevalence of spatial misconceptions—suggests that the adapted van Hiele model may have broad international applicability beyond the South African context in which this study is situated.

Rubric-based assessments tend to be characterised by a limited diagnostic capacity. In the context of EGD, we propose that adopting the van Hiele model offers the potential to not just assess VSR tasks at face value. The model provides a system that allows the pinpointing of the students' current levels of geometric reasoning and gives the lecturer a clear picture of what sort of intervention is necessary to mentor and teach the students through structured phases of cognitive development. Performance gaps are thus brought to light and transferable reasoning skills can then be taught in a targeted, need-directed way.

The three detailed examples demonstrate the framework's applicability across diverse EGD content areas, from basic orthographic-isometric conversion to complex assembly drawing interpretation. Each example shows how the nine cognitive descriptors provide specific guidance for understanding student thinking and designing appropriate interventions.

Conclusion

This paper addresses a critical gap in Engineering Graphics and Design education by adapting the van Hiele model of geometric reasoning for systematic development of visuospatial reasoning skills. Our analysis demonstrates strong alignment between van Hiele cognitive descriptors and EGD reasoning requirements, suggesting this framework can provide both diagnostic capabilities and instructional guidance. Thus, the framework's systematic approach to reasoning development offers several advantages over current EGD instructional practices: it facilitates diagnosis of student reasoning difficulties during the structured progression from basic analysis to formal deduction, simultaneously integrating spatial, analytical, and conventional knowledge.

As mentioned in the background of this article, numerous instances of poor conceptual understanding have been identified in the analysis of Grade 12 final examinations. We agree with van Hiele's sentiment that inadequate learning can often be attributed to ineffective instructional strategies and poor structured reasoning development. In answering our research question, which specifically addressed the issue of using an existing model for the teaching and learning of VSR in EGD, we looked at the core of the problem, which, according to Hurrel (2021), is predicated on the overuse of procedural knowledge in lieu of a deeper conceptual understanding. This problem is exacerbated by the fact that no model for developing such conceptual understanding and reasoning exists in the EGD field. However, the van Hiele model specifically provides a structure for the development of cognition in terms of geometry, which we link directly to VSR as required in EGD.

Our particularisation process shows a strong relationship between the cognitive descriptors of van Hiele and reasoning with EGD content. We posit that the van Hiele model of geometric reasoning is eminently suitable for EGD and can be used effectively in the teaching and learning of EGD by following the hierarchical cognitive reasoning process described in the model. Judging from the cognitive descriptors in Table 1, the constructs of visuospatial reasoning, analytical reasoning, and subject conventions can be successfully incorporated into a tailor-made pedagogical framework for EGD, as demonstrated in the example we used.

We propose that by using the cognitive descriptors derived from the van Hiele model, the degree of cognitive acquisition, as suggested by quantitative scores, can be qualitatively analysed to serve as a diagnostic tool. The hierarchical levels of different types of reasoning provide specific categories of cognitive skills that have to be acquired by EGD practitioners. When a singular drawing task is analysed against the cognitive descriptors, the different cognitive activities for that task can be assigned with appropriate van Hiele levels and grouped under visuospatial reasoning, analytical reasoning, and convention knowledge. Cognitive descriptors for each van Hiele level represent different cognitive skills, yet it should be made clear that certain skills could straddle two or more levels concurrently by virtue of their uniqueness and the task requirements.

Previous studies have shown that cognitive skills are not necessarily acquired on a linear path, and skills on higher levels may be acquired while skills on lower levels may still be lacking (Patkin & Barkai, 2014). Once the task is fully described by valid cognitive descriptors spanning different van Hiele levels, the quantitative score for that item serves to inform which cognitive skills were acquired and which ones had not yet been acquired. The framework has the

potential to assess conceptual deficiencies in both teachers and learners and can be used to inform remedial action plans. Teachers should understand their own and their learners' cognitive processes in terms of appropriate learning theories across hierarchical levels of acquisition. Once a complete diagnosis of reasoning deficiencies has been made, special intervention programmes and day-to-day classroom instruction can be designed around the five learning phases.

Nevertheless, this conceptual framework requires empirical validation before widespread implementation. Future research should focus on controlled studies testing the framework's effectiveness, development of reliable diagnostic instruments, teacher professional development in program design, and how cultural and contextual adaptation can be facilitated. The framework's potential extends beyond EGD to other technical drawing and design subjects, suggesting broader applications in STEM education. By providing systematic approaches to spatial reasoning development, this adapted van Hiele model could contribute to improved student retention and success in engineering and related fields.

Implications for teacher preparation and professional development

Given evidence that teachers' spatial abilities influence their pedagogical approaches (Atit & Rocha, 2021) and that spatial skills vary substantially across teacher populations (Atit et al., 2018), teacher preparation programs should explicitly address spatial reasoning development.

For Engineering Graphics and Design specifically, teacher education should address the development of teachers' own spatial reasoning and as well as training them in spatial pedagogy. The adapted van Hiele model proposed in this study provides a framework that can structure both pre-service and in-service teacher education. By understanding the developmental levels through which students' geometric reasoning progresses, teachers can more effectively diagnose students' current conceptual understanding, identify persistent misconceptions, and design instruction appropriately sequenced to support advancement through reasoning levels. Awareness of common misconceptions (Nabutola et al., 2018) can prepare teachers to anticipate and address specific conceptual difficulties before they are embedded.

The adaptation of the van Hiele model for EGD represents an important contribution toward evidence-based spatial reasoning instruction. While further empirical research is needed to validate the model's effectiveness in classroom settings, this conceptual framework provides a preliminary foundation for developing more structured approaches to spatial instruction in Engineering Graphics and Design. Future research should examine how the adapted model performs in actual classroom implementations, investigate its effectiveness across diverse student populations, and refine the cognitive descriptors based on empirical evidence of student progression through reasoning levels.

References

- Abdullah, A. H., & Zakaria, E. (2013). The effects of Van Hiele's phases of learning geometry on learners' degree of acquisition of Van Hiele levels. *Procedia- Social and Behavioral Sciences*, 102, 251-266. <https://doi.org/10.1016/j.sbspro.2013.10.740>
- Anderson, L. W., & Krathwohl, D. R. (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives*. Longman.

- Atit, K., Miller, D. I., Newcombe, N. S., & Uttal, D. H. (2018). Teachers' spatial skills across disciplines and education levels: Exploring nationally representative data. *Archives of Scientific Psychology*, 6(1), 130. <https://doi.org/10.1037/arc0000041>
- Atit, K., & Rocha, K. (2021). Examining the relations between spatial skills, spatial anxiety, and K-12 teacher practice. *Mind, Brain, and Education*, 15(1), 139-148. <https://doi.org/10.1111/mbe.12274>
- Battista, M. T. (2007). The development of geometric and spatial thinking. In F. Lester (Ed.), *Second handbook of research on mathematics teaching and learning* (pp. 843–908). Reston: National Council of Teachers of Mathematics.
- Battista, M. T. (2011). Conceptualizations and issues related to learning progressions, learning trajectories, and levels of sophistication. *The Mathematics Enthusiast*, 8(3), 507-570. <https://doi.org/10.54870/1551-3440.1228>
- Bertoline, G. B., Wiebe E. N., Hartman W., Ross W. A. (2011). *Fundamentals of Graphics Communication*. McGraw-Hill.
- Biggs, J.B. & Collis, K.F. (1982). *Evaluating the Quality of Learning: The SOLO Taxonomy*. Academic Press
- Bleeker, C., Stols, G., & van Putten, S. (2013). The relationship between teachers' instructional practices and their learners' level of geometrical thinking. *Perspectives in Education*, 31(3), 66-78. <https://hdl.handle.net/10520/EJC145555>
- Bloom, B. S., Engelhart, M. D., Furst, E. J., Hill, W. H. & Krathwohl, D. R. (1956). *Taxonomy of educational objectives: The classification of educational goals. Handbook I: Cognitive domain*. Longman
- Braithwaite, D. W. (2022). Relations between geometric proof justification and probabilistic reasoning. *Learning and Individual Differences*, 98, 102201. <https://doi.org/10.1016/j.lindif.2022.102201>
- Buckley, J. (2018). *Investigating the role of spatial ability as a factor of human intelligence in technology education: Towards a causal theory of the relationship between spatial ability and STEM education* (Doctoral dissertation, KTH Royal Institute of Technology). <https://research.thea.ie/bitstream/handle/20.500.12065/2858/Jeffrey%20Buckley%20Thesis.pdf?sequence=1&isAllowed=y>
- Buckley, J., & Seery, N. (2016). Framing spatial cognition: establishing a research agenda. In *70th ASEE Engineering Design Graphics Division Midyear Conference*. ASEE. <http://research.thea.ie/handle/20.500.12065/3263>
- Burger, W. F., & Shaughnessy, J. M. (1986). Characterizing the van Hiele levels of development in geometry. *Journal for research in mathematics education*, 17(1), 31-48. <https://doi.org/10.5951/jresmetheduc.17.1.0031>
- Carbonell Carrera, C., Saorín Pérez, J. L., De la Torre Cantero, J., & Marrero González, A. M. (2011). Engineers' spatial orientation ability development at the European Space for Higher Education. *European Journal of Engineering Education*, 36(5), 505-512. <https://doi.org/10.1080/03043797.2011.602184>
- Cheng, Y. L., & Mix, K. S. (2014). Spatial training improves children's mathematics ability. *Journal of cognition and development*, 15(1), 2-11. <https://doi.org/10.1080/15248372.2012.725186>
- Clark, A. C., & Ernst, J. V. (2012). A learner profile thematic review of introductory engineering design graphics learners. In *Proceedings of the Engineering Design Graphics Division of the American Society of Engineering Education's 67th Mid-Year Conference*, Limerick

- Ireland, Session (pp. 106-110). <https://edgd.asee.org/wp-content/uploads/sites/22/2019/09/ALEARN1.pdf>
- Cunningham, R. F., & Roberts, A. (2010). Reducing the Mismatch of Geometry Concept Definitions and Concept Images Held by Pre-Service Teachers. *Issues in the Undergraduate Mathematics Preparation of School Teachers*, 1, 1-17. <https://files.eric.ed.gov/fulltext/EJ914254.pdf>
- Curran, S. (2015). *Is The Van Hiele Model Useful in Determining How Children Learn Geometry?* GRIN Verlag.
- de Rosa, A. J., & Fontaine, M. (2018). Implementation and First-Year Results of an Engineering Spatial Skills Enhancement Program. In *2018 Mid Atlantic Section Fall Meeting*. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/file:///C:/Users/u04126505/Downloads/implementation-and-first-year-results-of-an-engineering-spatial-skills-enhancement-program.pdf
- de Villiers, M. (2010). Some reflections on the van Hiele theory. In *Invited plenary from 4th Congress of teachers of mathematics*.
- Delahunty, T., Sorby, S., Seery, N., & Pérez, L. (2016). Spatial skills and success in engineering education: A case for investigating etiological underpinnings. *70th Engineering Design Graphics Division Annual Mid-Year Conference*. Daytona Beach, Florida. pp.24- 29 <https://commons.erau.edu/asee-edgd/conference70/papers-2016/3>
- Delahunty, T., Seery, N., & Lynch, R. (2020). Exploring problem conceptualization and performance in STEM problem solving contexts. *Instructional Science*, 48(4), 395-425. <https://doi.org/10.1007/s11251-020-09515-4>
- Department of Basic Education (2022). *National Senior Certificate 2022: Diagnostic Report: PART 3: Technical Subjects*. <https://www.education.gov.za/Portals/0/Documents/Reports/Diagnostic%20Reports%202022/Diagnostic%20Report%20PART%203%20Technical%20Subjects.pdf?ver=2023-02-14-130652-000>
- Department of Basic Education (2021). *2021 National Senior Certificate: Diagnostic Report: PART 3: Technical Subjects*. <https://www.education.gov.za/Portals/0/Documents/Reports/2021NSCReports/2021%20Diagnostic%20Report%20Part%203%20Technology%20Subjects.pdf?ver=2022-02-08-103331-000>
- Department of Higher Education and Training (2013). *White paper for post-school education and training. Building an expanded, effective and integrated post-school system*. <https://www.dhet.gov.za/SiteAssets/Latest%20News/White%20paper%20for%20post-school%20education%20and%20training.pdf>
- Dienes, Z.P. (1960). *Building up mathematics*. Hutchinson Educational Company.
- Dubinsky, E., & McDonald, M. A. (2001). APOS: A constructivist theory of learning in undergraduate mathematics education research. In *The teaching and learning of mathematics at university level: An ICMI study* (pp. 275-282). Springer Netherlands.
- Duval, R. (2006). A cognitive analysis of problems of comprehension in a learning of mathematics. *Educational studies in mathematics*, 61(1), 103-131. <https://doi.org/10.1007/s10649-006-0400-z>
- Feza, N., & Webb, P. (2005). Assessment standards, Van Hiele levels, and grade seven learners' understandings of geometry. *Pythagoras*, 2005(62), 36-47. <https://hdl.handle.net/10520/EJC20858>

- Fraze, L. M. (2018). *The interaction of geometric and spatial reasoning: Student learning of 2D isometries in a special dynamic geometry environment* (Doctoral dissertation, The Ohio State University). http://rave.ohiolink.edu/etdc/view?acc_num=osu1531862080144028
- Fuys, D., Geddes, D., & Tischler, R. (1988). The van Hiele model of thinking in geometry among adolescents. *Journal for Research in Mathematics Education. Monograph, 3*, i-196. <https://doi.org/10.2307/749957>
- Gagne, R. (1985). *The conditions of learning and theory of instruction*. Holt, Rinehart and Winston.
- Gal, H., & Linchevski, L. (2010). To see or not to see: analyzing difficulties in geometry from the perspective of visual perception. *Educational Studies in Mathematics, 74*(2), 163-183. <https://doi.org/10.1007/s10649-010-9232-y>
- Galton, F. (1883). *Inquiries into human faculty and its development*. Macmillan.
- Gutierrez, A. (1992). Exploring the links between Van Hiele Levels and 3- dimensional geometry. *Structural Topology 1992 núm 18*. <https://www.iri.upc.edu/people/ros/StructuralTopology/ST18/st18-07-a3-ocr.pdf>
- Harle, M., & Towns, M. (2011). A review of spatial ability literature, its connection to chemistry, and implications for instruction. *Journal of Chemical Education, 88*(3), 351-360. https://pubs.acs.org/doi/pdf/10.1021/ed900003n?ref=article_openPDF
- Haviger, J., & Vojtkůvková, I. (2015). The Van Hiele levels at Czech secondary schools. *Procedia-Social and Behavioral Sciences, 171*, 912-918. <https://doi.org/10.1016/j.sbspro.2015.01.209>
- Hegarty, M. (2010). Components of spatial intelligence. In B. H. Ross (Ed.), *Psychology of learning and motivation* (Vol. 52, pp. 265–297). Academic Press. [https://doi.org/10.1016/S0079-7421\(10\)52007-3](https://doi.org/10.1016/S0079-7421(10)52007-3)
- Hendel, R. J. A. (2021). Comprehensive Interdisciplinary Program to Totally Transform Education. *Systemics, Cybernetics and Informatics, 19*(1), 38-76. <https://www.iiisci.org/journal/PDV/sci/pdfs/IP118LL21.pdf>
- Hurrell, D. (2021). Conceptual knowledge or procedural knowledge or conceptual knowledge and procedural knowledge: Why the conjunction is important to teachers. *Australian Journal of Teacher Education (Online), 46*(2), 57-71. <http://dx.doi.org/10.14221/ajte.2021v46n2.4>
- Jaime, A., & Gutierrez, A. (1995). Guidelines for teaching plane isometries in secondary school. *The Mathematics Teacher, 88*(7), 591-597. <https://doi.org/10.5951/MT.88.7.0591>
- Karakuş, F., & Peker, M. (2015). The effects of dynamic geometry software and physical manipulatives on pre-service primary teachers' van Hiele levels and spatial abilities. *Turkish Journal of Computer and Mathematics Education (TURCOMAT), 6*(3), 338-365. <https://dergipark.org.tr/en/pub/turkbilmat/issue/21577/231573>
- Kell, H. J., Lubinski, D., Benbow, C. P., & Steiger, J. H. (2013). Creativity and technical innovation: Spatial ability's unique role. *Psychological Science, 24*(9), 1831-1836. <https://doi.org/10.1177/0956797613478615>
- Khoza, S. D. (2014). Diagnosis as a Key Performance Indicator to Learning Engineering Graphics and Design: A case of Technology Education learners in a university based in the Eastern Cape Province. In *Ireland International Conference on Education Proceedings*. https://www.researchgate.net/profile/Samuel-Khoza/publication/274311899_Diagnosis_as_a_key_performance_indicator_to_learning_Engineering_Graphics_and_Design_A_case_of_Technology_Education_students_in_a

- [University based in the Eastern Cape Province/links/551ae8d90cf251c35b503212/Diagnosis-as-a-key-performance-indicator-to-learning-Engineering-Graphics-and-Design-A-case-of-Technology-Education-students-in-a-University-based-in-the-Eastern-Cape-Province.pdf](#)
- Khoza, S. D. (2017). Identifying the gaps of fourth year degree pre-service teachers' pedagogical content knowledge in teaching engineering graphics and design. *International Journal of Technology and Design Education*, 27, 537-548. <https://doi.org/10.1007/s10798-016-9363-2>
- Lithner, J. (2000). A research framework for creative and imitative reasoning. *Educational Studies in Mathematics*, 67(3), 255-276. <https://doi.org/10.1007/s10649-007-9104-2>
- Lowrie, T., Harris, D., Logan, T., & Hegarty, M. (2021). The impact of a spatial intervention program on students' spatial reasoning and mathematics performance. *The journal of experimental education*, 89(2), 259-277. <https://doi.org/10.1080/00220973.2019.1684869>
- Lowrie, T., Logan, T., Harris, D., & Hegarty, M. (2018). The impact of an intervention program on students' spatial reasoning: Student engagement through mathematics-enhanced learning activities. *Cognitive research: principles and implications*, 3(1), 50. <https://doi.org/10.1186/s41235-018-0147-y>
- Lowrie, T., Logan, T., & Ramful, A. (2016). Spatial Reasoning Influences Students' Performance on Mathematics Tasks. In White, B., Chinnappan, M. & Trenholm, S. (Eds.), *Opening up mathematics education research: Proceedings of the 39th annual conference of the Mathematics Education Research Group of Australasia*, pp. 407–414. Adelaide: MERGA. <https://files.eric.ed.gov/fulltext/ED572328.pdf>
- Lowrie, T., & Patahuddin, S. M. (2015). ELPSA as a Lesson Design Framework. *Indonesian Mathematical Society Journal on Mathematics Education*, 6(2), 1-15. <https://files.eric.ed.gov/fulltext/EJ1079522.pdf>
- Luh, D. B., & Chen, S. N. (2013). A novel CAI system for space conceptualization training in perspective sketching. *International Journal of Technology and Design Education*, 23, 147-160. <https://doi.org/10.1007/s10798-011-9171-7>
- Makgato, M. (2016). Difficulties of student teachers in the engineering graphics and design course at a South African university: Snapshot on sectional drawing. *Eurasia Journal of Mathematics, Science and Technology Education*, 12(4), 703-715. <https://doi.org/10.12973/eurasia.2016.1220a>
- Makina, A., & Wessels, D. (2009). The role of visualisation in data handling in Grade 9 within a problem-centred context. *Pythagoras*, 2009(69), 56-68. <https://hdl.handle.net/10520/EJC20909>
- Marunić, G., & Glažar, V. (2014). Improvement and assessment of spatial ability in engineering education. *Engineering Review: Međunarodni časopis namijenjen publiciranju originalnih istraživanja s aspekta analize konstrukcija, materijala i novih tehnologija u području strojarstva, brodogradnje, temeljnih tehničkih znanosti, elektrotehnike, računarstva i građevinarstva*, 34(2), 139-150. <https://hrcak.srce.hr/file/180873>
- Marzano, R. J. (2001). *Designing a new taxonomy of educational objectives*. Corwin Press.
- McLain, M. (2022). Towards a signature pedagogy for design and technology education: a literature review. *International Journal of Technology and Design Education*, 32(3), 1629-1648. <https://doi.org/10.1007/s10798-021-09667-5>

- McLaren, S.V. (2008) Exploring perceptions and attitudes towards teaching and learning manual technical drawing in a digital age. *International Journal of Technology and Design Education*, 18(2), 167–188.
- Metraglia, R., Villa, V., Baronio, G., & Adamini, R. (2015). High school graphics experience influencing the self-efficacy of first-year engineering learners in an introductory engineering graphics course. *The Engineering Design Graphics Journal*, 79(3), 16-30. <https://doi.org/10.18260/edgj.v79i3.562>
- Mohler, J. L. (2008). A review of spatial ability research. *The Engineering Design Graphics Journal*, 72(2), 19-30.
- Nabutola, K., Steinhauer, H., Nozaki, S., & Sadowski, M. (2018, July). Engineering graphics concept inventory: instrument development and item selection. In *4th International Conference on Higher Education Advances (Head'18)* (pp. 1317-1324). Editorial Universitat Politècnica de València. <http://dx.doi.org/10.4995/HEAd18.2018.8196>
- National Research Council (2006). *Learning to think spatially*. National Academies Press.
- Ndlovu, M., & Mji, A. (2012). Pedagogical implications of learners' misconceptions about deductive geometric proof. *Acta Academica*, 44(3), 175-205. <https://hdl.handle.net/10520/EJC131994>
- Newcombe, N. S., & Shipley, T. F. (2014). Thinking about spatial thinking: New typology, new assessments. In *Studying visual and spatial reasoning for design creativity* (pp. 179-192). Springer Netherlands.
- Patkin, D., & Barkai, R. (2014). Geometric thinking levels of pre-and in-service mathematics teachers at various stages of their education. *Educational Research Journal*, 29(1/2), 1-26. <https://search.informit.org/doi/10.3316/informit.901342534813113>
- Pegg, J. (2020). van Hiele Theory, The. In *Encyclopedia of mathematics education* (pp. 896-900). Springer International Publishing.
- Pegg, J., & Davey, G. (1998). Interpreting student understanding in geometry: A synthesis of two models. In D. Chazan (Ed.), *Designing learning environments for developing understanding of geometry and space* (pp. 109-135). Lawrence Erlbaum Associates.
- Perez Carrion, T. & Serrano, M. (2012). *Ejercicios para el desarrollo de la perception especial*. Editorial Club Universitario: Espania.
- Pinxten, M., De Laet, T., Van Soom, C., & Langie, G. (2015). Fighting increasing dropout rates in the STEM field: The European ready STEMgo Project. In *Proceedings of the 43rd Annual SEFI Conference* (pp. 1-8). SEFI.
- Pittalis, M., & Christou, C. (2010). Types of reasoning in 3D geometry thinking and their relation with spatial ability. *Educational Studies in Mathematics*, 75, 191-212. <https://doi.org/10.1007/s10649-010-9251-8>
- Potter, C., Kaufman, W., Delacour, J., Mokone, M., Van der Merwe, E., & Fridjhon, P. (2009). Three-dimensional spatial perception and academic performance in engineering graphics: A longitudinal investigation. *South African Journal of Psychology*, 39(1), 109-121. <https://hdl.handle.net/10520/EJC98520>
- Pusey, E. L. (2003). *The Van Hiele model of reasoning in geometry: A literature review* (Unpublished master's thesis). North Carolina State University, Raleigh, NC, United States. <http://www.lib.ncsu.edu/resolver/1840.16/2275>
- Ramatsetse, B., Daniyan, I., Mpofu, K., & Makinde, O. (2023). State of the art applications of engineering graphics and design to enhance innovative product design: a systematic review. *Procedia CIRP*, 119, 699-709. <https://doi.org/10.1016/j.procir.2023.05.006>

- Ruckpaul, A., Neliuss, T., & Matthiesen, S. (2015). Differences in analysis and interpretation of technical systems by expert and novice engineering designers. In Weber, C., Husung, S., Cantamessa, M., Cascini, G., Marjanovic, D., & Bordegoni, M. (Eds.). *Proceedings of the 20th international conference on engineering design (ICED 15)*, Milan, Italy (pp. 339e348). Glasgow: Design Society, 27-30.07.15.
https://www.designsociety.org/publication/37683/differences_in_analysis_and_interpretation_of_technical_systems_by_expert_and_novice_engineering_designers
- Seery, N., Buckley, J., & Delahunty, T. (2015). Developing a spatial ability framework to support spatial ability research in engineering education. In *Sixth International Research in Engineering Education Symposium*. REES.
<http://research.thea.ie/handle/20.500.12065/3266>
- Senk, S. L. (1985). How well do students write geometry proofs? *The mathematics teacher*, 78(6), 448-456. <https://doi.org/10.5951/MT.78.6.0448>
- Singh-Pillay, A., & Sotsaka, D. S. (2016). Engineering graphics and design teachers' understanding and teaching of assembly drawing. *EURASIA Journal of Mathematics, Science and Technology Education*, 13(5), 1213-1228.
<https://doi.org/10.12973/eurasia.2017.00668a>
- Slavin, R. E. (2018). Learners with exceptionalities. In R. E. Slavin (Ed.), *Educational Psychology: Theory and Practice* (12th ed.). Pearson.
- Sorby, S. A. (2009). Educational research in developing 3-D spatial skills for engineering learners. *International Journal of Science Education*, 31(3), 459-480.
<https://doi.org/10.1080/09500690802595839>
- Sotsaka, D., & Singh-Pillay, A. (2020). Meeting the challenges first year engineering graphic design pre-service teachers encounter when they read and interpret assembly drawing. *Journal of Education (University of KwaZulu-Natal)*, 80, 72-86.
<https://doi.org/10.17159/2520-9868/i80a04>
- Taylor, H. A., & Hutton, A. (2013). Think3d!: Training spatial thinking fundamental to STEM education. *Cognition and Instruction*, 31(4), 434-455.
<https://doi.org/10.1080/07370008.2013.828727>
- Thorndike, E. L. (1921). On the organization of the intellect. *Psychological Review*, 28, 141-151.
<https://psycnet.apa.org/doi/10.1037/h0070821>
- Thurstone, L. L. (1938). *Primary mental abilities*. University of Chicago Press.
- Thurstone, L. L. (1950). Some primary abilities in visual thinking. *Proceedings of the American Philosophical Society*, 94(6), 517-521. <https://www.jstor.org/stable/3143593>
- Tversky, B. (2005). Visuospatial reasoning. *The Cambridge handbook of thinking and reasoning*, 209-240.
https://pure.mpg.de/rest/items/item_2403326/component/file_2564262/content
- Usiskin, Z. (1982). *Van Hiele Levels and Achievement in Secondary School Geometry*. (Final Report of the cognitive Development and Achievement in Secondary School Geometry Project.) University of Chicago. <https://files.eric.ed.gov/fulltext/ED220288.pdf>
- Uttal, D. H., & Cohen, C. A. (2012). Spatial thinking and STEM education: When, why, and how? In *Psychology of learning and motivation*, 57, 147-181. Academic Press.
<https://doi.org/10.1016/B978-0-12-394293-7.00004-2>
- Uttal, D. H., Meadow, N. G., Tipton, E., Hand, L. L., Alden, A. R., Warren, C., & Newcombe, N. S. (2013). The malleability of spatial skills: a meta-analysis of training studies. *Psychological bulletin*, 139(2), 352. <https://doi.org/10.1037/a0028446>

- van der Sandt, S. (2007). Pre-Service Geometry Education in South Africa: A Typical Case? *Issues in the Undergraduate Mathematics Preparation of School Teachers*, 1. <https://files.eric.ed.gov/fulltext/EJ835495.pdf>
- van de Walle, J. A., Karp, K. S., & Bay-Williams, J. M. (2019). *Elementary and middle school mathematics*. Pearson.
- van Hiele, P.M. (1957). *The problem of insight, in connection with schoolchildren's insight into the subject of geometry*. English summary (by P.M. van Hiele) of De Problematiek van het Inzicht Gedemonstreerd van het Inzicht von Schoolkindren in meetkundeleerstof (Unpublished doctoral dissertation). University of Utrecht.
- van Hiele, P. M. (1986). *Structure and insight: A theory of mathematics education*. Academic Press.
- van Hiele-Geldof, D. (1957). *The didactics of geometry in the lowest class of the secondary school*. English summary by Dina van Hiele-Geldof of De didaktiek van de Meetkunde in de eerste klass van het V.H.M.O. (Unpublished doctoral dissertation). University of Utrecht.
- Van Putten, S. (2008). Levels of thought in geometry of pre-service mathematics educators according to the van Hiele model, MEd Dissertation, University of Pretoria, Pretoria. <http://hdl.handle.net/2263/24834>
- Verdine, B. N., Golinkoff, R. M., Hirsh-Pasek, K., & Newcombe, N. S. (2017). I. Spatial skills, their development, and their links to mathematics. *Monographs of the society for research in child development*, 82(1), 7-30. <https://doi.org/10.1111/mono.12280>
- Wai, J., Lubinski, D., & Benbow, C. P. (2009). Spatial ability for STEM domains: Aligning over 50 years of cumulative psychological knowledge solidifies its importance. *Journal of educational Psychology*, 101(4), 817. <https://doi.org/10.1037/a0016127>
- Watan, S., & Sugiman, S. (2018). The Van Hiele theory and realistic mathematics education: As teachers' instruction for teaching geometry. In *AIP Conference Proceedings* (Vol. 2014, No. 1). AIP Publishing. <https://doi.org/10.1063/1.5054479>

The invisible remains invisible: a study of systems thinking in compulsory school students' descriptions of a wastewater system

Nina Emami, KTH Royal Institute of Technology, Sweden

Susanne Engström, KTH Royal Institute of Technology, Sweden

Claes Klasander, Linköping University, Sweden

Abstract

This study investigates how ninth-grade students in Swedish compulsory school describe and explain a technological system: the wastewater system. The analysis focuses on students' verbal explanations while illustrating their self-drawn models of the system. Eleven students (aged 15–16) participated through semi-structured individual interviews. Transcripts and models were analysed using Hallström et al.'s (2022) classification model for system understanding and thematic analysis. The results indicate that most students were able to identify the system's purpose, namely, the collection and treatment of domestic wastewater, and describe components such as household outlets, sewer pipes, and treatment plants. However, their descriptions were largely linear and focused on visible components, such as inlets and manholes. Few references were made to energy flows, information control, system boundary, or interdependencies with other systems. Most students' reasoning remained at the Multistructural level; only two demonstrated relational understanding, and none reached an extended abstract level. The thematic analysis revealed that students faced difficulties in understanding temporal processes, feedback mechanisms, and the consequences of system failures, highlighting difficulties in grasping system complexity. The study calls for instruction that explicitly makes hidden structures, interconnections, and sustainability aspects visible in technological systems. It proposes combining student-generated drawings with visualizations, simulations, and structured reflection to promote deeper and more transferable systems thinking in technology education. Although grounded in a Swedish context, the findings and suggested teaching strategies may inform broader educational settings and contribute to strengthening systems thinking as a core competence in technology education globally.

Keywords

Technology education, technological systems, systems thinking, teaching strategies

Introduction

In today's technology-intensive society, technology education plays a crucial role in preparing students to understand and critically engage with the technological systems that permeate daily life. As digital infrastructures, energy networks, transportation systems, and communication technologies become increasingly complex and interconnected, the capacity to analyse, interpret, and make informed decisions about these systems is fundamental. This competence is essential not only for personal agency but also for participation in societal development and the pursuit of sustainable innovation.

At the heart of technological literacy lies the understanding of technological systems: complex networks of components, processes, and flows that function together to meet human needs. These systems extend beyond isolated artefacts or devices and encompass the interactions between multiple components as well as the broader social, economic, and environmental contexts within which they operate. Communication systems, energy supply chains, and transport networks, for example, all depend on integrated subsystems whose coordination determines the overall purpose of the system. To develop meaningful systems understanding, students must grasp both the structure of these systems, their components and organisation, and their behaviour over time, including how they respond to changes and connect with other systems.

Understanding technological systems involves more than identifying visible components. It requires analysing how these components interact together in relation to one another and how systemic processes influence outcomes at multiple levels. This relational perspective enables students to consider the societal and environmental consequences of technology, fostering not only technical competence but also ethical awareness and sustainable decision-making. As Örneäs (2007) demonstrates, students can describe a range of technological systems from everyday life when supported by pedagogical approaches that foreground the relationships between structure, purpose of the system, and human involvement. According to the same author, students' descriptions of technological systems are significantly enhanced when they engage with images, artefacts, and other forms of visual representation that help to make abstract or hidden system features more accessible. This emphasis on relational understanding, where the focus shifts from isolated components to integrated wholes, reflects a growing consensus in technology education research that systems thinking is essential for preparing students to navigate and critically reflect on the increasingly complex technological world in which they live.

A key aspect of developing this relational understanding is the cultivation of systems thinking, which involves the ability to recognize and analyse how different components within a system interact and influence each other. This aligns with Cabrera and Cabrera's (2015) view of systems thinking as the ability to identify patterns, relationships, and dynamics that shape complex systems over time. Riess and Mischo (2010) define systems thinking as the capacity to move beyond isolated observations and instead perceive systems as dynamic entities where actions in one part may have consequences elsewhere. This approach allows students to see not only the internal interactions within a system but also how technological systems connect to broader societal and environmental contexts.

Voulvoulis et al. (2022) underscore that systems thinking is not merely an educational strategy, but a critical cognitive competence for addressing large-scale sustainability challenges. They argue that it must be scaled up across society to enable systemic change, and that education plays a central role in catalyzing this transformation. Several studies illustrate that achieving this type of holistic understanding is challenging for students.

Research by Lind (2019) and Hallström et al. (2022) shows that students often focus on individual, visible components rather than on the complex interactions and hidden processes that characterize technological systems. Their descriptions tend to be linear and fragmented, with limited awareness of feedback mechanisms, system boundaries, or the role of human

agency. This narrow focus restricts students' ability to understand how systems behave as wholes and how they impact the world around them.

To address these difficulties, scholars have highlighted the importance of instructional strategies that help make systemic relationships and dynamics visible and meaningful to students. Visualizations, models, simulations, and artefacts can serve as powerful tools for bridging the gap between students' everyday experiences and the abstract nature of technological systems (Engström & Svensson, 2022; Citrohn et al., 2023; Örtinä, 2007). Such tools allow students to trace flows of energy, materials, and information, and to observe how changes in one part of a system can generate effects throughout the system. Örtinä (2007) emphasises that using images and physical representations supports students in identifying structures and roles, while also making it easier to understand the relationships that govern system behaviour.

The importance of systems thinking extends beyond technological competence to include education for sustainable development. Palmberg et al. (2017) argue that students need to understand the complex interconnections between ecological, social, and economic systems to critically examine the role of technology in sustainability. Meadows (2008) similarly describes systems as dynamic and self-regulating, where cause and effect are often separated by time and space. Senge (2006) highlights that perceiving such patterns requires an ability to think systemically, an essential skill for addressing global challenges such as climate change, resource scarcity, and environmental degradation.

Despite the relevance of systems thinking for both technological literacy and sustainability, research demonstrates that many students have difficulty grasping system boundaries, feedback loops, and the ways in which users interact with specific operational aspects of the system, such as input-output relationships, control mechanisms, or user interfaces (Koski & de Vries, 2013; Svensson, et al., 2012). Their interpretations often remain at the level of visible, physical components, with limited capacity to analyse abstract aspects such as energy flows or information exchange (Koski & de Vries, 2013). This fragmented understanding hinders students' ability to see systems holistically and to consider the implications of technological choices.

To support the development of systems thinking, several researchers propose the integration of visual and hands-on learning experiences. Engström and Svensson (2022) suggest combining reflective discussions with practical activities such as study visits, technical drawings, and the construction of models and simulations. Citrohn et al. (2023) underline those simulations, in particular, help make invisible system processes visible, allowing students to analyse dynamic behaviours and explore cause-and-effect relationships. Such approaches enable students to move from fragmented descriptions towards integrated understanding.

Visualizations and models also serve as cognitive tools that bridge theory and practice. As Senge (2006) argues, models help students grasp systemic relationships by externalizing abstract ideas in a concrete, manipulable form. Similarly, Örtinä (2007) shows that using images and artefacts allows students to describe system structures and identify functional relationships more effectively. These findings suggest that integrating visualization strategies into technology education not only enhances conceptual understanding but also supports the development of systems thinking competencies.

The relevance of systems thinking becomes particularly evident when considering the role of technology in sustainable development. Palmberg et al. (2017) highlight those systems thinking enables students to analyse the interconnected nature of environmental, social, and economic systems, thereby fostering a holistic perspective on sustainability. By helping students perceive technological systems as embedded within broader societal and ecological contexts, technology education can equip them with the analytical tools necessary for responsible citizenship and future innovation.

Despite the recognized importance of systems thinking for both technological literacy and sustainability, much existing research has primarily focused on older students or on disciplines such as biology and physics where systems thinking has a longer tradition (Riess & Mischo, 2010). In technology education, students often demonstrate fragmented understandings of systems, focusing on isolated components or outputs rather than integrated structures and flows (Svensson et al., 2012). In contrast, there is limited knowledge about how students in compulsory schooling conceptualize technological systems and how their emerging understanding can be supported within the context of technology education.

This study addresses this gap by exploring how lower secondary students (aged 15–16) describe and conceptualize a technological system, with particular attention to how visualizations and representations can support the development of systems thinking. These students, situated in the final year of compulsory schooling in Sweden, constitute a key educational stage where technology education can strengthen not only interest in technology but also the ability to think systemically about technological processes and their consequences.

The study builds on the idea that relational understanding of systems, seeing both components and wholes as well as flows and interactions, does not develop spontaneously but must be deliberately supported through pedagogy. Drawing on research by Koski and de Vries (2013), Palmberg et al. (2017), Meadows (2008), and Senge (2006), this study examines how instructional strategies such as visualization, authentic contexts, and structured reflection can foster more integrated systems thinking in younger students. In doing so, it responds to the call for empirical studies that investigate how systems thinking can be cultivated in the context of technology education at the compulsory school level.

By analysing students' descriptions of a wastewater management system, the study offers insights into both the strengths and limitations of their emerging systems thinking. It also contributes to a broader discussion on how pedagogical tools and approaches can help students move beyond linear, fragmented understandings towards a more holistic grasp of technological systems and their societal relevance. Ultimately, the study aims to inform the design of technology education that equips students not only with knowledge of technological artefacts but also with the capacity to analyse the complex systems in which these artefacts are embedded.

This study contributes new insights by combining students' verbal accounts and self-drawn models to explore their systems thinking about a technical system. Through the integrated use of a classification model, the SOLO taxonomy and a thematic analysis, the study captures both the structure and content of students' reasoning. This approach foregrounds students' own voices and adds depth to previous research by showing how systems thinking emerges when instruction and representation are closely connected.

Aim and research question

The aim of this study is to explore how compulsory school students express their understanding of technological systems, with a particular focus on their oral and written descriptions as well as their self-drawn models of a wastewater system. By analysing how students describe, explain, and reflect upon the system's purpose, structure, flows, processes, and boundary, the study seeks to identify key aspects of knowledge and characterize patterns in their systems understanding.

The goal is to contribute to a deeper knowledge of how students' understanding of technological systems is manifested, thereby providing didactic implications for teaching aimed at developing systems thinking. The study employs a theoretical classification model in combination with thematic analysis as tools to identify what emerges in students' expressed knowledge.

The study is guided by the following research question:

- What characterizes lower secondary students' expressed understanding of a technological system, specifically a wastewater system?


Theoretical framework of the study

This study applies the classification model for technological systems developed by Hallström et al. (2022) in combination with the SOLO taxonomy (Biggs & Collis, 1982). The model highlights four key aspects of systems knowledge:

- System boundary and relation to the environment
- The system's purpose
- System structure and behaviour
- Resource flows (material, energy, informational)

Each aspect is analysed using the SOLO taxonomy levels: Unistructural, Multistructural, Relational, and Extended Abstract. This dual framework enables an understanding of both what the students know and how deeply they reason. The framework has previously been used to map progression in students' systems thinking and thus provides an established basis for interpreting the data presented in this article.

Table 1. Hallström et al. (2022), Classification model for system understanding the SOLO taxonomy

Aspect/Quality	SOLO categories			
	Unistructural	Multistructural	Relational	Extended Abstract
1. System boundary and relation to the environment	Describes no boundary	Describes boundary	Relates to the system's environment: people, society, nature, and other systems	Relates to multiple other systems and compares systems with similar purposes
2. Purpose of the system	Relates purpose to individuals	Relates purpose to society	Relates purpose to the use of resources (energy, material, information)	Describes how questions about the system's purpose can be answered on a system level (e.g., identifying multiple purposes for a system)
3. System structure and behaviour (modelling)	Provides examples of components	Describes relationships between components	Relates components to system behaviour and describes the system using a relevant model (e.g., network, cyclic, hierarchical or input/output model)	Describes how changes in components/subsystems affect other components and the system's purpose
4. Resource flows in the system (energy, material, information)	Describes material flows	Describes flows of energy and/or information	Describes energy flowing and being used in the system.	Describes information being used in the system for control purposes
	Concrete	Increased level of abstraction 		

Method

Context description

The study was conducted in a Grade 9 technology class (students aged 15–16) as part of a longer teaching sequence aimed at developing systems thinking. The specific instructional context included prior classroom work on general system features, such as components, flows and boundaries, combined with a study visit to a local wastewater treatment plant. This provided an authentic and tangible reference system, already partially familiar to students from earlier grades (4–6), where wastewater had been addressed in technology.

The teaching sequence consisted of introductory discussions, system diagrams, analysis of system purposes and interconnections, and group work on either the wastewater system or other technological systems. Students were encouraged to describe, compare, and critique technological systems from both functional and societal perspectives. The wastewater system served as a pedagogical starting point due to its combination of visible infrastructure (e.g., manholes and treatment tanks) and hidden processes (e.g., flow dynamics and control mechanisms).

Instruction emphasised identifying system elements and describing flows, but paid less attention to feedback, control and interconnections. The SOLO classification and thematic analysis used in this study provide insight into the effects of this instructional focus on students' systems reasoning.

This pedagogical structure was intended to support students in recognising key system characteristics and applying their understanding across different contexts. However, the emphasis on concrete components and stepwise flows may have unintentionally reinforced a linear mode of reasoning, limiting students' opportunities to explore system dynamics and feedback mechanisms.

Data collection

Data were collected through individual conversations with eleven Grade 9 students who chose to continue working with the wastewater system after being given the option to explore another technological system. The aim was to gain insight into how the students reasoned about the system, with a particular focus on their understanding of structure, purpose of the system, and interconnections.

The study places particular emphasis on students' own voices and representations, both verbal and visual. The combination of spoken reasoning and self-drawn system models allows for a rich and situated insight into students' understanding. This approach is relatively uncommon in previous studies, which often rely on written tests or predefined tasks. By foregrounding students' own ways of expressing system reasoning, the study contributes new perspectives to the field of technology education, highlighting how students conceptualize technological systems beyond formal assessments.

Each student brought their self-drawn system model to the conversation. These models served as cognitive and visual tools to support memory, reflection, and articulation of prior learning. The conversations were conducted in a quiet meeting room at the school to foster a relaxed and secure environment (Kvale & Brinkmann, 2014). Each session lasted approximately 30–45 minutes, depending on the individual participant.

To capture both verbal reasoning and students' references to specific components in their drawings, all conversations were audio- and video-recorded. This ensured that gestures, pointing, and visual cues were preserved and could be analysed in relation to the students' verbal explanations. The interviews were semi-structured, starting with open-ended prompts to encourage free expression, followed by more specific follow-up questions aimed at deepening the dialogue and eliciting elaborated reasoning (Kvale & Brinkmann, 2014).

Analysis of data

The analysis combined two complementary approaches: a deductive classification based on Hallström et al. (2022) and an inductive, reflexive thematic analysis informed by Braun and Clarke (2020). This dual approach was chosen to combine the precision of a structured framework with the openness of an inductive method. This dual approach aimed to explore both the depth and quality of students' understanding of technological systems as well as the content and character of their reasoning.

The deductive framework builds on Hallström et al.'s (2022) extended use of the SOLO taxonomy (Biggs & Collis, 1982), integrating four analytical dimensions: "Level," "Structure," "Modality," and "Generability" to enable a more nuanced categorization of students' knowledge. "Level" refers to the complexity of understanding and is aligned with the SOLO taxonomy levels (e.g., unistructural, multistructural, relational, extended abstract). "Structure" assesses how coherent the reasoning is; "Modality" captures the form of expression (oral, written, or visual); and "Generability" evaluates whether students can apply their knowledge in broader or novel contexts.

This tool enabled the analyses not only of the types of knowledge, situated, conceptual, procedural, or strategic (de Jong & Ferguson-Hessler, 1996), but also of the quality and transferability of that knowledge. The model is particularly relevant when studying learning progression, as it considers students' ability to relate system components to each other and to broader contexts (Hallström et al., 2022).

The classification focused on four central aspects of technological system understanding: (1) system boundary and relation to the environment, (2) purpose of the system, (3) system structure and behaviour, and (4) resource flows. Each student's reasoning was assessed qualitatively for these aspects and assigned a SOLO level. Statements were first broken down into meaning-bearing units, which were coded and sorted under the relevant system aspects. The identification of each aspect was guided by operational definitions developed in the early coding process. For instance, statements indicating what the system is "meant to do" were sorted under "purpose," while references to elements entering or leaving the system, such as water, sludge, or energy, were coded as "resource flows." Descriptions involving connections between parts or sequential stages (e.g., "first the water goes here, then it goes there") were categorized as "structure and behaviour." Finally, indications of where the system begins or ends, or how it relates to its surroundings, were classified as "system boundary and relation to the environment." This consistent coding procedure ensured analytic clarity and intersubjective reliability across student accounts.

Individual analysis documents were created for all eleven students, combining quotations from the conversations with descriptions of their self-drawn system models. These documents provided a multi-layered view of each student's understanding, allowing for the integration of visual and verbal elements in the analysis. This enabled interpretation of how verbal and visual expressions interacted, an important consideration in previous studies (Lind, 2019; Örtinä, 2007). The documents formed the basis for a synthesized results table, where each student's SOLO level per system aspect is presented. The table offers a systematic overview of individual differences and common patterns across the group.

In parallel, a thematic analysis was conducted across the entire dataset, spoken comments and drawn models combined, to identify recurring themes in how students reasoned about system structure, purpose, and boundary. Unlike the deductive approach, this analysis treated the student group, seeking to uncover shared ways of thinking and expression.

The thematic analysis complemented the classification by making visible the students' conceptual framing of systems thinking. It allowed for the identification of recurring focal points and reasoning strategies that were not constrained by pre-defined categories. This contributed to a richer picture of students' understanding by highlighting how they expressed

relationships, boundaries, and functions in their own words and representations.

The two approaches were thus mutually informative: the classification offered a structured account of students' performance across defined aspects, while the thematic analysis captured more nuanced reasoning patterns and meaning-making processes.

Together, the two analytical strategies, classification and thematic analysis, provide a comprehensive understanding of both what students expressed about technological systems and how well-developed their reasoning was. While the classification model offers structured insights into levels of understanding, the thematic analysis highlights recurring patterns and varying levels of system understanding, particularly in how students focus on components, flows, and purposes, while systemic relationships and feedback mechanisms remain underdeveloped. This combined approach strengthens the study's relevance for developing teaching strategies that promote systems thinking in technology education, with particular importance for education for sustainable development (Koski & de Vries, 2013; Engström & Svensson, 2022).

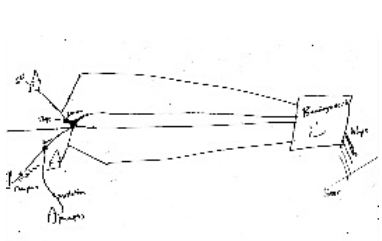
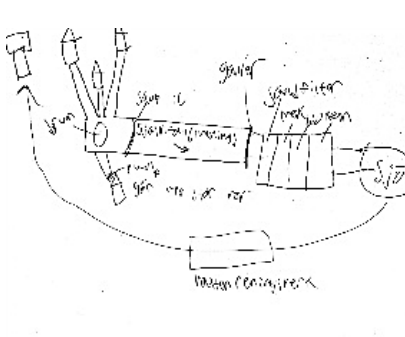
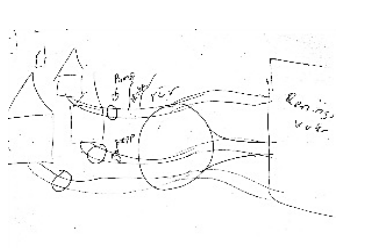
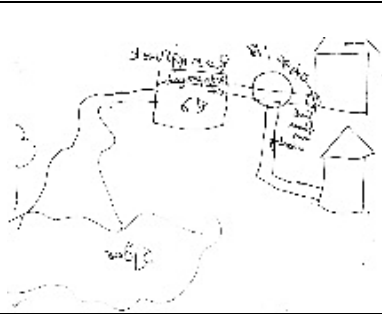
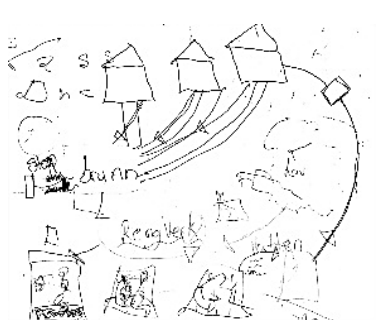
To enhance the credibility and transparency of the analysis, several measures were taken. The coding process was iterative and reflexive, with initial codes developed independently and then reviewed in relation to both theoretical constructs and empirical patterns. Throughout the analysis, analytical memos were used to document coding decisions and emerging interpretations. The SOLO classifications were discussed within the research team to ensure consistency and intersubjective agreement. In the thematic analysis, constant comparison was applied to verify the coherence of categories and to distinguish between surface-level similarities and deeper conceptual patterns. These strategies support the analytical trustworthiness and ensure that the findings are grounded in the data.

Research ethics and trustworthiness

The study was conducted in accordance with the guidelines set out in the Swedish Research Council's publication *Good Research Practice* (Vetenskapsrådet, 2024) to ensure adherence to sound ethical research practices and trustworthiness. Informed consent from the participants was central, and before participation began, everyone received detailed information about the purpose of the study and the nature of the data that would be collected. Participants were given the opportunity to ask questions and express any concerns before they provided written consent to participate. Only individuals who were 15 years of age or older were included in the study. To protect participants' privacy and safety, they were informed that their participation would be anonymous, and that personal information would be handled confidentially. No names or identifying details were used in the reporting or in any other contexts not directly linked to the study. Furthermore, participants received clear information about their right to withdraw from the study at any time without any negative consequences.

Results

To provide an overview of the students' visual representations of the system, the content of their drawn models is summarized in Table 2. This table serves as a complement to the subsequent analysis, as the models in several cases constitute an important part of the students' system expressions.

Mary		Model with sloping pipes illustrating continuous gravity flows.	Emphasises pipe inclination and constant flows; lacks technology for elevation differences or system links.
John		Model with three houses → pump well → purification boxes → purification plant → sea.	Typical linear model 'household → pump → purification plant → sea'; contrasts with Mia's circular model.
Angelina		Model with multiple houses, blockage symbols, pump, sludge well and purification plant.	Everyday image emphasizing operation, hygiene and environment, student perspective on purpose and maintenance.
Sara		Model with house → pump well → purification plant → open channel to lake.	Simple linear model with a stop/warning state; illustrates unistructural level.
Ryan		Model with simple flows and text about fat in pipes.	Illustrates simple flows direction and fat problems; few technical details but clear everyday connection.

Part 1. Classification of System Understanding According to Hallström et al (2022) and the SOLO Taxonomy

Table 3 summarizes the results and illustrates how the students' expressions are distributed across the four aspects of technological systems and the levels of the SOLO taxonomy. The table provides an overall picture of the variation in the quality of knowledge and enables comparisons between different forms of expression and levels of understanding.

Table 3. Students' qualities of knowledge about a wastewater system according to the SOLO taxonomy

Aspect/Quality	SOLO categories			
	Unistructural	Multistructural	Relational	Extended Abstract
1. System boundary and relation to the environment	Describes no boundary Angelina, Sara, Ryan.	Describes boundary Anna, Diana, Fredrik, Hamid, Aida, Mia, Mary, John.	Relates to the system's environment: people, society, nature, and other systems Diana, Fredrik, Hamid, Aida, Mia, Mary, John	Relates to multiple other systems and compares systems with similar purposes
2. Purpose of the system	Relates purpose to individuals Angelina, Sara, Anna, Ryan, Diana, Fredrik, Hamid, Aida, Mia, Mary, John	Relates purpose to society	Relates purpose to the use of resources (energy, material, information) Diana, Fredrik, Hamid, Aida, Mia, Mary, John	Describes how questions about the system's purpose can be answered on a system level (e.g., identifying multiple purposes for a system)
3. System structure and behaviour (modelling)	Provides examples of components Sara, Angelina, John, Fredrik, Hamid, Aida, Mia, Mary, John, Ryan	Describes relationships between components Anna, John, Fredrik, Hamid, Aida, Mia, Mary, John, Ryan	Relates components to system behaviour and describes the system using a relevant model (e.g., network, cyclic, hierarchical or input/output model) John, Fredrik, Hamid, Aida, Mia, Mary, John, Ryan	Describes how changes in components/ subsystems affect other components and the system's purpose
4. Resource flows in the system (energy, material, information)	Describes material flows Angelina, John, Sara, Ryan, Diana, Fredrik, Hamid, Aida, Mia, Mary, Anna	Describes flows of energy and/or information	Describes energy flowing and being used in the system. John, Sara, Ryan, Diana, Fredrik, Hamid, Aida, Mia, Mary, Anna	Describes information being used in the system for control purposes
	Concrete	Increased level of abstraction 		

Summary of classification results

The classification shows that many students demonstrate multistructural reasoning when describing the purpose of the system and its structure and behaviour. They are often able to identify several components or steps but have difficulty connecting these into a coherent whole. Aida and Diana stand out by showing relational understanding, where the function of the system is described in relation to its components.

In the aspects concerning system boundary and resource flows, the responses are generally less developed. Some students, like Sara and Ryan, mention where the system starts and ends, but without relating it to other systems or broader environmental contexts. Flows of energy and information are seldom addressed, and no student reached the extended abstract level in any of the aspects.

Overall, the analysis reveals a variation in both the number of aspects each student touches upon and the depth of their reasoning. While some responses are limited to listing components or steps in a process, others begin to explore relationships between components and link the system to societal or environmental concerns. Still, most descriptions reflect a linear understanding of the system, typically moving from household to treatment plant to nature. Few students describe systems as networks or refer to feedback mechanisms, and there are very few mentions of interactions with other technological systems. These findings highlight the need for instruction that supports students in moving beyond surface-level descriptions towards a more connected and dynamic view of technological systems.

Shading in Table 3 indicates the SOLO level of students' expressions. Light grey corresponds to *unistructural* responses, where students mention isolated aspects of the system. Medium grey represents *multistructural* reasoning, where multiple components are described without connections. Dark grey is used for *relational* expressions, in which students integrate components into a functional whole. Very dark grey indicates *extended abstract* responses, where students reason beyond the immediate context. White cells indicate that no relevant expression was found for that aspect.

Part 2: Thematic Analysis

Themes were identified through an inductive and iterative coding process. Each theme highlights patterns in how students articulated their understanding of the wastewater system.

The overall purpose of the system

Students commonly described the system's purpose as transporting and treating wastewater to protect human health and the environment. This understanding was typically framed through an input–output perspective, in which contaminated water is moved from households to a treatment plant and then released back into nature.

Aida stated: "We have the wastewater system because otherwise the sewage water goes to lakes and the sea and pollutes them so that it leads to eutrophication and too many nutrients and proteins in the water." Similarly, John described: "The purpose of the system is to provide a clean environment and health." These responses emphasise the system's value based on its outcomes, rather than its internal structure or broader connections.

Most students conceptualised the system as a linear and unidirectional flow, emphasising removal over circulation or reuse. While household sources of pollutants, such as toilets, dishwashing, and laundry, were often mentioned, students did not describe links to other infrastructures, such as drinking water supply or energy recovery from sludge. The system was primarily perceived as an isolated solution to a hygiene-related problem.

The central role of a subsystem – the wastewater treatment plant

The treatment plant was frequently identified as the core of the system. Although students occasionally referred to it as a subsystem, their descriptions often assigned it a central, even dominant, role. Other components, such as pipes and manholes, were typically seen as passive conduits.

Many students described treatment stages, mechanical, biological, and chemical, but with limited technical detail. Angelina explained: “The purpose of the sewage system is to clean the water and remove poo and pee from the home; otherwise, one would have to take it out to the trash oneself, and it would smell, and people would get sick.” This reflects a view of the system as a solution to a domestic problem, grounded in everyday experience.

However, few students elaborated on issues like energy use, system-wide coordination, or environmental impacts beyond the local context. The treatment plant was largely viewed as a standalone unit where pollution is processed in a stepwise manner, without connections to broader ecological or technical systems.

The depiction of the system’s structure – linear flow

Students described the wastewater system as a series of sequential components. The flow from household to treatment plant was presented as a straightforward path, with little emphasis on interdependencies or networked structures.

Mia said: “I have drawn the entire sewage system with all the pipes and the wells.” Her description indicates an understanding of the system as a linear assembly rather than a dynamic whole. Similarly, Anna noted: “There are pumps for the houses that are located lower down, which can pump up the sewage water.” This illustrates a problem-solution logic, but without broader system reasoning.

While some students referred to subsystems, such as sludge management, these were often seen as just additional steps, not as components with internal processes or feedback mechanisms. Diana said: “Then there are subsystems in the system too, and that is the sludge management system[...]” but did not elaborate further.

Students frequently attributed maintenance issues to individual user behaviour. Fredrik explained: “Through education and awareness, one can try to reduce the number of unnecessary objects being flushed down the drains[...]” and Hamid added: “There can be blockages[...] and then you fix it yourself[...] Otherwise, the men who work with the pipes come and fix it.” These responses suggest a localized understanding of problems, rather than one informed by system-wide design or operational load.

Overall, the system was perceived as a linear arrangement of components, rather than a network with dynamic flows and regulation.

Transport and system boundary

Students described wastewater transport primarily as passive flow via gravity, occasionally supported by pumps. Aida explained: “The wastewater from the apartments or houses always goes downward, so that the flow will work even when there is a power outage.” Diana similarly noted: “The wastewater moves forward through the pipes; they are sloped like this, so it flows by itself down there.” These statements reflect a surface-level understanding of physical conditions, without reference to flow dynamics, pressure, or energy dependence.

Some students acknowledged the role of pumping stations in overcoming elevation differences, but did not reflect on power supply, redundancy, or failure scenarios. John said: “The larger pipes go downward using gravity, but in the houses that are lower down, the water moves upwards with the help of a pumping station.”

System boundaries were usually defined spatially, from household to nature. Diana expressed this clearly: “The wastewater systems start in the home and end out in nature with clean water.” Few students mentioned feedback, loops, or integration with other systems.

A few students touched on potential system connections. Mia said: “When you flush, air goes down and gets pressed down[...] that also has something to do with the ventilation system.” Aida noted: “They take all the fertilizer to the fields.” These ideas hint at systemic thinking but were not developed further.

Challenges such as pharmaceutical residues, industrial discharges, or stormwater inflow were largely absent from student reasoning. Descriptions focused on visible components and straightforward movement, suggesting a limited understanding of system-environment interactions.

Discussion

The aim of this study was to explore lower secondary school students’ understanding of technological systems through their descriptions of a wastewater system, using the SOLO taxonomy combined with Hallström et al.’s (2022) four aspects of system understanding and thematic analysis. The findings illustrate that students primarily express a linear understanding of the system, focusing on visible components and sequential processes, while connections between subsystems, feedback loops, and inter-system relationships are limited.

This study adds to previous research by combining classification, SOLO levels and thematic analysis to offer a more complete picture of students’ systems thinking. The approach highlights not only what students understand, but how they express and organise that understanding. By attending to both verbal reasoning and visual representations, the study provides new perspectives on how students engage with technological systems in school, and how teaching can support that development.

As shown in **Table 3**, most students were placed at the **multistructural level**, particularly regarding system structure and purpose. This aligns with the theme “*Linear flow*”, where students described the system as a simple sequence from household to nature. Similarly, their focus on visible components and isolated subsystems, such as the treatment plant, reflects a fragmented understanding, with few references to energy flows, feedback, or interconnections.

Students demonstrate basic knowledge of the system's components and purpose of the system, but their understanding of system integration, dynamics, and feedback remains underdeveloped. Students demonstrate basic knowledge of the system's components and purpose of the system, but their understanding of system integration, dynamics, and feedback remains underdeveloped. This pattern has been recognised in earlier research, where students' reasoning about systems often centres around isolated elements rather than dynamic interrelations (Palmberg et al., 2017; Riess & Mischo, 2010).

The classification places most students at the multistructural level of the SOLO taxonomy, where multiple system components are described but rarely connected into a coherent whole (Hallström et al., 2022; Koski & de Vries, 2013). The thematic analysis confirms this pattern: students tend to describe the system as a simple flow from household to treatment plant to nature. While key components are correctly identified, their interrelationships, feedback loops, and invisible processes such as energy flows or system monitoring are rarely addressed (Meadows, 2008; Senge, 2006).

A key finding is that many students seem to conceptualize the system in a stepwise fashion, where each stage is treated as independent rather than interconnected. This compartmentalized view suggests that students struggle to visualize how changes in one part of the system can affect the whole, or how flows of material, energy, and information are maintained across boundaries.

Although the teaching sequence included both visualisation tasks and a study visit, it may not have provided sufficient opportunities for students to work actively with systemic relationships. The instruction placed emphasis on identifying system components and describing the sequence of flows, but did not explicitly support reasoning about feedback, control or cross-system interactions. This could partly explain why many students remained at the multistructural level. Rather than indicating a lack of conceptual ability, their reasoning may reflect how systems thinking was framed and made visible in the classroom context. By triangulating classification, SOLO levels and thematic analysis, this study provides an integrated view of students' system understanding that goes beyond prior research. While earlier studies have reported similar challenges in fostering students' systemic reasoning (e.g., Riess & Mischo, 2010; Palmberg et al., 2017), this study contributes by combining multiple analytical lenses and providing detailed insight into how these limitations are expressed in students' own reasoning.

One important observation is that while students often associate the system's purpose with environmental and health protection, their reasoning seldom extends to circular processes, long-term effects, or system interdependencies (Palmberg et al., 2017). Subsystems, such as sludge management, are described in isolation rather than as part of a larger network (Lind, 2019). The lack of attention to feedback mechanisms or reciprocal relationships indicates that students' system understanding is often static rather than dynamic. For instance, sludge management is rarely linked by students to agricultural reuse or energy recovery systems, even though these connections are central to sustainable wastewater treatment. Similarly, pumping stations or monitoring systems are almost never mentioned, despite their key roles in regulating flows and connecting different parts of the infrastructure. This suggests that subsystems are not only seen in isolation but also disconnected from broader technological and societal systems, such as farming, energy production, or digital control networks.

Moreover, system boundaries are typically framed as a linear path from household to nature, with limited references to connections with other infrastructures such as ventilation systems or agriculture (Hallström et al., 2022). Students rarely mention how the wastewater system interacts with or depends on broader urban systems, such as energy provision, governance, or circular economy initiatives. This linearity reflects what other studies have identified as a common pattern in young students' system reasoning, where input–output thinking dominates while feedback, regulation, and cross-system relations remain unexplored (Riess & Mischo, 2010).

These findings point to the need for instruction that not only supports the identification of system components but also explicitly highlights system dynamics, hidden processes, and interconnections. Without such pedagogical scaffolding, students risk remaining at a surface level of understanding, unable to transfer or apply systems thinking to other technological or sustainability contexts.

To support the development of systems thinking, instruction should therefore move beyond concrete, linear descriptions towards more integrated, dynamic perspectives. Visualizations, comparative system analyses, and authentic examples can play a key role in this progression (Engström & Svensson, 2022). Additionally, explicit discussions about how real-world systems rarely function in isolation, but instead are embedded within wider societal and environmental contexts, could help extend students' understanding. However, it is also important to acknowledge that students' linear representations may not solely reflect a lack of understanding, but rather a developmental stage in their systems thinking. As such, these representations can serve as valuable starting points for pedagogical interventions that gradually introduce complexity, interconnections, and feedback. The combination of classification and thematic analysis in this study provides valuable insight into how such instructional approaches could be targeted to foster more advanced reasoning.

The findings suggest that instructional design should support the transition from descriptive to integrative reasoning by scaffolding students' attention to system boundaries, feedback mechanisms, and interdependencies. Practical strategies may include comparative analysis of different systems, model-based reasoning, and explicit reflection tasks where students consider the consequences of changes in one part of the system. These approaches could strengthen students' ability to engage with complex technological and socio-ecological systems, aligning with goals in education for sustainable development.

By combining a structured classification model with a reflexive thematic analysis, this study contributes methodologically by illustrating how quantitative indicators of system understanding (e.g., SOLO levels) can be complemented by qualitative insights into students' reasoning processes. This dual approach may be particularly valuable in educational research on complex cognitive domains, such as systems thinking, where both breadth and depth of understanding are important to capture.

Limitations

This study has some limitations that are important to acknowledge. It was conducted in a single compulsory school in Sweden with a relatively small group of eleven students. While the intention was to gain in-depth insights into students' systems thinking, the limited sample size

and specific teaching context mean that the findings should not be generalised without caution. The results provide indications of patterns in students' reasoning but cannot be assumed to represent wider populations without further studies across different schools and contexts.

The students had previously encountered the wastewater system through classroom instruction and a study visit. These experiences likely shaped how they described the system in the interviews, and while this was part of the intended design, it also makes it difficult to separate what stems from prior teaching and what reflects students' independent reasoning. Despite the structured instructional approach, many students' responses remained at the unistructural or multistructural level. This may reflect the complexity of systems thinking but also points to challenges in making abstract system aspects visible and accessible in teaching.

Furthermore, the analysis draws on a combination of students' verbal reasoning and self-drawn models. This allowed for a rich interpretation of their understanding, but it also involved interpretation by the researchers—particularly in the classification of reasoning levels using the SOLO taxonomy. Although efforts were made to ensure consistency and transparency, a degree of subjectivity remains. The use of two analytic frameworks strengthened the analysis but also introduced interpretative complexity, especially in borderline cases of classification.

Finally, the study focused on one specific system. The wastewater system was chosen because it is both concrete and complex, but it is unclear whether students would reason in the same way about other systems, such as those involving digital infrastructure or energy flow. While this system provided a relevant context for exploring flows and boundaries, other systems might evoke different conceptual challenges. Future studies could explore how students' systems thinking develops across different types of systems and instructional designs.

Implications for teaching

The study illustrates that lower secondary students can develop an emerging understanding of technological systems when teaching highlights concrete components, flows, and functions. However, this understanding is shaped by what is made visible in instruction. Students tend to grasp what is concrete, like pipes and treatment stages, while abstract or systemic aspects remain hidden. This underscores the importance of deliberate instructional choices that reveal both the visible and invisible dimensions of technological systems.

To foster more coherent systems thinking, teaching must address not only the content of systems but also how systems operate as interconnected wholes. This involves emphasizing structures, processes, relationships, and system behaviours that may not be immediately apparent (Meadows, 2008; Senge, 2006). Many students illustrate a basic, linear understanding of systems. Instruction should therefore highlight network structures, feedback loops, energy and information flows, and links to other societal and ecological systems (Palmberg et al., 2017).

One effective strategy could be to have students compare multiple system models, for example, linear and circular wastewater systems. Such comparative analysis can help make system structures explicit and encourage students to question simplistic or fragmented representations. Engström and Svensson's (2022) teaching model, which combines visualisations, authentic experiences, and reflection, offers practical strategies for making both

visible and invisible system aspects accessible. Drawing on students' everyday experiences, such as prior visits to treatment plants, can also help ground abstract concepts in familiar contexts. Moreover, sustainability aspects can be integrated by illustrating circular flows, such as the transformation of sludge into fertiliser or biogas, thus making resource use and environmental impacts more tangible.

Hallström et al.'s (2022) classification model supports both planning and assessment by identifying which system aspects students grasp and which need reinforcement. By combining this with the SOLO taxonomy, teachers can plan for progression from unistructural and multistructural levels towards relational and extended abstract understandings. Formative assessment that explicitly targets students' ability to connect system components, identify feedback, and reason about broader system implications could help guide this progression.

The findings indicate that many students remain at the multistructural level, where system components are identified but not yet coordinated into a holistic understanding. To support progression towards relational and extended abstract reasoning, instruction needs to scaffold students' ability to connect components, functions, and flows within and beyond the system. One approach is to engage students in structured comparisons between systems, where common patterns such as flows, boundaries, and feedback can be discussed. Whole-class modelling activities, using teacher-led visualisations, can also support the identification of interactions and causal relationships between components. Furthermore, Engström and Svensson's (2022) model highlights the value of combining visualisation, authentic contexts and reflective tasks to support students in articulating system relationships. Hallström et al.'s (2022) classification model can be used formatively to identify which system aspects are present in student reasoning and to guide instructional focus. Teachers may support students' movement up the SOLO taxonomy by drawing attention to system dynamics, inviting predictions, and encouraging reasoning about system-level consequences. Together, these strategies can support a shift from fragmented descriptions to more coherent, transferable understandings of technological systems.

Finally, systems thinking should be embedded across the technology curriculum rather than treated as an isolated competence. Early and continuous exposure to systems concepts, increasing in complexity over time, can help students build transferable knowledge and cognitive strategies for analysing diverse technological systems (Riess & Mischo, 2010; Voulvoulis et al., 2022). This progression is crucial for preparing students not only to understand existing technologies but also to critically engage with future sustainability challenges.

In conclusion, fostering systems thinking in technology education requires targeted instruction that makes systems visible, highlights interconnections and dynamics, and situates learning within real-world sustainability contexts. Through this, students can be supported in developing deeper, relational, and dynamic understandings that extend beyond surface-level knowledge and contribute to responsible technological citizenship.

References

Biggs, J. and Collis, K. F. (1982) 'Evaluating the quality of learning: The SOLO taxonomy (Structure of the Observed Learning Outcome)', Academic Press.

- Braun, V. and Clarke, V. (2020) 'Reflecting on reflexive thematic analysis', *Qualitative Research in Sport, Exercise and Health*, vol. 11, no. 4, pp. 589–597.
<https://doi.org/10.1080/2159676X.2019.1628806>
- Cabrera, D. and Cabrera, L. (2015) 'Systems thinking made simple: New hope for solving wicked problems', *Odyssean Press*.
- Citrohn, B., Stolpe, K. and Svensson, M. (2023) 'The use of models and modelling in design projects in three different technology classrooms', *International Journal of Technology and Design Education*, vol. 33, no. 1, pp. 63–90. <https://doi.org/10.1007/s10798-022-09730-9>
- de Jong, T. and Ferguson-Hessler, M. G. M. (1996) 'Types and qualities of knowledge', *Educational Psychologist*, vol. 31, no. 2, pp. 105–113.
https://doi.org/10.1207/s15326985ep3102_2
- Engström, S. and Svensson, M. (2022) 'An educational model for teaching about technological systems', in Hallström, J. and Williams, P. J. (eds.) *Teaching and learning about technological systems: Philosophical, curriculum, and classroom perspectives*, Springer, pp. 249–268. https://doi.org/10.1007/978-981-16-7719-9_6
- Hallström, J., Klasander, C. and Zetterqvist, A. (2021) 'Towards a student systems thinking inventory: Defining “qualities of knowledge” about technological systems', in Hallström, J. and Williams, P. J. (eds.) *Teaching and learning about technological systems: Philosophical, curriculum, and classroom perspectives*, Springer, pp. 215–232. 2
https://doi.org/10.1007/978-981-16-7719-9_11
- Hallström, J., Klasander, C. and Zetterqvist, A. (2022) 'Investigating school students' knowledge about technological systems: Towards “qualities of knowledge”', in Hallström, J. and Williams, P. J. (eds.) *Teaching and learning about technological systems: Philosophical, curriculum, and classroom perspectives*, Springer, pp. 215–232. 2
https://doi.org/10.1007/978-981-16-7719-9_11
- Koski, M.-I. and de Vries, M. J. (2013) 'An exploratory study on how primary pupils approach systems', *International Journal of Technology and Design Education*, vol. 23, no. 4, pp. 835–848. <https://doi.org/10.1007/s10798-012-9207-7>
- Kvale, S. and Brinkmann, S. (2014) 'Den kvalitativa forskningsintervjun', 3rd edn, Studentlitteratur.
- Lind, J. (2019) 'Elevers förståelse av tekniska system: En studie av skriftliga och visuella uttryck i årskurs 6', *NorDiNa*, vol. 19, no. 2, pp. 145–160.
- Meadows, D. H. (2008) 'Thinking in systems: A primer', Chelsea Green Publishing.
- Örtnäs, A. (2007) 'Teknik, barn och vardagsliv: En studie om teknik i förskolebarns vardag', *Licentiatavhandling, Göteborgs universitet*.
- Palmberg, I., Hofman-Bergholm, M., Jeronen, E. and Yli-Panula, E. (2017) 'Systems thinking for understanding sustainability? Nordic student teachers' views on the relationship between species identification, biodiversity, and sustainable development', *Education Sciences*, vol. 7, no. 3, Article 86. <https://doi.org/10.3390/educsci7030086>
- Riess, W. and Mischo, C. (2010) 'Promoting systems thinking through biology lessons', *International Journal of Science Education*, vol. 32, pp. 705–725.
<https://doi.org/10.1080/09500690902769946>
- Senge, P. M. (2006) 'The fifth discipline: The art & practice of the learning organisation', Doubleday.

- Svensson, M., Zetterqvist, L. and Ingerman, Å. (2012) 'On young people's experience of systems in technology', *International Journal of Technology and Design Education*, vol. 22, no. 4, pp. 749–761. <https://liu.diva-portal.org/smash/get/diva2:1192114/FULLTEXT01.pdf>
- Vetenskapsrådet (2024) 'God forskningssed 2024', Vetenskapsrådet. ISBN 978-91-89845-08-4
- Voulvoulis, N., Giakoumis, T., Hunt, C., Kioupi, V., Petrou, N., Souliotis, I. and Vaghela, C. (2022) 'Systems thinking for sustainable development: Taking it to scale', *Science of the Total Environment*, vol. 804, Article 150139. <https://doi.org/10.1016/j.gloenvcha.2022.102544>

A Serious Game Proposal for Raising Awareness on Sustainable Development in the Built Environment

Burcu Olgen, Concordia University, Canada

Negarsadat Rahimi, Concordia University, Canada

Carmela Cucuzzella, Université de Montréal, Canada

Abstract

Interactive serious games enhance science-based communication and promote deeper learning about sustainable development. It is yet undiscovered that how can AI-augmented interactive experiences enhance the engagement and spread awareness. This study proposes an AI-augmented digital serious game in public installation format. First, the study introduces a serious board game centered on Sustainable Development Goal (SDG) 11 to test the learning aspects and the engagement of the game. The study hypothesizes that a serious game with a clear message, engaging mechanics, and appealing design can significantly enhance understanding of sustainability's relevance to everyday life. Using a Research through Design (RtD) approach, the study incorporated iterative feedback from pilot tests. These tests highlighted the effectiveness of problem-solving and group discussions in fostering engagement. The insights directly informed the design of the digital version, which emphasizes streamlined and accessible gameplay.

Keywords

Sustainability, built environment, serious games, eco-didactic, game-based learning, AI

Introduction

Raising awareness about sustainable development is becoming increasingly urgent in the face of accelerating climate change and environmental degradation. In fostering sustainability literacy, interdisciplinary education, systems thinking, project-based learning, and civic engagement are among the most recognized approaches (Boarin & Martinez-Molina, 2022). Experimental approaches, such as self-directed learning, museological learning, game-based learning, and gamification could create engaging experiences regarding spreading public awareness on sustainability in the built environment (Boragine, 2023; Falk & Dierking, 2000; Kolb, 2014; Sailer et al., 2017). However, how these methods connect with broader audiences in informal or public settings and how digital technologies and Artificial Intelligence can enhance the experiences remain under discovered. Therefore, this study aims to explore learning mechanisms and engagement strategies of a serious board game that teaches sustainable development in the built environment. Consequently, the findings from the serious game are used to develop an AI-powered interactive digital public installation for raising environmental awareness and promote sustainable development. Therefore, this paper presents the initial phase of a larger project that aims to develop an AI-enhanced digital installation for public use. The current study focuses on the analog and semi-digital prototypes used to explore effective gameplay elements and educational strategies. The outcomes of pilot tests inform the ongoing development of a digital version intended for deployment in public spaces.

According to the *Sustainable Development Report 2023* (Sachs et al., 2023), progress on SDG 4 (Quality Education) remains insufficient at the midpoint toward the 2030 Agenda (*Education*, 2015). Likewise, a 2022 Canadian survey on climate change education (Schwartzberg et al., 2022) revealed that 64% of respondents believe the education system is not doing enough to address climate change. These findings point to the need for complementary educational tools that promote public engagement and self-directed learning beyond formal institutions. Alternative educational tools such as serious games, have demonstrated effectiveness in simulation of complex subjects, specifically regarding sustainability in the built environment (Boragine, 2023; Dib et al., 2012; Dib & Adamo-Villani, 2014; Romano & Rogora, 2023). On the other hand, public realm offers unique opportunities for experiential learning and raising awareness through interactive installations, public art, and gamified experiences. Eco-art installations in particular have shown strong potential to engage citizens in environmental issues by transforming complex topics into accessible, multisensory encounters (Cucuzzella et al., 2020, 2021; Karimimoshaver et al., 2021; Lee, 2021). One notable example is Mary Miss's *Broadway: 1000 Steps*, which localized environmental issues and produced positive community outcomes (Miss, 2009). In the same token, interactive installations have demonstrated high public engagement (Horst, 2022; Ntalla, 2021; Olgen & Cucuzzella, 2024; van Renswouw et al., 2022), transforming public spaces into experimental playgrounds that would be open for many opportunities. Such initiatives demonstrate how the public realm can foster civic dialogue, learning, and behavior change.

Building on this potential, the study introduces the initial phase of an eco-didactic installation, drawing inspiration from eco-art as a means to advance urban sustainability education in the public realm. The central hypothesis is that a well-designed game, combining clear messaging, interactive mechanics, and aesthetic appeal, can significantly improve public understanding of sustainability in the built environment and its connection to everyday life. To test this, we developed and evaluated an analog board game based on SDG 11: Sustainable Cities and Communities, due to its relation to sustainable development in the built environment. This study understands sustainability in the built environment as combination of actions including designing, developing, constructing, and operating buildings and urban constructions in ways to decrease environmental impact. The game design was informed by a Research through Design (RtD) methodology and emphasized participatory development, iterative feedback, and interdisciplinary learning principles. RtD methodology is significant in this case due to its exploratory nature, allowing flexibility with iterative experimental testing which is suitable in designing and testing a serious game and an interactive digital installation (Godin & Zahedi, 2014; Koskinen et al., 2011; Zimmerman et al., 2007).

The remainder of this article structured as follows: Following section provides a literature review on playful and educational eco-experiences, establishing the theoretical grounding for the study. After the literature review, methodology is defined, including the research questions and objectives, the development of the game prototypes, participant sampling and ethical considerations, and the evaluation tools and experiment setup. Results section presents the findings from the focus group evaluation, the in-person playtest and survey results of Version A, and the survey results of Version B. Discussion section connects the outcomes to the design of a digital, AI-augmented eco-didactic installation intended for public engagement.

Literature Review: Playful and Educational Eco-Experiences

Environmental education has increasingly embraced experiential and participatory methods that emphasize active learner engagement. Falk and Dierking argue that self-directed, physically grounded learning experiences enhance knowledge retention and relevance, particularly in formal settings (2000). Such approaches are well-suited to public spaces and museums, where visitors interact with content through their senses, actions, and discussion.

Studies have consistently shown that interactivity and playfulness significantly enrich environmental learning, especially in informal contexts (Lesen et al., 2016; Ntalla, 2021; Wang & Chen, 2021). Regarding sustainability education in the built environment, the educational tools that use gamification (Deterding et al., 2011; Sailer et al., 2017) and serious games (Boragine, 2023; Polys et al., 2017) has shown significant potential in fostering environmental awareness, facilitating multifaceted systems thinking approach, by simulating real-life applications. Unlike gamification, which typically incorporates game elements into non-game settings, serious games are designed specifically with educational goals at their core (Den Haan & Van der Voort, 2018; Ouariachi et al., 2019; Stanitsas et al., 2019; Wouters et al., 2013). In sustainability context regarding the built environment, serious games have been found to increase learner engagement, promote interdisciplinary dialogue, and encourage long-term behavioral change (Gatti et al., 2019; Ho et al., 2022; Isaacs et al., 2008; Iyer-Raniga & Andamon, 2016).

Among many effective alternative educational approaches, board games, in particular, have shown strong potential for facilitating sustainability learning. Eisenack's *KEEP COOL* game enables players to simulate climate negotiations, integrating biophysical, economic, and political aspects of climate change (2013). The game encourages interdisciplinary communication and has been used successfully in academic and public settings. Similarly, Tsai et al.'s developed *Be Blessed Taiwan*, which teaches the trade-offs between economic development and biodiversity preservation (2021). Players reported increased understanding of conservation concepts and gained policy decision-making and teamwork skills. Fjællingsdal and Klöckner evaluated four environmental-themed board games and found that they effectively simplified complex sustainability concepts and stimulated reflection on cause-effect relationships in environmental systems (2020). Cheng et al. designed a problem-based board game on water resource adaptation, which used role-play to enhance responsibility, negotiation, and critical thinking (2019).

Other forms of game-based learning, specifically in the context of teaching sustainability in the built environment, such as digital games, have proven effective, supporting the traditional lectures on the subject (Ayer et al., 2016; Juan & Chao, 2015; Lamas et al., 2013). These examples show the potential of the educational value of games that are purpose-built for sustainability learning.

Beyond analog games, digital and immersive experiences also support eco-didactic goals. Ntalla explored play and playfulness in an interactive museum installation titled *The High Arctic Installation*, noting that multisensory environments shifted adult perceptions of learning and engagement (2021). Participants who initially perceived play as "childish" became more enthusiastic, suggesting the transformative potential of spatial and sensory-rich formats. Wang and Chen demonstrated that interactive, multi-level tablet-based games for marine education

increased both engagement and correct knowledge retention rates (81,7% post-game accuracy), underscoring the value of interactive technology in science education (2021).

Emerging technologies such as Artificial Intelligence (AI) also hold promise for enhancing serious games. AI can personalize feedback, simulate complex scenarios, and support real-time interactions in public installations. While few studies have yet explored AI-integrated eco-didactic tools, early examples suggests that AI can act as both guide and collaborator, adapting content dynamically to player choices and offering tailored insights (Audry, 2021; Boragine, 2023).

In a preliminary study at Montreal's Biosphere Environment Museum, the authors evaluated interactive installations demonstrated in two exhibitions: *Eco Lab* and *This is Not an Umbrella* (Olgen & Cucuzzella, 2024). A comparative analysis between digital and analog interactive installations and non-interactive installations were conducted within the study. Results show that analog and multisensory installations generated more dialogue, engagement, and collaborative learning than passive or purely digital ones. Participants gravitated toward more playful interactive experiences than mere touch screens, reinforcing the effectiveness of play-based environmental education.

Identified Gap and Study Contribution

While these examples demonstrate the pedagogical potential of board and digital games, there remains a lack of research combining serious game mechanics, AI-powered interactivity, and public realm installations for sustainability in the built environment education. This study addresses that gap by testing analog and digital prototypes of a serious game informed by SDG 11. It contributes to the literature by integrating participatory design, iterative development, and empirical evaluation into a framework for a future AI-powered interactive public installation.

Materials and Methods

This study adopts a Research through Design (RtD) methodology, which is particularly well-suited for educational interventions involving participatory design and iterative prototyping (Godin & Zahedi, 2014; Koskinen et al., 2011; Zimmerman et al., 2007). RtD enables the exploration of design as a method of inquiry, emphasizing learning-through-making and refining solutions based on stakeholder feedback. In this research, RtD provides a framework for developing, testing, and refining a serious game that integrates educational theory with real-world learner experiences.

RtD was chosen for this capacity to support participatory and iterative development in the context of sustainability education. By engaging students, educators, and interdisciplinary collaborators in the design process, the method ensures that the resulting game is grounded not only in theoretical principles but also in users' cognitive, social, and experiential needs.

Research Objectives and Questions

The study explores how game-based learning can support sustainable development education in the built environment in both formal and informal learning environments, particularly those within the public realm. The overarching goal is to evaluate the effectiveness of interactive and

didactic components, through board game designs, in the early development stages of an AI-powered eco-didactic installation. Specifically, the study is guided by two research questions:

- **Interactivity:** How can interactive gameplay elements, such as decision-making, negotiation, and collaboration, be integrated into a board game to maximize engagement and meaningful player interaction?
- **Didactic Aspects:** How can a game be designed to effectively convey sustainability principles, especially those related to SDG 11: Sustainable Cities and Human Settlements, while fostering critical thinking and collaborative learning?

Game Design and Prototypes

The serious game, titled Next-Gen Islands, was developed through three iterative stages, each building on the findings of the previous:

- **Version A:** A physical board game prototype emphasizing target-based challenges and collaboration tested in small, in-person focus groups.
- **Version B:** A digital, collaborative problem-solving adaptation developed using the Miro platform, tested in a virtual classroom to simulate collaborative gameplay.
- **Version C:** A planned AI-augmented digital prototype currently under development.

Both Version A and B contextualize SDG 11 through four thematic targets: housing, public transportation, green spaces, and environmental impact. The analog version features four fictional islands with each team acting as decision-makers for their island's sustainable development. Gameplay is designed to prompt discussion, argumentation, and justification, students solve randomly drawn problem cards using "action cards," all color-coded to represent SDG targets. Progress depends on the strategic allocation of limited resources, represented by dice rolls simulating government funding.

Version B simplifies these mechanics to prioritize dialogue and collaboration. Tested online during a virtual class, this version removed game competitiveness and time constraints, shifting the focus group deliberation and peer-reviewed decision-making. Students used breakout rooms to discuss problems and present solutions, which other teams would approve or reject. This version was also used to simulate future AI-driven interactions using Wizard of Oz prototyping, where facilitators manually replicated AI functions (e.g., prompts, reactions, dynamic content) (Dow et al., 2005).

Next-Gen Islands Board Game (Version A)

The Next-Gen Islands board game was developed to contextualize the four primary targets of SDG 11: Sustainable Cities and Human Settlements within an engaging, real-time simulation (Figure 1). The game's pedagogical objective is to promote critical thinking and collaborative decision-making by challenging players to address urban sustainability issues through scenario-based gameplay. The game offers a competitive play where four groups of people compete to each other to first achieve the objectives.



Figure 1. Selected 4 targets of SDG 11

The game features four fictional islands, each assigned to a team of 2-3 players, who assume the roles of urban decision-makers. These islands are represented on the board (see Figure 4). The core mechanic revolves around resolving challenges drawn from key SDG 11 themes: housing, public transportation, green spaces, and environmental impact, through the strategic use of action cards. These paired with problem cards, both color-coded and categorized by SDG targets (Figures 2 and 3).

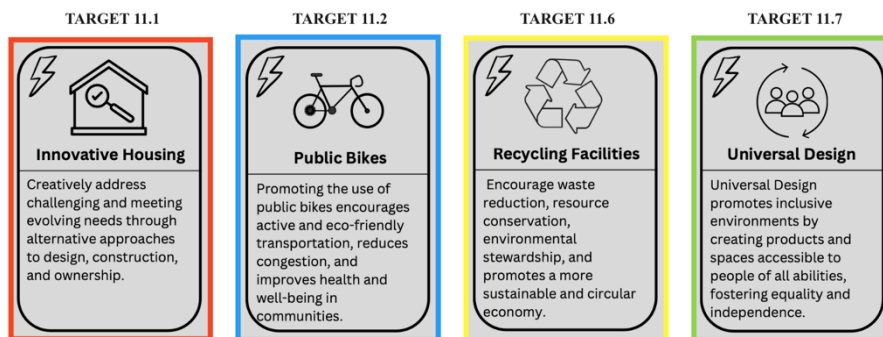


Figure 2. Examples of action cards categorized by targets

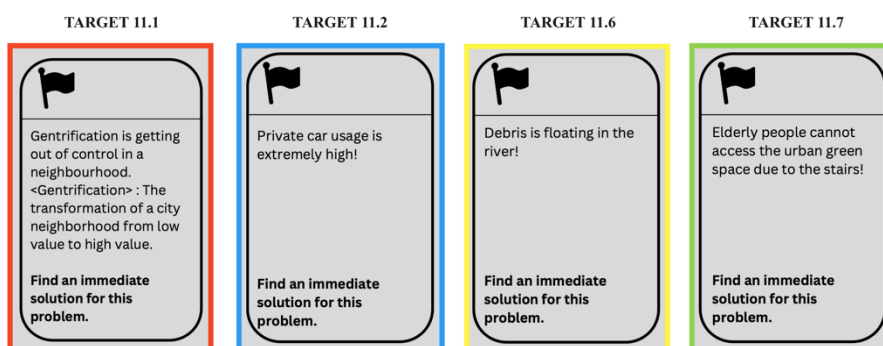


Figure 3. Examples of problem cards categorized by targets

Each team progresses by justifying their chosen actions to solve the assigned problems. They progress on the board. Funding, simulated by two dice, is allocated randomly based on island and target categories, representing the unpredictability of public budgeting. The board shows 4

themed paths, one for each target, on all the islands (Figures 4 and 5). This allows players to track their process in the game. These paths also show the amount of payment they need to do (1, 2, or 3 money tokens) to be able to implement their solution for the problems (Figure 4). Cross-category action cards may be used, but at an added cost and with group approval.

The teacher plays a facilitative rather than authoritative role. They introduce the game, clarify rules, and provide guidance if needed. However, gameplay and discussion are led entirely by students, fostering autonomy and peer learning. Post-game debriefs are used to reflect on learning outcomes and strategy.

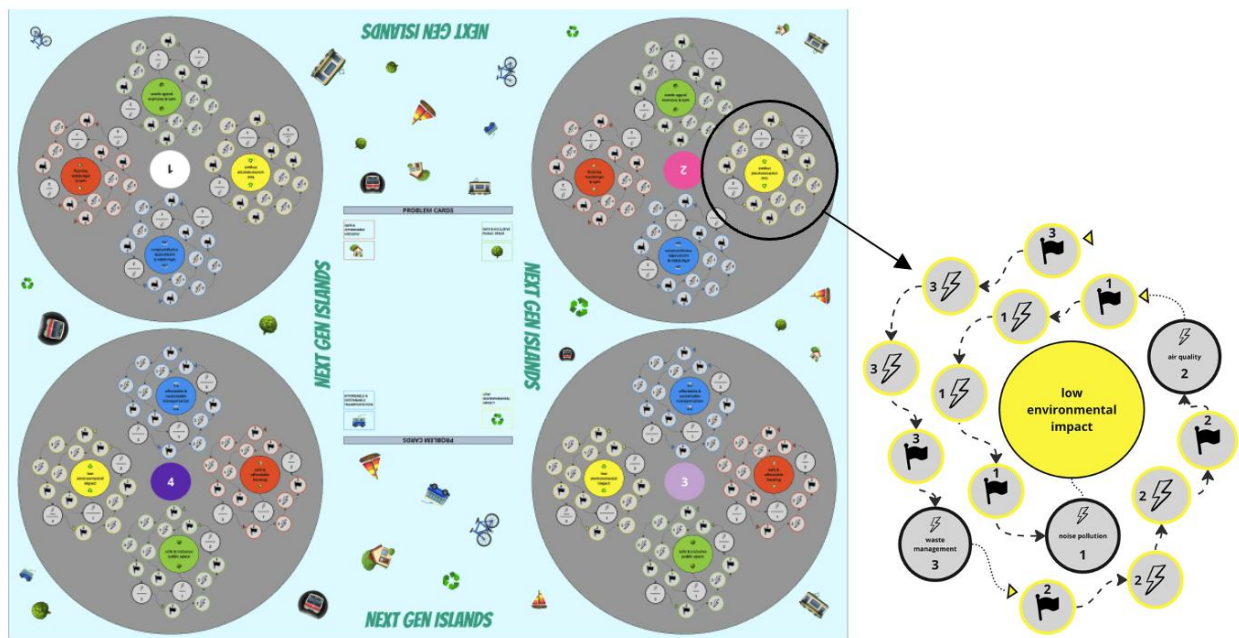


Figure 4. The board and one of the four target paths placed on each island on the board

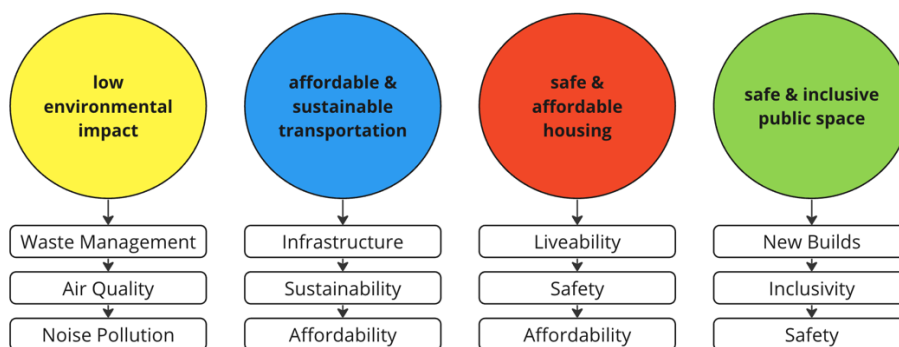


Figure 5. Different levels for each target

Digital Adaptation (Version B)

To simulate the collaborative and decision-oriented nature of a future AI-powered installation, a streamlined digital version of the game (Version B) was developed using Miro, a cloud-based

collaborative platform. Unlike the board game, Version B focuses exclusively on problem-solving and dialogue, eliminating the competitive element to prioritize cooperative learning.

Each team received a randomized problem card and all available action cards (Figure 6). Players collaborated in breakout rooms for five minutes to devise a solution using three action cards. Once reconvened in the main session, each group presented and justified their proposed solution. Other teams responded using emojis (thumbs-up or X) to simulate peer approval, mirroring the social validation process built into Version A.

This format was particularly effective for encouraging real-time discussion and peer critique, reflecting how such a system might operate in a digitally augmented public space.

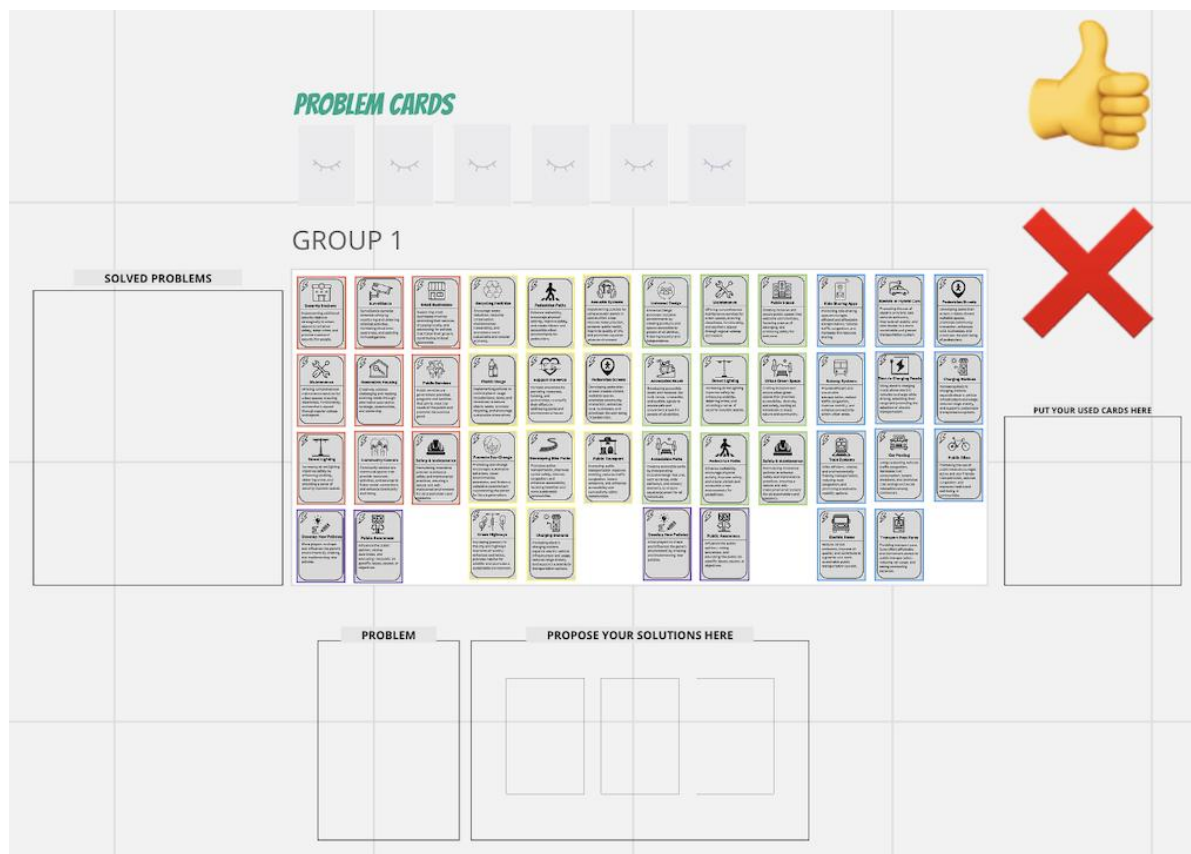


Figure 6. Game setting for the group 1 in Version B

Participants, Sampling, and Ethical Considerations

Participants were recruited through convenience sampling across three different educational settings, ensuring diversity in academic background, institutional context, and exposure to sustainability concepts:

- **Group 1 (Focus Group):** Four graduate students and recent graduates from interdisciplinary backgrounds at Concordia University.
- **Group 2 (In-Person Undergraduate Class):** Twelve undergraduate students enrolled in the “Sustainability in Design: History and Theory” course at Concordia University.

- **Group 3 (Online Class):** Eleven undergraduate students from Işık University's "Living Tomorrow: Smart Buildings" course.

All student participants had prior exposure to sustainable education through course lectures, ensuring a foundational understanding for gameplay evaluation. Only some of the participants in Group 1 did not have any educational knowledge on sustainability.

The research protocol followed standard ethical guidelines for educational research. Participants were informed of the purpose and voluntary nature of the study and gave written or verbal consent to participate. No identifying information was collected, and responses were anonymized during analysis.

Evaluation Tools, Experiment Setup, and Evaluation Process

Data collection involved both quantitative and qualitative methods:

- Pre-game survey evaluated baseline understanding of sustainability and SDG 11.
- Post-game survey (Figure 7) included 5-point Likert-scale items and open-ended questions across four categories: (1) gameplay experience, (2) sustainability knowledge, (3) attitudes and awareness, and (4) interaction, engagement, and dialogue.
- Observational data (notes during gameplay and debriefs) provided contextual insights into team dynamics, rule comprehension, and emergent behavior.

Surveys were adapted from Scurati et al. (2023) and tailored to reflect the learning goals of each game version. Both quantitative (5-point Likert scale) and qualitative (open-ended responses) data were collected. The data provided insights into the game's usability, educational value, and ability to promote discussion and systems thinking. No participants repeated the game, ensuring unbiased first impressions.

<p>(1) GAMING EXPERIENCE <i>How was your experience?</i></p> <ol style="list-style-type: none"> 1. Playing the game was fun. 2. The aim of the game and rules were clear. 3. It was easy to stay engaged throughout the game. 4. If given the chance, I would play the game again. 	<p>(2) SUSTAINABILITY KNOWLEDGE <i>After playing the game I think that...</i></p> <ol style="list-style-type: none"> 1. I know more facts regarding the possible sustainability implications of city management. 2. I know more concepts related to sustainable development targets for the built environment. 3. I am aware there are diverse sustainable solutions for the built environment. 4. I grasp a more comprehensive concept of sustainable development in the built environment. 	<p>(3) ATTITUDES & AWARENESS <i>After playing the game I think that...</i></p> <ol style="list-style-type: none"> 1. I am inspired to reflect sustainability in my daily life. 2. I feel that there is a strong need to prioritize a city's environmental and social aspects. 3. I become more concerned about sustainability aspects and the possible consequences of human activities. 4. If I imagine my role as a citizen, I am more committed to taking action to improve the environmental and social impact of the city I'm living. 	<p>(4) INTERACTION, DISCUSSION & INTEREST <i>After playing the game I think that...</i></p> <ol style="list-style-type: none"> 1. I am inspired to reflect sustainability in my daily life. 2. I feel that there is a strong need to prioritize a city's environmental and social aspects. 3. I become more concerned about sustainability aspects and the possible consequences of human activities. 4. I would like to have the chance to discuss sustainability with other people.
---	---	---	--

Figure 7. Post-game questionnaire

Results

Focus Group Evaluation (Version A – Group 1)

A preliminary focus group was conducted on July 14, 2023, at Concordia University to test the first iteration of the *Next-Gen Islands* board game. The group included four participants: two graduate students from architecture and two from unrelated disciplines. This session aimed to identify usability challenges, gauge initial reactions, and inform refinements for the next iteration.

The setup balanced facilitation and observation: one researcher introduced the rules while participating in gameplay, and another took notes and posed reflective questions. This dual approach allowed for deep insight into player behavior and cognitive engagement.

Participants appreciated the discussion-based nature of the game, particularly open-ended action cards that prompted collaboration and debate. However, they also found the mechanics overly complex.

Key issues included:

- Lack of clarity in rules and card functions
- Difficulty tracking progress without visual clues
- Confusion over uncategorized cards and game flow

Constructive suggestions included:

- Color-coded instruction cards for each SDG target
- Improved visual hierarchy on the board
- Enhanced illustrations and iconography
- More structured approval rules for gameplay decisions

This feedback directly informed the design of Version A.2, demonstrating the value of participatory input in refining educational tools. The group confirmed the game's potential for promoting reflective thinking but highlighted the need for streamlining to reduce cognitive overload, which is a key insight that shaped later versions.

In-Person Playtest and Survey Results (Version A.2 – Group 2)

The second iteration of the board game was tested during the ninth week of the undergrad course “Sustainability in Design: History and Theory” at Concordia University. Twelve students participated after completing eight weeks of related coursework, providing a sound foundation for engaging with the game's content.

To evaluate the playtest, a mixed-methods approach was employed, combining quantitative data from Likert-scale questions with qualitative feedback from open-ended responses. This analysis method was chosen to provide a comprehensive understanding of participant experiences: the Likert scale items (rated on a 5-point scale from 1 = Strongly Disagree to 5 = Strongly Agree) offered measurable indicators of agreement across key dimensions such as enjoyment, engagement, and clarity, while the qualitative comments provided contextual depth, explanations, and nuances that helped interpret the numerical scores. For instance, neutral Likert ratings (e.g. 3 = Neither Agree nor Disagree) could be clarified or contextualized by participants' descriptive feedback, revealing underlying positives or suggestions that might not be captured in averages alone. Descriptive statistics (e.g., means and distributions) were calculated for the Likert items, and qualitative data were thematically analyzed by identifying recurring patterns, such as specific praises or recommendations, to triangulate findings and ensure robust conclusions. This integration allowed for a more balanced assessment, avoiding overreliance on quantitative data where participant elaboration could refine interpretations.

Post-game survey results (Figure 8) showed varied responses on the Likert-scale items. For questions related to enjoyment and engagement (Category-1: Q1, Q3, Q4), 7 participants out of 12 rated 4-agree, with a notable proportion of “5” ratings indicating neutral positions for some participants. However, when supported by qualitative feedback, these results suggested that participants generally found the game enjoyable and engaging, particularly in terms of collaborative gameplay and group interaction, though not uniformly “highly” so, as the neutral scores reflect areas for improvement. For example, several students described the game as “fun and interactive” in their open-ended responses, emphasizing how group discussions “sparked interesting conversations” and “made sustainability feel more relatable,” which contextualized some neutral ratings as stemming from initial confusion rather than disinterest. In contrast, the clarity of the rules (Category-1: Q2) received lower scores (4 people rating 2-disagree), with qualitative comments consistently highlighting that the initial explanation was insufficient. Participants recommended providing printed rule sheets for reference during play, noting that this would address early frustrations. That said, many appreciated the verbal guidance offered during the first round, which helped them grasp the mechanics more effectively in real-time and contributed to positive engagement once underway. Additional suggestions included incorporating a greater number of problem cards to deepen educational value and provide more opportunities for critical engagement, while introducing empty problem cards later in the game to avoid overwhelming players early on.

In terms of knowledge acquisition (Category 2: Q1), Likert scores were moderately positive, with students reporting they did not learn entirely new sustainability concepts but gained greater awareness of the diversity and the complexity of potential solutions related to sustainable urban development. Qualitative responses reinforced this, with many highlighting that the clearly labeled keywords on the action cards helped connect specific strategies to broader sustainability goals. This indicates the game served effectively as a reinforcement and application tool rather than an introducer of novel content, aligning with its design intent.

Responses concerning sustainability awareness and attitudes (Category-3: Q2) were largely neutral on the Likert scale, which was anticipated given that most students played the game only once. Nonetheless, qualitative feedback emphasized reinforcement of understanding in environmental and social dimensions of sustainable cities, with some participants reporting renewed motivation to take action in their communities, citing both course content and the game as catalysts. Notably, several pointed to a desire to contribute to a livable future for coming generations as their primary inspiration.

Finally, feedback on interaction, discussion, and interest (Category-4: Q1 and Q2), although showed lower Likert scores, supported by positive qualitative descriptions of the game as a useful medium for practicing communication and collaborative reasoning. While some participants noted in comments that the problem-solving aspect felt somewhat limited due to the straightforward nature of the action cards (Category-4: Q3), they still valued the structured debate opportunities. Several expressed that the game encouraged deeper thinking about sustainability and inspired conversations beyond the classroom, recommending more real-world examples and emphasis on peer collaboration to enhance dynamism.

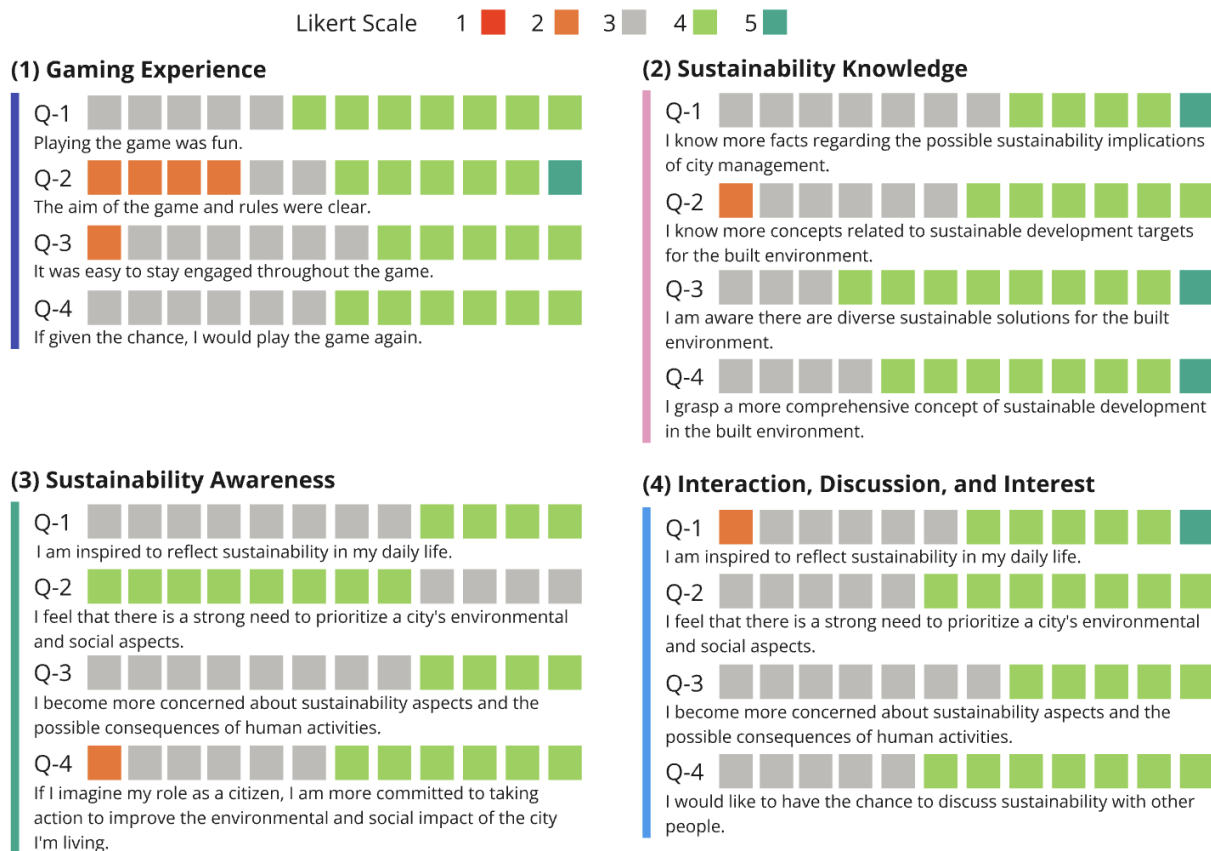


Figure 8. Group 2 post-game survey answers for all categories

During the session, observations aligned with survey findings: students understood the game mechanics more effectively through active participation rather than pre-game explanations alone. This underscored the need for simpler, more concise rule presentation to reduce initial confusion and support smoother gameplay. An integrated “how to play” guide that initiates the game and walks players through the first steps could significantly improve understanding and ease the learning curve. Despite these challenges, students showed strong interest, engaging enthusiastically in discussions, exchanging ideas, sharing humor, and asking thoughtful follow-up questions.

Based on these integrated insights, particularly the neutral-to-positive Likert trends contextualized by qualitative recommendations regarding complexity, Version B was developed with a focus on collaborative problem-solving, streamlining mechanics for better accessibility engagement.

Survey Results (Version B – Group 3)

The third workshop was conducted with undergraduate students from Işık University’s Interior Architecture and Environmental Design Department, as part of the elective course, “Living Tomorrow: Smart Buildings.” Taking place in the sixth week of the course, after five weeks of sustainability-focused lectures, the workshop assessed the educational and interactive potential of Version B, the digital adaptation of the board game. Eleven students participated via Miro, an online collaborative platform. One researcher guided setup and briefly explained rules before play began. Each participant completed both pre- and post-game surveys to

evaluate learning, interaction, and overall experience. The same mixed-methods analysis was applied in this game-play and survey as well, integrating quantitative Likert-scale data with qualitative open-ended responses.

Post-game results (Figure 9) revealed generally positive Likert trends. For enjoyment and ease of understanding (Category 1: Q1, Q3), scores were high, most responses in the 4-5 range. Qualitative feedback aligned strongly, with participants describing the game as “fun” and “engaging,” and several expressing eagerness to replay it (Category 1: Q4). The streamlined digital format and clear objectives were frequently praised in comments, supporting the conclusion that participants broadly found the game highly enjoyable and engaging, despite occasional neutral scores reflecting individual variability. Some suggested enhancements such as “bonus actions” or surprise elements to further boost dynamism.

On the sustainability knowledge, the Likert responses were neutral to positive, with participants reporting exposure to new concepts and a wider array of sustainable city management strategies. Open-ended answers reinforced that the action cards were identified as particularly effective tools for learning, due to their clarity and the way they presented concrete, actionable solutions. Students noted that the cards not only introduced them to unfamiliar approaches but also facilitated productive group discussions, making complex topics more accessible.

For sustainability awareness and attitudes, Likert agreement was neutral to strong, with most participants agreeing the game prompted deeper reflection on environmental issues and personal agency. Qualitative responses consistently cited a desire to help create a livable world for future generations as a core motivator for behavioral change, adding emotional depth to the numerical trends.

Interaction and engagement received strong endorsement, with qualitative data emphasizing playful yet substantive dialogue, critical thinking, and communication practice in a collaborative setting (Category 4: Q1, Q2, Q3). Participants frequently stated the game motivated sustainability conversations beyond class (Category 4: Q4) and saw potential for civic applications. Suggestions included integrating similar mechanics into community events, seminars, or online forums to sustain dialogue.

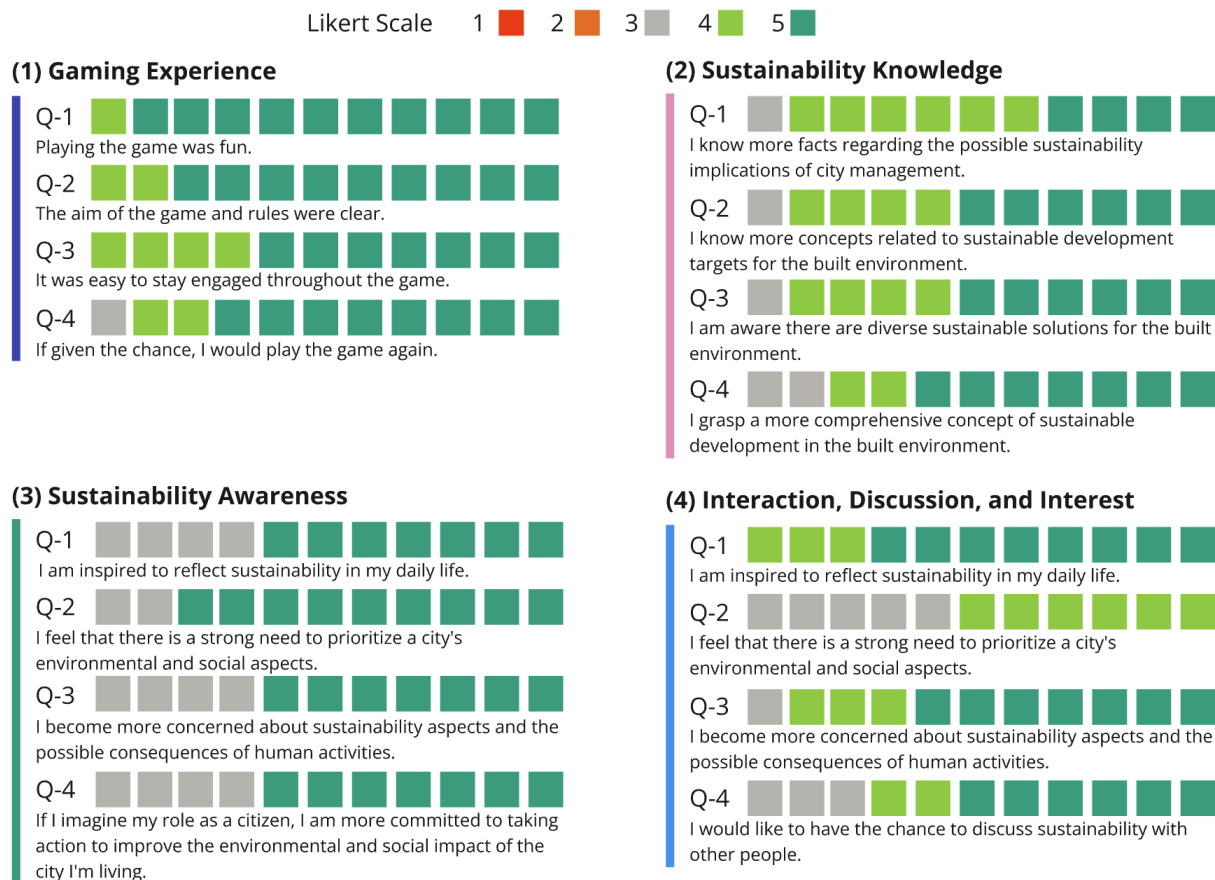


Figure 9. Group 3 post-game survey results for all categories

Overall, the integrated analysis confirms that Version B's simplified structure, particularly the focused set of action cards, reduced cognitive load, enhanced accessibility, and supported meaningful engagement. The digital format proved intuitive and educationally effective, validating its design for a public-facing installation aimed at fostering informal learning and civic discourse on urban sustainability.

Third Iteration: Toward a Digital Game Installation for Public Engagement

The findings from the focus group and two pilot workshops provided valuable insights into how serious game design can be optimized for sustainability education in informal learning settings. A key takeaway from all test groups was the importance of simplifying gameplay mechanics without diminishing the depth of discussion. Participants consistently responded positively to collaborate decision-making, especially when problem-solving tasks were clearly framed and manageable within short timeframes. These findings directly influenced the design of the upcoming digital installation, "Next-Gen Montreal," which is intended for public interaction in urban spaces.

The installation draws inspiration from water pollution and the urgent need to act on it. Therefore, the digital screen flows as a river, when played by many users, it is clean and colorings are natural greens and blues, but when it's not being played for a while, the river becomes desolated, creating abstract unnatural forms and turning into red (Figure 10).

Given the transient nature of public engagement with installations, where most individuals spend only a few minutes, the digital version is intentionally streamlined. Instead of involving complex mechanics, it focuses on a single core interaction: players choose a category aligned with SDG 11 (e.g., housing, transportation, etc.), are presented with a contextual problem, and then select two of three possible solutions (Figure 10). Because none of the options are strictly “correct” or “incorrect,” this structure encourages players to prioritize values and trade-offs based on their understanding and preferences. This design draws on pedagogical principles from constructivist and experiential learning theories, which emphasize the learner’s role in making meaning through active choice and reflection (Kolb, 2014). Projectors reflect the screen on the curved surface and motion sensors offer touchless interaction. There’s a time constraint, represented by the answers sliding down the screen indicating the time will be up. To enhance engagement and reinforce impact, the game generates a visual outcome: an AI-produced image representing the cumulative effects of the selected solutions. The result is then plotted on a digital map of Montreal as a symbolic “citizen contribution,” visually accumulating collective input and reinforcing the idea of shared responsibility in shaping sustainable cities.

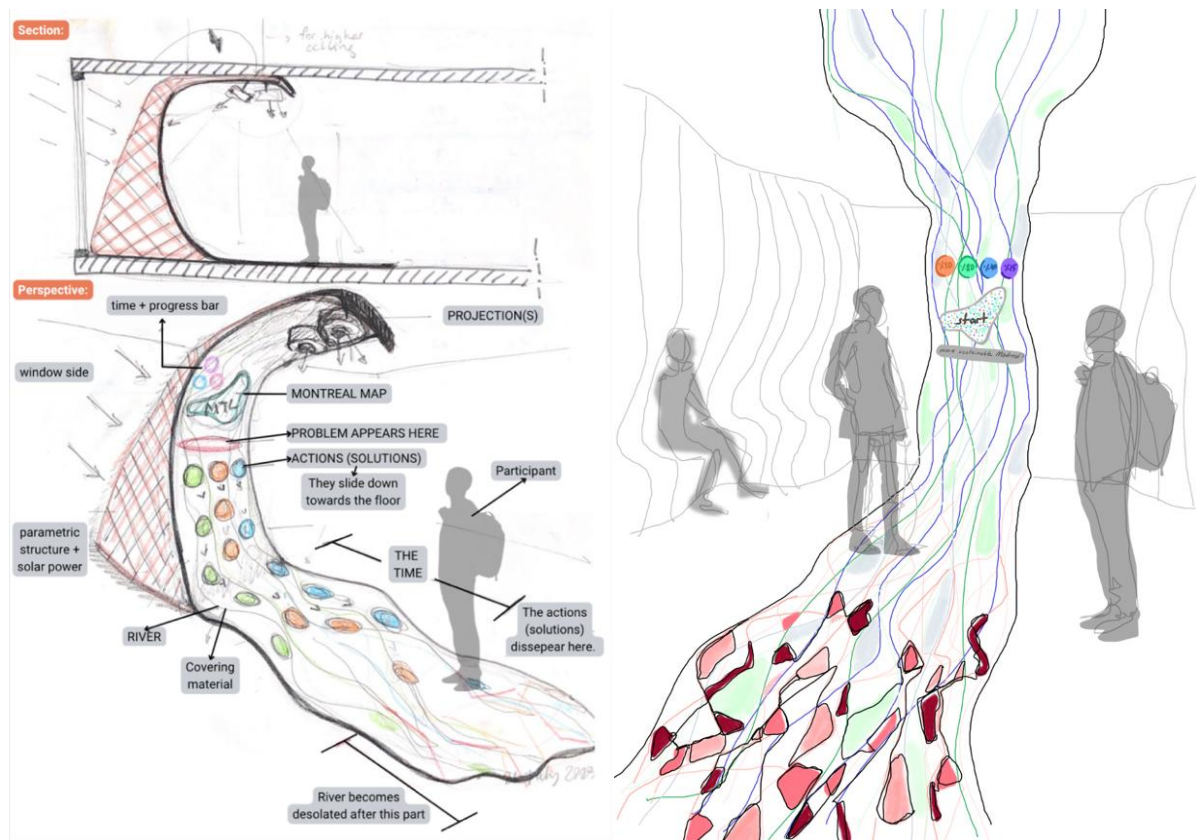


Figure 10. Initial idea sketches for the digital game installation

Importantly, this design evolution was not only driven by usability but also by educational considerations. The analog game trials revealed that while students valued the collaborative experience, many encountered barriers due to rule complexity, dense mechanics, or unclear instructions, particularly in early rounds. These barriers risk detracting from the core educational goals. Streamlining the interface as gameplay for the digital version directly addresses this issue, while still promoting systems thinking, a critical learning outcome in sustainability education (Gatti et al., 2019).

Moreover, while participants reported increased awareness and motivation, the evaluation relied primarily on self-reported perceptions, which introduces limitations. The possibility of novelty effects, self-selection bias, and limited exposure time must be acknowledged. Future evaluations of the digital game will need to incorporate triangulated data, combining qualitative interviews with performance-based measures or longitudinal tracking to assess changes in attitudes or behavior overtime.

The development process for Next-Gen Montreal continues to follow a Research through Design approach, enabling iterative prototyping, user testing, and refinement. The first prototype for the digital game has been developed. The user interface is shown in Figure 11. A clear road map that outlines internal testing, student trials, public presentation, and repeated revisions based on user feedback is also designed (Table 1). Semi-structured interviews and post-game surveys will be used in the next testing phases to generate richer evaluated data, particularly regarding how users interpret the visual outputs and how the game influences their understanding of sustainability in urban contexts.

By grounding design decisions in empirical insights and educational theory, the Next-Gen Montreal project moves beyond mere gamification to offer critical, participatory tool for sustainability learning in the public realm. The approach reflects a growing recognition that learning does not occur only with informal institutions but also through meaningful, interactive experiences in everyday environments.

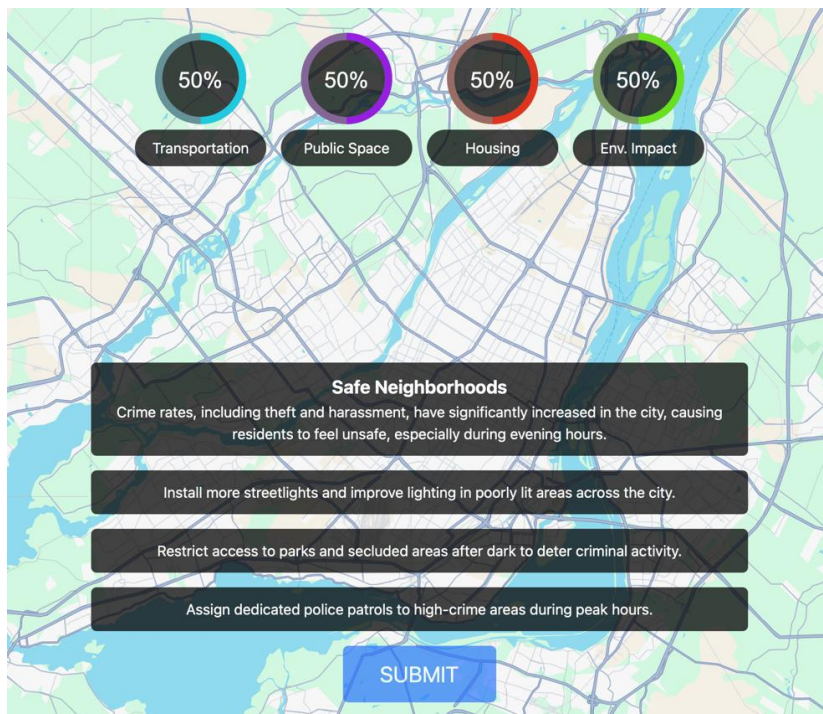


Figure 11. First prototype of the Next-Gen Montreal digital game

Interactive Narration for the Public Installation

The digital installation operates in an engaging, gesture-driven sequence designed to draw passerby into collaborative sustainable challenges.

1. Stand-by Mode: A dynamic river graphic flows in the background, overlaid with a Montreal Island map. Progress bars track advancement across key urban categories (housing, urban space, transportation, waste). An inviting prompt appears, such as “Join the challenge to make Montreal more sustainable!” or “Would you like to contribute to a greener Montreal?”
2. Player Approach: Upon detection, the prompt transitions to a welcoming message, such as “Welcome to Next Gen Montreal! Select a category to improve.” Users choose via hand gesture.
3. Gameplay Cycle:
 - A sustainability problem appears on-screen.
 - Three solution cards emerge after a brief pause; multiple selections are allowed, including one intentionally tricky option.
 - A countdown begins as cards slide downward.
 - Players discuss, decide, and select solutions by pointing.
 - Chosen cards ascend; a generative image visualizes the outcome.
4. Continuation or Completion:
 - Players are asked to continue (yes/no via gesture).
 - No: The image shrinks into a colored pin (category-specific) and is placed on the map, accumulating with prior solutions to show collective progress.
 - Yes: A new problem appears, and the cycle repeats.

This loop ensures intuitive, discussion-rich interaction while progressively mapping user-driven improvements across the city.

Materials

A significant challenge is presented by the development of a sustainable and energy-efficient digital media installation, due primarily to the substantial energy consumption inherent in the required technology. The question of how an energy-efficient digital media installation could be created was thus prompted. Collaboration was therefore engaged with Negarsadat Rahimi, whose work focuses on environmentally adaptive and energy-efficient eco-façade applications through parametric architecture. A parametric architectural shell was designed in partnership, incorporating sustainable materials to ensure environmental adaptivity and energy efficiency.

Practical Applications of the Project

The project provides actionable pathways for sustainability education and civic discourse on environmental challenges. Its flexible, interactive format supports deployment across diverse settings, such as:

- Community engagement: Localized content enables reflection and collective action on region-specific issues.
- Civic interface: Integration with public datasets (e.g., Montreal’s open data) and user input creates bidirectional communication between residents and urban systems.
- Data visualization: User choices are aggregated into a living archive that maps evolving community priorities.
- Educational tool: The analog board game serves classrooms, libraries, and museums, rendering complex sustainability concepts accessible and engaging.

Path to Implementation

Immediate steps toward realizing the Next-Gen Montreal installation are outlined in Table 1. Analog and digital prototypes were created to test educational efficacy and interaction mechanics. Developed via participatory design, these prototypes replicate the third iteration's core logic, allowing collaborative problem-solving, negotiation, and outcome reflection. This low-fidelity approach enabled iterative refinement of mechanics and content prior to digital translation. Currently the study is on the second step: Developing the Demo Algorithm.

Table 1. Initial research design for the digital game and installation

1	Creating a Sample Database	Developing a database for the algorithm that includes themes, problems, solutions, results, result images, and associated impact metrics.
2	Developing the Demo Algorithm	Implementing a demo algorithm with a sample set of 10 problems to test functionality and mechanics.
3	Initial Testing	Conducting preliminary testing of the game with the developer and researchers to ensure the core mechanics work as intended.
4	Student Testing	Testing the game with students at Concordia University to gather initial feedback and assess gameplay by conducting post-game survey and semi-structured interviews.
5	Presentation	Presenting the demo game at Concordia University to engage a broader audience and collect additional feedback.
6	Second Iteration	Refining the game based on the feedback collected from testing and presentations.
7	Repeat Testing	Conducting another round of testing to evaluate the updated version.
8	Further Iterations (if needed)	Repeating the process of testing and refinement as necessary to achieve the desired level of interactivity, engagement, and educational value.

A conceptual framework has been presented for AI-augmented, eco-didactic installations that advance public sustainability learning. The integration of Artificial Intelligence, interactivity, and experiential learning is positioned as a potent mechanism for heightening environmental awareness and catalyzing behavioral shifts.

Spatial and social dynamics are equally emphasized: meaningful interaction emerges from the interplay of users, environment, and content. Place-based design that promotes dialogue, reciprocity, and aesthetic appeal, while upholding transparency, safety, and privacy, potentially transforms public spaces into inclusive arenas for environmental learning.

Ultimately, this foundation underpins installations like Next-Gen Montreal: playful, visually striking, pedagogically robust, and socially impactful. As AI integrates further into daily life, its strategic use for eco-didactic ends offers a timely lever for sustainable urban futures.

Discussion

The third iteration, Next-Gen Montreal, marks the transition from tabletop prototyping to a public-facing, AI-augmented digital installation. Deployed as an interactive eco-didactic interface, it synthesizes insights from prior analog playtests into a scalable, gesture-driven experience embedded in urban space.

- **Educational and Engagement Outcomes:** Quantitative and qualitative data confirm that the streamlined digital mechanics, limited action cards, clear objectives, and real-time feedback, significantly enhanced accessibility and enjoyment. Likert scores and comments highlighted the intuitive flow and discussion-rich gameplay. The digital format preserved the collaborative essence of earlier versions while reducing cognitive barriers, enabling broader participation across skill levels.
- **AI Integration and Adaptive Learning:** Generative AI was employed to visualize solution outcomes dynamically, transforming abstract decisions into vivid, context-specific imagery. This not implemented only for reinforced learning but also to evoke emotional investment, for participants to visualize “future city” scenarios as motivators for sustained engagement. Adaptive difficulty scaling, informed by playtest observations, ensured challenges remained appropriately paced, preventing the early round overwhelm noted in Version A.2.
- **Public Space Activation:** Potentially will be positioned in high-traffic civic areas, the installation functions as both spectacle and dialogue catalyst. The stand-by river animation and evolving progress pins create a persistent visual narrative of collective impact, inviting spontaneous participation. Gesture-based interaction eliminates onboarding friction, while the accumulating map of user contributions fosters a sense of shared stewardship, transforming passive observation into active co-creation.
- **Sustainability of the Medium:** Energy efficiency was addressed through proposing the use of sustainable materials, minimizing environmental footprint without compromising interactivity.
- **Limitations and Future Directions:** While the digital prototype works on paper, it is yet remain untested. Longitudinal data on repeat engagement and behavioral influence are also absent. Future iterations will incorporate live integration with Montreal’s open data APIs, enabling real-time reflection of municipal sustainability metrics. Multi-lingual support and accessibility features (e.g., audio descriptions, seated interaction zones) are planned to broaden inclusivity.

In conclusion, the third iteration successfully scales participatory sustainability learning into public space. By merging refined game mechanics, AI-driven visualization, and environmentally adaptive design, Next-Gen Montreal installation proposal demonstrates that digital installations potentially can be simultaneously playful, pedagogically rigorous, and ecologically conscientious, offering a replicable model for cities worldwide.

Conclusion and Future Works

This study explored the potential of serious games as tools for enhancing awareness and understanding of sustainable development in the built environment. Through a Research through Design methodology, the project examined how interactive, problem-solving game mechanics and collaborative discussions can support learning in both formal educational settings and public spaces. The development and testing of two game versions, an analog board

game and a digital problem-solving variant, revealed that participants were most engaged when gameplay emphasize dialogue, decision-making, and teamwork. These findings reinforce existing research on game-based learning, which suggests that active, participatory experiences are especially effective for complex topics such as sustainability.

The feedback collected from focus groups and classroom pilot tests informed the initial design of *Next-Gen Montreal*, an AI-augmented digital game installation tailored for public environments. The simplified mechanics and value-driven choices in the digital version were designed in response to usability challenges observed in earlier iterations. These changes aim to ensure that the installation remains intuitive, accessible, and engaging, even for casual passerby with limited time. By transforming abstract sustainability concepts into interactive, tangible experiences, the project contributes to ongoing efforts to make sustainability education more inclusive and impactful.

The study's core knowledge contribution lies in articulating evidence-based design principles, clarity through constraint, learning through co-creation, and engagement via adaptive visualization, grounded in structured user data rather than speculative innovation. While prior work addresses serious games in controlled environments, this research provides empirical validation for AI-mediated, place-based learning in transient public settings, offering a replicable model for eco-didactic systems.

At the same time, the study acknowledges several limitations. The evaluation relied primarily on self-reported data from short-term gameplay sessions, which may be influenced by novelty effects or participant enthusiasm. The learning outcomes were not triangulated with performance-based assessments or long-term behavioral indicators, as the primary objective at this stage was to design and test the board games as exploratory tools for evaluating didactic potential. This intentional focus limits the ability to draw conclusions about long-term knowledge retention or sustained behavioral change for the board games. While student feedback provided valuable insights into engagement and comprehension, the sample was intentionally limited in scope. Broader demographic testing was not conducted, as the primary goal was to assess the board games' didactic elements to inform the development of the AI-augmented digital version.

Looking ahead, the first Next-Gen Montreal prototype is being deployed in a campus public space for field testing with diverse users. Further research will explore opportunities for integrating the installation into civic spaces, museum and educational campaigns. Collaborations with municipal agencies, cultural institutions, and educational organizations will be pursued to scale the platform and evaluate its potential as a tool for public communication, participatory planning, and sustainability advocacy.

Through its iterative, user-centred design and empirical grounding, this study contributes to the growing body of work demonstrating that serious games, when critically designed and contextually situated, can potentially serve as powerful mediums for sustainability education and civic engagement.

Acknowledgements

This research was funded by The Social Sciences and Humanities Research Council of Canada, grant number 435-2018-1161.

References

- Audry, S. (2021). *Art in the Age of Machine Learning*. MIT Press.
- Ayer, S. K., Messner, J. I., & Anumba, C. J. (2016). Augmented Reality Gaming in Sustainable Design Education. *Journal of Architectural Engineering*, 22(1), 04015012.
[https://doi.org/10.1061/\(ASCE\)AE.1943-5568.0000195](https://doi.org/10.1061/(ASCE)AE.1943-5568.0000195)
- Boarin, P., & Martinez-Molina, A. (2022). Integration of environmental sustainability considerations within architectural programmes in higher education: A review of teaching and implementation approaches. *Journal of Cleaner Production*, 342, 130989.
<https://doi.org/10.1016/j.jclepro.2022.130989>
- Boragine, L. H. (2023). Roll the Dice: Using Game-Based Learning to Teach Sustainability in Higher Education. In W. Leal Filho, A. Lange Salvia, E. Pallant, B. Choate, & K. Pearce (Eds.), *Educating the Sustainability Leaders of the Future* (pp. 59–73). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-22856-8_4
- Cheng, P.-H., Yeh, T.-K., Tsai, J.-C., Lin, C.-R., & Chang, C.-Y. (2019). Development of an Issue-Situation-Based Board Game: A Systemic Learning Environment for Water Resource Adaptation Education. *Sustainability*, 11(5), Article 5.
<https://doi.org/10.3390/su11051341>
- Cucuzzella, C., Chupin, J.-P., & Hammond, C. (2020). Eco-didacticism in art and architecture: Design as means for raising awareness. *Cities*, 102, 102728.
<https://doi.org/10.1016/j.cities.2020.102728>
- Cucuzzella, C., Morteza Hazbei, & Sherif Gouburan. (2021). Activating Data through Eco-Didactic Design in the Public Realm: Enabling Sustainable Development in Cities. 13(4577), 4577.
<https://doi.org/10.3390/su13084577>
- Den Haan, R.-J., & Van der Voort, M. C. (2018). On Evaluating Social Learning Outcomes of Serious Games to Collaboratively Address Sustainability Problems: A Literature Review. *Sustainability*, 10(12), Article 12. <https://doi.org/10.3390/su10124529>
- Deterding, S., Dixon, D., Khaled, R., & Nacke, L. (2011). From game design elements to gamefulness: Defining “gamification.” *Proceedings of the 15th International Academic MindTrek Conference: Envisioning Future Media Environments*, 9–15.
<https://doi.org/10.1145/2181037.2181040>
- Dib, H., & Adamo-Villani, N. (2014). Serious Sustainability Challenge Game to Promote Teaching and Learning of Building Sustainability. *Journal of Computing in Civil Engineering*, 28(5), A4014007. [https://doi.org/10.1061/\(ASCE\)CP.1943-5487.0000357](https://doi.org/10.1061/(ASCE)CP.1943-5487.0000357)
- Dib, H., Adamo-Villani, N., & Niforooshan, R. (2012). A Serious Game for Learning Sustainable Design and LEED Concepts. *Computing in Civil Engineering* (2012), 137–144.
<https://doi.org/10.1061/9780784412343.0018>
- Dow, S., Lee, J., Oezbek, C., MacIntyre, B., Bolter, J. D., & Gandy, M. (2005). Wizard of Oz interfaces for mixed reality applications. *CHI '05 Extended Abstracts on Human Factors in Computing Systems*, 1339–1342. <https://doi.org/10.1145/1056808.1056911>
- Education. (2015). Sustainable Development Goals. <https://sdgs.un.org/topics/education>
- Eisenack, K. (2013). A Climate Change Board Game for Interdisciplinary Communication and Education. *Simulation & Gaming*, 44(2–3), 328–348.
<https://doi.org/10.1177/1046878112452639>
- Falk, J., & Dierking, L. D. (2000). *Learning from museums: Visitor experiences and the making of meaning*. AltaMira Press.

- Fjællingsdal, K. S., & Klöckner, C. A. (2020). Green Across the Board: Board Games as Tools for Dialogue and Simplified Environmental Communication. *Simulation & Gaming*, 51(5), 632–652. <https://doi.org/10.1177/1046878120925133>
- Gatti, L., Ulrich, M., & Seele, P. (2019). Education for sustainable development through business simulation games: An exploratory study of sustainability gamification and its effects on students' learning outcomes. *Journal of Cleaner Production*, 207, 667–678. <https://doi.org/10.1016/j.jclepro.2018.09.130>
- Godin, D., & Zahedi, M. (2014, June 16). Aspects of Research through Design: A Literature Review. DRS Biennial Conference Series.
- Ho, S.-J., Hsu, Y.-S., Lai, C.-H., Chen, F.-H., & Yang, M.-H. (2022). Applying Game-Based Experiential Learning to Comprehensive Sustainable Development-Based Education. *Sustainability*, 14(3), Article 3. <https://doi.org/10.3390/su14031172>
- Horst, M. (2022). Science Communication as a Boundary Space: An Interactive Installation about the Social Responsibility of Science. *Science, Technology, & Human Values*, 47(3), 459–482. <https://doi.org/10.1177/01622439211003662>
- Isaacs, J., Falconer, R., & Blackwood, D. (2008). A unique approach to visualising sustainability in the built environment. 2008 International Conference Visualisation, 3–10. <https://ieeexplore.ieee.org/abstract/document/4568665/>
- Iyer-Raniga, U., & Andamon, M. M. (2016). Transformative learning: Innovating sustainability education in built environment. *International Journal of Sustainability in Higher Education*, 17(1), 105–122. <https://doi.org/10.1108/IJSHE-09-2014-0121>
- Juan, Y.-K., & Chao, T.-W. (2015). Game-Based Learning for Green Building Education. *Sustainability*, 7(5), Article 5. <https://doi.org/10.3390/su7055592>
- Karimimoshaver, M., Eris, B., Aram, F., & Mosavi, A. (2021). Art in Urban Spaces. *Sustainability*, 13(10), Article 10. <https://doi.org/10.3390/su13105597>
- Kolb, D. A. (2014). *Experiential Learning: Experience as the Source of Learning and Development*. FT Press.
- Koskinen, I., Zimmerman, J., Binder, T., Redstrom, J., & Wensveen, S. (2011). *Design Research Through Practice: From the Lab, Field, and Showroom*. Elsevier.
- Lameras, P., Petridis, P., Dunwell, I., Hendrix, M., Arnab, S., de Freitas, S., & Stewart, C. (2013). A game-based approach for raising awareness on sustainability issues in public spaces. The Spring Servitization Conference: Servitization in the Multi-Organisation Enterprise, 20–21. <https://pure.coventry.ac.uk/ws/files/3939006/A%20game-based%20approach.pdf>
- Lee, K. (2021). Urban Public Space as a Didactic Platform: Raising Awareness of Climate Change through Experiencing Arts. *Sustainability*, 13(5), Article 5. <https://doi.org/10.3390/su13052915>
- Lesen, A. E., Rogan, A., & Blum, M. J. (2016). Science Communication Through Art: Objectives, Challenges, and Outcomes. *Trends in Ecology & Evolution*, 31(9), 657–660. <https://doi.org/10.1016/j.tree.2016.06.004>
- Miss, M. (2009). *City As Living Laboratory Broadway: 1000 Steps*.
- Ntalla, I. (2021). Play and manifestations of playfulness in interactive and immersive museum spaces. *Culture, Theory and Critique*, 62(3), 266–286. <https://doi.org/10.1080/14735784.2021.1968306>
- Olgen, B., & Cucuzzella, C. (2024). Artificial Intelligence for Eco-Didactic Installations through Interactive Museological Experience to Encourage Sustainable Action. *Research on Humanities and Social Sciences*, 14(5), 51.

- Ouariachi, T., Olvera-Lobo, M. D., & Gutiérrez-Pérez, J. (2019). Serious Games and Sustainability. In W. Leal Filho (Ed.), *Encyclopedia of Sustainability in Higher Education* (pp. 1450–1458). Springer International Publishing. https://doi.org/10.1007/978-3-030-11352-0_326
- Polys, N., Hotter, J., Lanier, M., Purcell, L., Wolf, J., Hession, W. C., Sforza, P., & Ivory, J. D. (2017). Finding frogs: Using game-based learning to increase environmental awareness. *Proceedings of the 22nd International Conference on 3D Web Technology*, 1–8. <https://doi.org/10.1145/3055624.3075955>
- Romano, M., & Rogora, A. (2023). A Serious Game Proposal for Exploring and Designing Urban Sustainability. In E. Arbizzani, E. Cangelli, C. Clemente, F. Cumo, F. Giofrè, A. M. Giovenale, M. Palme, & S. Paris (Eds.), *Technological Imagination in the Green and Digital Transition* (pp. 811–820). Springer International Publishing. https://doi.org/10.1007/978-3-031-29515-7_72
- Sachs, J. D., Lafortune, G., Fuller, G., & Drumm, E. (2023). *Sustainable Development Report 2023 Implementing the SDG Stimulus*. Dublin University Press. <https://sdgtransformationcenter.org/reports/sustainable-development-report-2023>
- Sailer, M., Hense, J. U., Mayr, S. K., & Mandl, H. (2017). How gamification motivates: An experimental study of the effects of specific game design elements on psychological need satisfaction. *Computers in Human Behavior*, 69, 371–380. <https://doi.org/10.1016/j.chb.2016.12.033>
- Schwartzberg, P., Stevens, J., & Acton, K. S. (2022). *Canadians' Perspectives on Climate Change & Education: 2022 Executive Summary [Executive Summary]*. Learning for a Sustainable Future.
- Scurati, G. W., Kwok, S. Y., Ferrise, F., & Bertoni, M. (2023). A Study on the Potential of Game Based Learning for Sustainability Education. *Proceedings of the Design Society*, 3, 415–424. <https://doi.org/10.1017/pds.2023.42>
- Stanitsas, M., Kirytopoulos, K., & Vareilles, E. (2019). Facilitating sustainability transition through serious games: A systematic literature review. *Journal of Cleaner Production*, 208, 924–936. <https://doi.org/10.1016/j.jclepro.2018.10.157>
- Tsai, J.-C., Liu, S.-Y., Chang, C.-Y., & Chen, S.-Y. (2021). Using a Board Game to Teach about Sustainable Development. *Sustainability*, 13(9), Article 9. <https://doi.org/10.3390/su13094942>
- van Renswouw, L., van Hamersveld, Y., Huibers, H., Vos, S., & Lallemand, C. (2022). Fontana: Triggering Physical Activity and Social Connectedness through an Interactive Water Installation. *Extended Abstracts of the 2022 CHI Conference on Human Factors in Computing Systems*, 1–7. <https://doi.org/10.1145/3491101.3519765>
- Wang, C.-M., & Chen, I.-T. (2021). Applying Interactive Technology to Construct a Popular-Science Teaching Aid System for Protecting Cetaceans along Sea Coasts. *Journal of Coastal Research*, 38(2), 389–413. <https://doi.org/10.2112/JCOASTRES-D-21-00019.1>
- Wouters, P., van Nimwegen, C., van Oostendorp, H., & van der Spek, E. D. (2013). A meta-analysis of the cognitive and motivational effects of serious games. *Journal of Educational Psychology*, 105(2), 249–265. <https://doi.org/10.1037/a0031311>
- Zimmerman, J., Forlizzi, J., & Evenson, S. (2007). Research through design as a method for interaction design research in HCI. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 493–502. <https://doi.org/10.1145/1240624.1240704>

Design Thinking in educational publications: A document analysis of books issued by Turkish Public Institutions and implications for the Technology and Design course^{*}

Ahsen Öztürk, Kütahya Dumlupınar University, Türkiye

Abstract

This research aims to investigate how the design thinking (DT) approach in education is defined and implemented in related books published by public institutions in Türkiye. The document analysis method, a qualitative research method, was used for data collection and analysis. Seven books published by the Republic of Türkiye Ministry of National Education (MONE) and the Scientific and Technological Research Council of Türkiye (TÜBİTAK) were selected as the data. Findings indicate that DT is perceived as a human-centered and interdisciplinary problem-solving process that requires a set of skills and mindsets and incorporates some values associated with 21st-century skills. In the books, the matter of how to develop a designer's mindset and skills in non-designers – teachers and students – is generally overlooked or under-emphasized. Therefore, the DT approach in education is not comprehended and practiced as a holistic approach that requires the interaction between relevant processes, mindsets, and tools. Considering the findings, incorporating the human-centered, experimental, and collaborative characteristics of the DT approach into the educational culture or teaching method can help teachers and students to adopt DT as a holistic approach rather than just a problem-solving process. The DT approach can also be employed as a tool to establish a context for technology teaching or integration. In line with this, some strategies are proposed to strengthen the integration of the DT approach within *Technology and Design* education. This research is considered significant in terms of providing teachers with a perspective on the DT approach and how it is integrated into *Technology and Design* education.

Keywords

Design thinking, Design thinking in Türkiye, Design thinking in K-12 education, Design thinking for educators, Design thinking in Technology and Design Education

^{*} This article was produced from the study titled “What Does Design Thinking Mean in Turkey? Analysis of DT-related Books Published by Public Institutions”, which was presented as an extended abstract at EDUCONGRESS 2022 (International Education Congress) on 18.11.2022.

Introduction

Design thinking (DT), an interdisciplinary, iterative, and human-centered problem-solving approach, is utilized for multiple purposes in education, such as curriculum design, learning environment design, and improving students' skills (Öztürk, & Korkut, 2022).

The use of DT in K-12 education has recently gained popularity in Türkiye. In the 2023 education vision report of the Türkiye Ministry of National Education (MONE), the statement on the establishment of "Design Skill Workshops" (named "Tasarım Beceri Atölyeleri" in Turkish) in all educational institutions draws attention. These workshops aim to provide DT and STEM/STEAM education (Türkiye's Education Vision 2023 report, n.d.). Furthermore, under the framework of the National Technology Initiative in Türkiye, cooperation has been made to establish the "Experimental Technology Workshops" (named "Deneyap Teknoloji Atölyeleri" in Turkish) in 81 cities. The Design and Production course to be given in these workshops intends to educate the students within the framework of the DT approach (Deneyap, n.d.). Books were also published through MONE to disseminate the DT approach in national education and to support STEM and STEAM education (Karataş et al., 2021; Aksoy et al., 2020). Additionally, while the literature predominantly comprises various systematic literature reviews, bibliometric analyses, and extensive research and applications on articles related to the DT approach (Lin et al., 2025; Li, & Zhan, 2022), there is a dearth of publications providing comparative analyses or reviews of DT books.

This research investigates how the DT approach in education is defined and implemented in the books published by Turkish public institutions. The purpose of this paper is to compare and evaluate the books on DT published by public institutions in Türkiye to gain an understanding of the DT approach and how it is applied. This research addresses a notable deficiency in academic literature by carefully analyzing and contrasting various DT books. This paper is also considered significant in terms of providing a perspective on the DT approach and how it can be integrated into *Technology and Design* education.

Design Thinking Approach

Design thinking (DT) is a holistic approach that stresses the collaborative, human-centered, and experimental problem-solving process (Guha et al., 2017) and offers a wide range of tools and strategies to handle wicked problems (Peng, 2022). In education, the DT approach is used to redesign the school system, facilitate teachers' collaboration on curriculum creation, and solve school-related problems (Diefenthaler, 2017). Mindsets of the DT approach help students acquire 21st-century skills¹ (Goldman et al., 2017).

¹ 21st-century skills are:

Learning and Innovation Skills (4Cs): Critical Thinking & Problem Solving; Communication & Collaboration; Creativity & Innovation.

Information, Media and Technology Skills: Information Literacy; Media Literacy; ICT Literacy.

Life and Career Skills: Flexibility & Adaptability; Initiative & Self-Direction; Social & Cross-Cultural Skills; Productivity & Accountability; Leadership & Responsibility (The P21 Framework for 21st Century Learning, 2009).

The literature states that the DT approach is utilized as an iterative problem-solving process that includes multiple methods, principles, and tools for dealing with wicked problems (what designers do) (Peng, 2022; Kimbell, 2011) that entails a range of skills (what designers know; their skills) (Lin et al., 2025; Kimbell, 2011) and ways of thinking (how designers approach and comprehend the task; their mindsets) (Diefenthaler, 2017; Kimbell, 2011). Accordingly, the DT can be practiced in four different ways (Gerken, 2022):

- Tool (ways of creating an artifact): DT as an approach is used to generate artifacts due to its methods and techniques (using brainstorming as a single tool, for example).
- Process (ways of working): DT is an organized, non-linear problem-solving activity that identifies users' needs, frames the problem, and develops user-centered solutions. To manage complicated issues at this level, tools at the relevant stages and particular skills (collaboration, self-reflection, etc.) are utilized collectively during the problem-solving process.
- Mindset (ways of approaching the task): DT is used as a way of thinking, where experiencing the DT process with its tools cultivates mental representations and leads to adopting the DT mindset.
- Holistic approach (includes all the mentioned above): DT is a comprehensive, holistic approach that comprises all relevant processes, mindsets, and tools. These components are interconnected and affect each other in the problem-solving process.

This paper discusses the five stages of the Stanford University d.school's DT approach (Figure 1) due to its widespread use in the Turkish setting (Kaygan et al., 2025a; Aksoy et al., 2020). Accordingly, the *Empathize* stage entails developing empathy with users to uncover their wants and desires. The *Define* stage includes identifying the problem or challenge by synthesizing the acquired data. The *Ideate* stage requires brainstorming potential solutions to the defined design problem. *Prototype* and *Test* stages involve prototyping several concepts and arriving at a final design through iterative testing and user feedback ("Design Thinking Bootleg" n.d.).

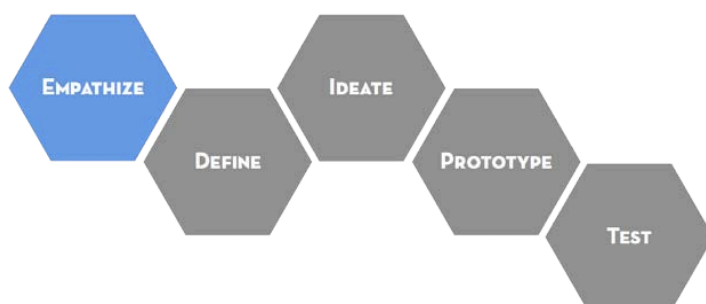


Figure 1: The Stanford d.school's DT Approach ("Design Thinking Bootleg" n.d.)

The literature identifies three DT approaches commonly used in the field of education (Öztürk, & Korkut, 2022) (Table 1): Stanford d.school's ("Design Thinking Bootleg" n.d.), HPI's

(HPI, n.d.), and IDEO's (IDEO, 2012) DT approaches. Table 1 presents stages with similar functions, but some with different names, in the same column. Accordingly, two HPI stages correspond to IDEO's *Discovery* and d.school's *Empathize* stages. The *Experimentation* stage of IDEO encompasses both the *Prototype* and *Test* stages. The *Evolution* stage is distinctive to IDEO, where the progress of the concept is documented based on stated success criteria, and additional steps are planned to produce the actual product with high precision.

The literature can describe DT mindsets as DT characteristics or attributes of design thinkers (Gerken, 2022). Human-centered and collaborative, for instance, are defined as both characteristics (Guha et al., 2017) and mindsets of the DT approach (IDEO, 2012). Although many mindsets are identified in the literature, Table 1 describes those highlighted in these three DT approaches. Accordingly, shared characteristics/mindsets of these DT approaches can be found around the following: human-centered/empathy², collaboration, and experimentation.

Table 1. A comparison of the stages of Stanford d.school, HPI, and IDEO design thinking approaches and a description of the mindsets they adopted

Note: The color red denotes shared mindsets discovered in all DT approaches

Source. Based on Öztürk and Korkut's "A comparison of d.school, HPI, and IDEO DT approaches" (2022), with the addition of DT mindsets.

DT Approach	Stages of Design Thinking						DT Mindsets	Description of Mindsets
Stanford d.school's DT approach ("Design Thinking Bootleg" n.d.)	Empathize		Define	Ideate	Prototype	Test	<p>Focus on human values</p> <p>Radical collaboration</p> <p>Embrace experimentation</p> <p>Be mindful of process</p> <p>Craft clarity</p> <p>Bias towards action</p> <p>Show don't tell</p>	<p>-Focus on human values (Think & Act in a human-centered way/Human-centered): Focus on users' needs/desires through developing empathy.</p> <p>-Radical collaboration (Collaborate in diverse teams /Collaborative): Collaborate with people from diverse backgrounds/experiences to comprehend/solve the problem.</p> <p>-Embrace experimentation³ (Learn through experimentation /Experimental): Prototype to learn through failures/mistakes and iterate to improve the concept.</p>
HPI's DT approach (HPI, n.d.)	Understand	Observe	Define the Point of View	Ideate	Prototype	Test	<p>Think & Act in a human-centered way</p> <p>Collaborate in diverse teams</p> <p>Learn through experimentation</p> <p>Envision a radically new future (Optimistic)</p> <p>Explore the problem space</p> <p>Embrace uncertainty</p>	<p>-Be Mindful of Process: Use the DT approach to guide you in the design process, where you are, what you aim to achieve, and what you need to do next.</p> <p>-Craft clarity: Express your idea clearly/simple so that others can easily comprehend the concepts.</p> <p>-Bias towards action: To turn your idea into reality, focus on</p>

² The IDEO toolkits (IDEO, 2012; The Field Guide to Human-Centered Design, 2015) use the terms "human-centered" and "empathy" interchangeably.

³ This mindset can be expressed as the combination of "Learn from failure" and "Iterate" mindsets (The Field Guide to Human-Centered Design, 2015).

IDEO's DT approach (IDEO, 2012)	Discovery	Interpretation	Ideation	Experimentation	Evolution	Human-centered Collaborative Experimental Optimistic	<p>action rather than talking or thinking.</p> <p>-Show don't tell: Communicate your ideas through creating prototypes.</p> <p>-Envision a radically new future (Optimistic): Be resilient, have faith to solve problems, and imagine new things/ideas.</p> <p>-Explore the problem space: Adopt a holistic thinking approach to investigate the problem from multiple perspectives/experiences.</p> <p>-Embrace uncertainty: Embrace complexity and tolerate uncertainty/ambiguity when dealing with unforeseen challenges.</p>
---------------------------------	-----------	----------------	----------	-----------------	-----------	---	--

In this paper, it may be helpful to distinguish between “design thinking” and “design as a problem-solving process”, that is, the design process. The phrase “design as a problem-solving process” can be defined as the process of iteratively and systematically solving problems to transform or solve an existing situation or problem into a desired one or tangible design (Sameti, Koslow, & Mashhady, 2022; Aspelund, 2017). The meaning of the word “product” can also vary from discipline to discipline; it can refer to tangible, digital, system, or service products. While the stages may vary depending on the type of product being developed (Ulrich, Eppinger, & Yang, 2019), “design as a problem-solving process” may include the following stages:

- *Defining the Problem*: Examining the current situation, environmental concerns, and user needs; and determining or refining the problem to be solved (Ulrich, Eppinger, & Yang, 2019; Aspelund, 2017).
- *Analysis*: Detailed examination of the causes/context of the problem, identification of user needs/constraints (Ulrich, Eppinger, & Yang, 2019).
- *Ideation*: Developing different concepts and design ideas through both written and visual means.
- *Developing and Implementing the Solution*: Iteratively prototyping, testing, and implementing to explore selected ideas/concepts in more detail (Ulrich, Eppinger, & Yang, 2019; Aspelund, 2017).
- *Evaluation and Improvement*: Evaluating the results of the implemented solution and improving it if necessary (Ulrich, Eppinger, & Yang, 2019).
- *Production*: Communicate and collaborate with internal/external suppliers on matters involving a wide range of disciplines (Ulrich, Eppinger, & Yang, 2019; Aspelund, 2017).

Accordingly, encompassing all relevant processes, mindsets, and tools, the DT approach stresses user-centeredness, empathy, iterative prototyping, and testing in the problem-solving process. The “design as a problem-solving process” usually concentrates on the creation of a functional and ergonomic product while also considering technical specifications, detailing, manufacturing procedures, and considerations.

Technology and Design Education in Türkiye

In 2018, changes were executed in the national curriculum of *technology and design* education in Türkiye (Turkish Technology and Design Education Curriculum, 2018). The aim of the *Technology and Design* course is described in the MONE textbook as developing individuals who understand the technology and design development process, can think analytically, understand the problem-solving processes applied by designers, can develop creative solutions with an interdisciplinary approach, know the concepts related to design and technology, are prone to teamwork, and are technology and design literate.

When the weekly schedules of K-12 educational institutions in Türkiye for the 2025-2026 academic year are examined, it is discovered at the secondary school level that the *Technology and Design* course is given for 2 hours per week in the 7th and 8th grades. The *Information Technologies and Software* course is taught for 2 hours per week in the 5th and 6th grades. *Robotics Coding* (in 5th and 6th grades) and *Artificial Intelligence Applications* courses (in 7th and 8th grades) are offered only as electives. None of these courses is taught in primary school. At the high school level, only *Information Technologies and Software* is given as compulsory or elective course, depending on the school type (Weekly Course Schedule, n.d.). The *Technology and Design* course is also recommended to be conducted in collaboration with other disciplines (Turkish Technology and Design Education Curriculum, 2018). This suggestion may be due to the difficulty of providing two hours of hands-on, interdisciplinary technology and design training per week.

The curriculum review reveals that the same learning areas are found in grades 7 and 8: “Fundamentals of Technology and Design,” “Design Process and Presentation,” “Built Environment and Product,” “Needs and Innovation” and “Design and Technological Solutions.” Within these learning areas, we encounter a program that strives to raise awareness of various design fields, such as architectural design, visual communication design, engineering design, computer-aided design, design-focused process, and product development. There is no topic, or unit called the Design Thinking (DT) Approach within the curriculum (ibid). The *Technology and Design* course curriculum in Türkiye intends to enhance understanding of various design and technology fields and teach concepts pertinent to them.

Since there are no institutions in Türkiye that train teachers for this course, teachers are selected and appointed from among graduates of different departments (such as Industrial Design department, Art education, etc.) (Fields in Teacher Appointments, n.d.). This situation raises questions about their competence and experience in the field of design and technology, and the equivalence and quality of the education provided in the classroom.

There are some problems that can be encountered in technology integration in schools: not every school and student has the same internet speed, workshops, and technological tools or is completely devoid of them; there are differences between the technological competencies of in-service teachers (due to their limited in-service training in technological approaches) and pre-service teachers (due to the limited number of technology-content courses in education faculties). Literature also states that technology integration should be

done with a purpose; The training provided should not focus solely on the use of technological tools and equipment (Akgündüz, Kurt, & Seferoğlu, 2023). Accordingly, technology can be integrated into education under three categories:

As a tool or facilitator (An electronic hardware/software device, Web 2.0/3.0/4.0 tools, etc.) (Ellis et al., 2020; Doğan, & Robin, 2015).

This category can include CAD/CAM tools, calculators, virtual environments, online communication, data collection, collaboration and artificial intelligence (AI) tools, Google Docs & Spreadsheets, portable technologies, and the tools used by practitioners of STEM disciplines (such as using microscopes, modeling with CAD software) (ibid).

To facilitate the problem-solving process (Ellis et al., 2020; Akgun, 2013; Bruce, & Levin, 1997).

In this category, the learner uses educational/instructional technology for inquiry (doing research, data collection/analysis), communicating (collaborating, documenting, presenting the findings), construction (prototyping things by using waste/simple materials, robotics, computer-aided design, digital fabrication tools, etc.), and expression (the presentation of the results by using editing programs, animation software, etc.) (Bruce, & Levin, 1997). This approach to technology use aims to integrate and embed technology directly into educational activities to facilitate the implementation of a problem-solving process in courses (Ellis et al., 2020; Bruce, & Levin, 1997). This category can include using technology (Lego Mindstorms sets, etc.) for coding to solve a required task/challenge (Ellis et al., 2020).

To teach technological contents or skills (Ellis et al., 2020; Akgun, 2013).

Integrated or embedded technology can be learned as a subject in education (Akgun, 2013). For example, by using particular tools and practices, students can design a specific device to measure the temperature and learn the intended content, instead of utilizing the thermometer itself (Ellis et al., 2020). Under this category, one can develop their skills via engaging educational technologies, such as gaining algorithmic thinking skills while working with the Arduino robot kit to create a software prototype.

Considering these categories, in the *Technology and Design* course textbook, technology appears to be used as a tool (using 2D/3D modeling programs, etc.) and to facilitate the problem-solving process (preparing PowerPoint presentations to present the result, etc.).

Methodology

This article aims to evaluate the books on DT in education published by state entities in Türkiye by comparing them with popular DT approaches used in education (IDEO, 2012; “Design Thinking Bootleg,” n.d.; HPI, n.d.). The document analysis method, a qualitative research method, was utilized for data collection and analysis. Document analysis is the analysis of materials carrying information about the research subject (such as videos, books, academic papers, or journals, etc.). It entails document collection, review, reading, analyzing, and interpretation (Bowen, 2009).

Because they were published by MONE and TÜBİTAK (The Scientific and Technological Research Council of Türkiye), the following seven books were chosen and used as data (Table 2). Four of these books are prepared solely according to the DT approach (Kaygan et al., 2025a, 2025b; Avcı et al., 2023; Aksoy et al., 2020) while the others refer to the DT approach in some chapters. Except for one book (Turan et al., 2021; Sarıkoç et al., 2021), the target audience of other books is secondary/high school students, as well as teachers/educators.

Table 2. Books on design thinking (DT) published by public institutions in Türkiye

Name of the book	Editors/Authors	Publishers	The number of pages investigated	Target group	
Deneyap Türkiye: Tasarım ve Üretim-Ortaokul (2025a)*	Pınar Kaygan, Sedef SÜNER Pla-Cerda, Nur Akkuş Çakır, Alper Karadoğaner, Gizem Hediye Eren, Engin Kapkın, Tolga Yılmaz (Authors)	TÜBİTAK Publications	313 (Total 313 pages)	Secondary school students / Educators	
Deneyap Türkiye: Tasarım ve Üretim-Lise (2025b)				High school students / Educators	
Tasarım Odaklı Düşünme ile Proje Hazırlama: Öğretmen Rehber Kitabı (Örnek Proje Tasarımlarıyla) (2023)	Sarper Serkan Avcı, Kemal Şimşek, Lokman Güzelyurt, Atilla Çıfci, Bülent Akça, Hülya Olgun (Authors)	MONE, General Directorate of Secondary Education	106 (Total 106 pages)	High school teachers	
Eğitimde İnovasyon için Tasarım Odaklı Düşünme (2020)	Sibel Akbıyık, Volkan Hasan Kaya (Eds.)	Behiye Dinçer Aksoy Ece Balçık Emre Uykun Ercüment Erdemli Fatma Ayça Yıldırım Fatma Kaya Gökhan Biçer Kenan Gökdağ Kürşat Demir Merve Kızanlık Murat Öztürk Özgül Eynel Zeynep Sarıkoç (Authors)	MONE, General Directorate of Teacher Training and Development	384 (Total 384 pages)	Secondary school students / Teachers
Okul Öncesinden Ortaöğretime Farklı Disiplinlerde STEM Eğitimi Uygulamaları (2021)	İpek Saralar-Aras (Ed.)	Ali Turan, Mustafa Talha Soysal, Türkan Dümbüllü, Özlem Çelikkol (Authors)	MONE, General Directorate of Teacher Training and Development	Between 99-130 (Total of 462 pages)	Not specified
		Zeynep Sarıkoç, Sevda Baydar, Selin Sarıça, Tuğçe Ekici, Kısmet Türkan Kurnaz, Işılay Güneş Torun (Authors)		Between 355-370 (Total of 462 pages)	Not specified

⁴ The DT approach, narrative, and process are applied nearly identically in both books within the context of the same project, despite being published as two separate volumes for High School and Secondary School. Accordingly, the article will proceed through Deneyap Türkiye: Tasarım ve Üretim-Ortaokul (2025a). Additionally, the “Student Workbook” was available for download in the 2021 version of the book, but not in the 2025 version.

Different Approaches in STEM Trainers' Training (2021)	Asaf Murat Karapınar, Rukiye Orman, İlkay Solmaz (Eds.)	Serçin Karataş, Ebru Kılıç Çakmak, Mutlu Tahsin Üstündağ (Authors)	MONE, General Directorate of Teacher Training and Development	Between 12-14 (Total 152 pages)	Teachers
Tasarım Beceri Atölyeleri Öğretmen El Kitabı (n.d.)	Not specified		MONE, General Directorate of Secondary Education	Between 15-16 (Total 347 pages)	High school teachers

In the analysis process of the data (Bowen, 2009), using the Microsoft Excel application, the author coded and evaluated the data. The data were processed using an initial framework in which categories were primarily determined by reviewing the literature. Accordingly, a comparison was carried out under the categories described in Tables 3 and 4 to comprehend the general view of the DT approach and each stage of the DT approach. The initial framework was updated many times throughout the coding process. The findings were interpreted using this framework.

Data were encoded using the coding format types of Corbin and Strauss (2008). In general comparison, data were coded according to predetermined concepts for the categories of *adopted DT approach*, *approach to implementing DT*, *characteristics of DT approach*, *DT mindsets*, and *Technology integration*. The categories of *view of DT from an educational perspective* and *expectations from the implementation of the DT approach* were coded according to the concepts extracted from the data.

In general comparison, Gerken's (2022) model, which is based on four different ways to implement DT, was utilized to investigate the second category -*approach to implementing DT*. The categories of *views of DT from an educational perspective* (Kaygan et al., 2025a, p. 3) and *expectations from the implementation of the DT approach* (Aksoy et al., 2020, p. 10) were explored by examining the definition, purpose, and benefits of the DT approach in the relevant books.

"The general and specific objectives of the course are determined as follows: ... *approaching the challenges with a human-centered perspective* (Way of thinking), ... *collaborating effectively* (Skill), *understanding that the design and production process is iterative, learned by making mistakes* (Way of thinking)"⁵

"Stanford University (d.school) characterizes the DT approach as a learning approach that focuses on *developing students' self-confidence*."⁶

⁵ Dersin genel ve özel hedefleri aşağıdaki gibi belirlenmiştir: ... zorluklara *insan merkezli bir bakış açısıyla yaklaşma*, ... *etkin bir şekilde işbirliği yapma*, tasarım ve üretim sürecinin *tekrarlı, hata yapılarak öğrenilen bir süreç olduğunu benimseme*. (Text of the book in Turkish)

⁶ Standford Üniversitesi, TOD yaklaşımını, *öğrencilerin öz güvenlerini geliştirmeye odaklanan bir öğrenme yaklaşımı* olarak nitelendirir. (Text of the book in Turkish)

A model that covers the fundamental 21st-century skills and values was developed for Türkiye (Türel et al., 2023). This model focuses on promoting social-emotional development and learning skills in a supportive educational environment. Accordingly, 11 core values associated with these skills were identified: justice, friendship, honesty, love, respect, patriotism, helpfulness, morality, conscience, manners, and thrift⁷ (Türel et al., 2023). Under the category of *expectations from the implementation of the DT approach*, the books were also reviewed considering these values. The names of these values, their synonyms, and antonyms were used as keywords, and the findings were evaluated according to whether they were seen as a “value” in the context of the sentence in which they were found.

“...To prevent material *waste* (*the antonym of the word ‘thrift’*), and to provide equal opportunities for each student to use materials, instructors can follow the following strategies”⁸

“While asking students to empathize, they are expected to display a *respectful* attitude without *judgment*”⁹

Literature can describe DT mindsets as DT characteristics. To distinguish between DT’s characteristics and mindsets, the way they are presented in the sentence was examined. If it was stated as a way of thinking, it was regarded as a mindset (p. 18). If it was presented as an attribute of the DT approach, it was considered as a characteristic (Aksoy et al., 2020, p. 5). Considering the literature, the following keywords were used to explore DT’s mindsets and characteristics: iteration, prototyping, reflection, experimental, creativity, innovation, human-centered/empathy, collaboration, failure/mistake, and uncertainty/ambiguity.¹⁰

“An *optimistic perspective* should always be maintained throughout the process for innovative and creative solutions.”¹¹

⁷ Keywords in Turkish: Adalet, Dostluk, Dürüstlük, Sevgi, Saygı, Vatanseverlik, Vatanseverlik, Yardımseverlik, Ahlak, Vicdan, Görgü, Tasarruf

⁸...Malzeme *israfını* (*Tasarruf kelimesinin zıt anlamlısı*) önlemek ve her öğrenciye eşit miktarda kullanım imkânı sunabilmek için öğretmenler aşağıdaki stratejileri izleyebilirler...: (Text of the book in Turkish)

⁹ Öğrencilerden empati kurmalarını isterken *yargılamadan ... saygılı* bir tavır sergilemeleri beklenir. (Text of the book in Turkish)

¹⁰ Keywords in Turkish: Yineleme, prototip yapma, yansıtma, deneysel, yaratıcılık, yenilik, insan odaklı/empati, iş birliği, hata/yanlış, belirsiz

¹¹ Süreç boyunca yenilikçi ve yaratıcı çözümler için hep *iyimser bir bakış açısı* sergilenmelidir. (Text of the book in Turkish)

“...The DT approach is powerful for ... bringing diverse disciplines together to generate *human-centered* and *innovative* solutions to problems in a *collaborative* and *experimental* structure.”¹²

In the category of *technology integration*, the sample activities in the books were reviewed, considering the previously mentioned three types of technology usage in education.

As a tool or facilitator.

Using the Figma Web 2.0 tool for logo design (Avcı et al., 2023); AutoCAD for 3D modelling (Aksoy et al., 2020); Making models using simple materials (Karataş et al., 2021); Making an award statuette using a laser cutter (Kaygan et al., 2025a).

To facilitate the problem-solving process.

Creating a project exhibition in the Metaverse (Avcı et al., 2023); Preparing a digital presentation (Kaygan et al., 2025a; Aksoy et al., 2020).

To teach technological content or skills.

Using the Arduino robot kit, getting information about electrical circuit elements and developing coding skills (Avcı et al., 2023; Aksoy et al., 2020); Learning planning (which model parts will be produced and how) and time management (time allocated for production) skills while making high-fidelity prototypes (Kaygan et al., 2025a).

The *stage*, the *purpose of the stage*, and the *method name* of the DT approach are clearly mentioned in the books of Avcı et al. (2023, pp. 8-105), Kaygan et al. (2025a, pp. 167-245), and Aksoy et al. (2020, pp. 22-37). These served as data for a comparison of each step of the DT approach with the Stanford d.school DT approach used in the books.

Validity and Reliability

The document analysis methodology employed in this study was founded on the preliminary coding performed in 2023 and subsequently re-evaluated and refined in 2025. This re-evaluation at various intervals illustrates that the data are not solely reliant on immediate interpretations but are assessed within context. The study's validity was enhanced through the implementation of the “time triangulation” approach (Kimchi, Polivka, & Stevenson, 1991). The coding method conducted by the same researcher across different years enhanced the study's reliability by reinforcing the “intra-coder reliability” (Hoonard, 2008). Accordingly, in contrast to the analysis conducted in 2023, the 2025 analysis incorporated the secondary school and high school books authored by Kaygan et al. (2025a, 2025b) - replacing the secondary school book by Kaygan et al. (2021)- as well as the book by Avcı et al. (2023). Consequently, a total of seven textbooks were analyzed, compared to five in the initial study. Furthermore, under the “Findings” section, the recent analysis introduced a new category titled *technology integration*. Within the category of *expectations from the*

¹²... Tasarım odaklı düşünme yaklaşımı, ... farklı disiplinleri bir araya getirerek *iş birlikli* ve *deneyisel* bir yapı içinde problemlere *insan odaklı* ve *yenilikçi* çözümler üretmek için güçlü bir modeldir. (Text of the book in Turkish)

implementation of the DT approach, eleven values associated with 21st-century skills were examined.

Findings

General Perspective on the Design Thinking Approach

According to the findings (Table 3), all books employ the DT approach used at Stanford d.school. Three books view it as a holistic approach to problem-solving that incorporates tools, processes, and mindset (Kaygan et al., 2025a; Avcı et al., 2023; Aksoy et al., 2020), while others solely consider it as a process for problem-solving. From an educational standpoint, it is thought to cover a set of skills, particularly 21st-century skills, in all books. Holistic thinking (Kaygan et al., 2025a; Avcı et al., 2023; Aksoy et al., 2020), hands-on, model-making, iterative, prototyping (Kaygan et al., 2025a; Avcı et al., 2023), and analytical thinking (Sarıkoc et al., 2021; Aksoy et al., 2020) are the other skills associated with the DT approach. It is also regarded as a way of thinking due to its particular mindsets (Kaygan et al., 2025a; Avcı et al., 2023; Sarıkoc et al., 2021; Aksoy et al., 2020), an engineering approach in STEM education (Turan et al., 2021), a competence (Karataş et al., 2021), and a teaching method (Tasarım Beceri Atölyeleri Öğretmen El Kitabı, n.d.). It is further highlighted as an active learning approach that includes hands-on, collaborative, and reflective practices (Kaygan et al., 2025a; Aksoy et al., 2020).

Some expectations are expressed regarding the implementation of the DT approach: its ability to increase students' engagement (Kaygan et al., 2025a; Avcı et al., 2023), motivation, interaction (Kaygan et al., 2025a); boost students' self-esteem (Aksoy et al., 2020), and its potential to improve their skills and acquisitions (Kaygan et al., 2025a; Avcı et al., 2023; Aksoy et al., 2020). DT is reported to provide them the ability to construct their own learning environments and school systems (Aksoy et al., 2020). Except for three books, in others, the DT approach is also expected to facilitate the product (physical, interior, software, building, and system) design process (Kaygan et al., 2025a; Avcı et al., 2023; Sarıkoc et al., 2021; Aksoy et al., 2020). Furthermore, it has been noticed in three books that some of the strategies suggested in the implementation of the DT approach can develop some values related to 21st-century skills in students; these are, respect, thrift (Kaygan et al., 2025a; Avcı et al., 2023; Aksoy et al., 2020); morality (Avcı et al., 2023; Aksoy et al., 2020); conscience, manners (Avcı et al., 2023); justice (Kaygan et al., 2025a); and honesty (Aksoy et al., 2020).

The DT approach is characterized by two qualities in all books: human-centered/user-centered and interdisciplinary. In two books, it is considered to provide a context for integrating STEM disciplines (Turan et al., 2021; Sarıkoc et al., 2021; Karataş et al., 2021). It is also associated with innovation (Kaygan et al., 2025a; Avcı et al., 2023; Sarıkoc et al., 2021; Karataş et al., 2021; Aksoy et al., 2020), collaboration (Kaygan et al., 2025a; Avcı et al., 2023; Sarıkoc et al., 2021; Aksoy et al., 2020), iteration (Kaygan et al., 2025a; Avcı et al., 2023; Aksoy et al., 2020), reflection (Kaygan et al., 2025a; Avcı et al., 2023), and experimental (Avcı et al., 2023; Aksoy et al., 2020).

The mindsets of the DT approach used in Stanford d.school are explicitly underlined in two books (Sarıkoc et al., 2021; Aksoy et al., 2020). While the mindset of human-centered/

empathy is prominent throughout the books, the mindsets of radical collaboration and embracing experimentation are the other mindsets most explored in the books (Kaygan et al., 2025a; Avcı et al., 2023; Sarıkoç et al., 2021; Karataş et al., 2021; Aksoy et al., 2020). Some of HPI's mindsets are also discovered in the books: explore the problem space (Avcı et al., 2023; Turan et al., 2021; Aksoy et al., 2020), envision a radically new future, and embrace uncertainty (Aksoy et al., 2020). However, there is no information on how to emphasize these mindsets when applying the DT approach to students.

Except for two books in which technology is used only as a tool or facilitator (A) (Karataş et al., 2021; Sarıkoç et al., 2021), in others (Kaygan et al., 2025a; Avcı et al., 2023; Aksoy et al., 2020), there is also technology usage in education to facilitate the problem-solving process (B) and to teach technological content and skills (C). According to the findings, prototyping and presentation activities in problem-solving processes involve the use of technology in categories A and B, while the integration of robotics into the learning process generally involves technology integration in category C.

The three books explicitly provide a relevant DT workbook/template/form. In the book by Kaygan et al. (2021), the student workbook can be downloaded to help students follow the DT approach. In Aksoy et al.'s book (2020), teachers are provided with some forms/rubrics to manage and evaluate the implementation of the DT approach. For students, monitoring forms and worksheets for all stages of the DT approach are also presented. In Avcı et al.'s book (2023), teachers are provided with forms to measure and evaluate each stage of the DT approach. While there are forms for students to assess themselves and their peers (Reflection, Self-Assessment & Peer Review Forms), many forms/tables are also designed for them for each stage of the DT approach.

Table 3. General view of the DT approach in books published by public institutions in Türkiye

Note: The color red refers to the common findings under each category discovered in the books

Name of the book	Adopted DT approach	Approach to implementing DT	View of DT from an educational perspective	Expectations from the implementation of the DT approach	Characteristics of the DT approach	DT Mindsets	Technology Integration	Workbook/Template/Form in the book
Deneyap Türkiye: Tasarım ve Üretim-Ortaokul (2025a; 2025b)	Stanford d.school' DT approach	<ul style="list-style-type: none"> Holistic approach: Include tools, mindset, and process for problem-solving 	<ul style="list-style-type: none"> An active learning approach A way of thinking Set of skills (hands-on, model-making, iterative prototyping, holistic thinking, & 21st-century skills, such as problem-solving, teamwork, 4C skills) 	<ul style="list-style-type: none"> Increase students' engagement. Increase students' motivation. Increase students' interaction. Improve students' particular skills & acquisitions. Have students design a physical product. Develop students' specific values, 	<ul style="list-style-type: none"> Human-centered/user-centered Interdisciplinary Collaboration Innovation Iteration Reflection 	<ul style="list-style-type: none"> Human-centered /Empathy Embrace experimentation Radical collaboration 	<ul style="list-style-type: none"> A-As a tool or facilitator B-To facilitate the problem-solving process C-To teach technological contents or skills 	Student workbook (Kaygan et al., 2021)

				such as respect, justice, & thrift.					
Tasarım Odaklı Düşünme ile Proje Hazırlama: Öğretmen Rehber Kitabı (2023)	Stanford d.school' DT approach	•Holistic approach: Include tools, mindset, and process for problem-solving	•A way of thinking •Set of skills (hands-on, model-making, iterative prototyping, holistic thinking, & 21st-century skills, such as problem-solving, teamwork, 4C, and Information, Media, and Technology Skills)	•Increase students' engagement. •Develop students' specific values, such as respect, morality, conscience, manners, & thrift. •Improve students' particular skills & acquisitions. •Have students design a physical product, systems (food safety systems), a software product (smart traffic light), & a building.	•Human-centered/user-centered •Interdisciplinary •Collaboration •Innovation •Iteration •Reflection •Experimental	• Human-centered /Empathy • Embrace experimentation • Radical collaboration • Explore the problem space (Holistic thinking)	A-As a tool or facilitator B-To facilitate the problem-solving process C-To teach technological contents or skills	For teachers: •Measurement and Evaluation Forms specific to each stage of the DT approach	For students: •Reflection Form •Self-Assessment Form •Peer Review Form •Forms/ Tables specific to each stage of the DT approach
Eğitimde İnovasyon için Tasarım Odaklı Düşünme (2020)	Stanford d.school' DT approach	• Holistic approach: Include tools, mindset, and process for problem-solving	• An active learning approach • A way of thinking • Set of skills (holistic thinking, analytical thinking, inquiry, & 21st-century skills, such as problem-solving and teamwork)	• Improve students' self-esteem. • Improve students' particular skills & acquisitions. • Have students design a physical product, interior (the learning environment), systems (school rules, school management, lesson plans, or lunch menu), & a software product (automatic plant irrigation system). •Develop students' specific values, such as respect, honesty, thrift, & morality.	• Human-centered/user-centered • Interdisciplinary • Collaboration • Innovation • Iteration • Experimental	• Stanford d.school's Mindsets • Explore the problem space (Holistic thinking) • Envision a radically new future (Optimism) • Embrace uncertainty	A-As a tool or facilitator B-To facilitate the problem-solving process C-To teach technological contents or skills	For teachers: • Teachers' Process Observation List • Product Evaluation Criteria • Social and Emotional Skills Observation Form • Process Evaluation Rubric	For students: •Monitoring Form and Worksheet specific to each stage of the DT approach • Forms for o Process Analysis Matrix o Post-interview Problem Analysis Map o Empathy Map o 2X2 Matrix
Okul Öncesinden Ortaöğretime Farklı Disiplinlerde STEM Eğitimi Uygulamaları (2021)	Stanford d.school' DT approach	• A process for problem-solving activity	• Set of skills (21st-century skills) • An engineering approach	Not specified	• Human-centered/user-centered • Interdisciplinary	• Human-centered/ Empathy • Explore the problem space (Holistic thinking)	Not specified		
		• A process for problem-solving activity	• A way of thinking • Set of skills (analytical thinking & 21st-century skills, such as problem-solving)	• Have students design a physical product.	• Human-centered/user-centered • Interdisciplinary • Collaboration • Innovation	• Stanford d.school's Mindsets	A-As a tool or facilitator		

Different Approaches in STEM Trainers' Training (2021)	Stanford d.school' DT approach	• A process for problem-solving activity	• A competence	Not specified	• Human-centered/user-centered • Interdisciplinary • Innovation	• Human-centered /Empathy • Embrace experimentation	A-As a tool or facilitator
Tasarım Beceri Atölyeleri Öğretmen El Kitabı (n.d.)	Stanford d.school' DT approach	• A process for problem-solving activity	• A teaching method • Set of skills (21st-century skills)	Not specified	Not specified	• Human-centered /Empathy	Not specified

Stages of Design Thinking Approach

The results from Table 4 indicate that only Aksoy et al.'s book contains the same stages as the Stanford d.school's DT approach. The DT approach outlined in the book of Kaygan et al. (2025a) is the same as the d.school's DT approach up until the *Prototype* stage. Unlike other books, the *Prototype* stage in this book includes the production of low-fidelity prototypes and testing the concepts with students before user testing. The *Test* stage evaluates test results and plans the high-precision manufacturing production process for the selected design. The DT process has one more *Prototype* stage: producing and assessing a high/low-fidelity prototype, followed by presenting it to students/users by preparing posters/presentations. Although there is no comparable stage in the d.school's DT approach, the *Test* and the final *Prototype* stages are thought to be akin to the IDEO *Evolution* stage (2012), and the *Production* stage within "design as a problem-solving process". The DT approach followed in the book of Avcı et al. (2023) is almost the same as the d.school's DT approach. The *Testing and Assessment* stage has the same purpose as other *Test* stages; only the name of the stage is different. Distinctively, after this stage, there is another stage called *Presentation and Dissemination*. In this stage, students develop strategies for marketing the product to introduce, deliver, and disseminate the product/prototype to students/users. If the design is deemed appropriate, the necessary applications are made for obtaining a patent/utility model acquisition and for national/international project competitions.

No books integrate AI tools into the DT approach; instead, they continue to use conventional methods at each stage of the DT process. While all books present almost identical methods for each stage, Aksoy et al.'s book, similar to IDEO's classification (IDEO methods, n.d.), categorizes diverse methods into four difficulty levels from the point of the implementation process. Books present shared methods, such as interview, observation, and empathy map (also available in the d.school toolkit), as well as different methods, such as the 5W1H Method, hot potato, and reverse thinking, for each DT stage. Furthermore, in the *Ideate* stage, all books offer different brainstorming methods that are not available in the d.school's DT approach. In the *Prototype* stage, most of the methods are available in the d.school toolkit, except for the "Prototyping with digital tools (software prototype)" method. While one book (Aksoy et al., 2020) presents the relational map, journey map, and 2x2 matrix as methods under the group of create frameworks, as in one of the IDEO toolkits (The Field Guide to Human-Centered Design, 2015), they are offered as stand-alone methods in the d.school toolkit. Some methods discovered at certain stages of the DT approach in the books are presented at different stages of the d.school's DT approach. For instance, methods offered in the *Empathize* stage, such as empathy map, journey map, and 2x2 matrix, are

presented in the *Define* stage of the d.school toolkit. Alternative methods are also available to be used in each stage of the d.school's DT approach.

Table 4. Comparison of each stage of the DT approach presented in books published by public institutions in Türkiye with each other and with Stanford d.school's DT approach

Note: The color red refers to the shared methods presented under each DT stage discovered in the books

	Deneyap Türkiye: Tasarım ve Üretim-Ortaokul (Kaygan et al., 2025a; 2025b)	Tasarım Odaklı Düşünme ile Proje Hazırlama: Öğretmen Rehber Kitabı (Avcı et al., 2023)	Eğitimde Inovasyon için Tasarım Odaklı Düşünme (Aksoy et al., 2020)	Stanford d.school's DT approach ("Design Thinking Bootleg" n.d.)
Stage	Empathize	Empathize	Empathize	Empathize
Purpose of the Stage	Investigate the needs/expectations of the target group and the context where the designed product is used.	Develop an insightful perspective on the problem by engaging with users and focusing on their needs/thoughts/emotions.	Investigate the needs/emotions/behaviors /expectations of the people affected by the problem.	Build empathy with users to discover their needs/desires.
Method Name	<ul style="list-style-type: none">•Interview•Observation	<ul style="list-style-type: none">• Interview• Observation• Empathy map• Role-playing• Mind-mapping	<ul style="list-style-type: none">• Interview / Asking open-ended questions• Observation / Live or video observation• Why-How Laddering• Create frameworks (Journey map, 2x2 matrix, Relational map)• Dig deeper• Community mapping	<ul style="list-style-type: none">• Interview for Empathy• Observation <p>Methods to be used in the "Define" stage</p> <ul style="list-style-type: none">• Empathy map• Why-How Laddering• Journey map• 2x2 matrix <p>Methods to be used in the "Ideate" stage</p> <ul style="list-style-type: none">• Role-playing <p>Alternative methods to be used in the "Empathy" stage</p> <ul style="list-style-type: none">• User Camera Study• What? How? Why?• Assume a beginner's mindset
Stage	Define	Define	Define	Define
Purpose of the Stage	Interpret results and identify insights from collected user information.	Gather, analyze, and synthesize data obtained from the beginning of the process to create a specific problem statement that can be acted upon.	Develop a point of view based on the user's needs/experiences to identify a problem statement.	Identify the problem/challenge by synthesizing the collected data.
Method Name	<ul style="list-style-type: none">• Empathy map• Role-playing	<ul style="list-style-type: none">• Point of view madlibs	<ul style="list-style-type: none">• Empathy map• 2x2 matrix• Point of view madlibs• POV analogy• "How might we" (HMW) questions	<ul style="list-style-type: none">• Empathy map• 2x2 matrix• Point of view madlibs• POV analogy <p>Methods to be used in the "Ideate" stage</p> <ul style="list-style-type: none">• Role-playing• "How might we" (HMW) questions <p>Alternative methods to be used in the "Define" stage</p> <ul style="list-style-type: none">• Saturate and group• Why-How Laddering• Journey map
Stage	Ideate	Ideate	Ideate	Ideate
Purpose of the Stage	Generate diverse, creative ideas for the defined problem statement.	Develop different/multiple ideas for users' real needs, based on the defined problem.	Develop multiple ideas for new/alternative solutions or improvements.	Generate multiple ideas for potential solutions to the identified design problem.
Method Name	<ul style="list-style-type: none">Brainstorming methods:• Speak within yourself• Hot potato• Reverse brainstorming• Reverse thinking	<ul style="list-style-type: none">Brainstorming methods:• Brainstorming with small papers (post-its)• Visual brainstorming• Mind-mapping• Idea filter (A method based on evaluating originality & feasibility)	<ul style="list-style-type: none">Brainstorming methods:• Brainstorming with small papers (post-its)• Visual brainstorming• Bodystorming• Get broad audience opinions	<ul style="list-style-type: none">• Level 1: Brainstorming with small papers• Level 2: Brainstorming by following rules• Level 3: Visual brainstorming, bodystorming• Level 4: Get <ul style="list-style-type: none">• Bodystorming <p>Alternative methods to be used in the "Ideate" stage</p> <ul style="list-style-type: none">• Brainstorming (individually or with a scribe)• "How might we" (HMW) questions• Role-playing

		to select the best idea) • 5W1H method • Storyboarding	using online surveys, forms, or forums	broad audience opinion using online surveys, forms, forums
Stage	Prototype (Low-fidelity prototype production & Test)	Prototype	Prototype	Prototype
Purpose of the Stage	Create low-fidelity prototypes to implement and test ideas quickly with other student groups/users.	Concrete ideas quickly and economically.	Turn the best idea into a prototype.	Turn ideas into physical forms through prototypes.
Method Name	<ul style="list-style-type: none"> • Model-making o Prototyping with physical model making • Peer review • User testing 	<ul style="list-style-type: none"> • Model-making o Prototyping with paper o Prototyping with physical model making • Prototyping with digital tools (software prototype) • Drawing 	<ul style="list-style-type: none"> • Model-making o Prototyping with paper o Prototyping with physical model making • Prototyping a case/experience • Prototyping with digital tools • Identify a variable • Drawing 	<ul style="list-style-type: none"> • Level 1: Prototyping with paper • Level 2: Prototyping with physical model making, Identify a variable • Level 3: Role-playing • Level 4: Prototyping a case/experience <ul style="list-style-type: none"> • Model-making o Prototyping with paper o Prototyping with physical model making • Prototyping a case/experience (Role-playing or bodystorming activity) • Identify a variable • Drawing <p>Methods to be used in the “Test” stage</p> <ul style="list-style-type: none"> • User testing
Stage	Test (Assessment and Manufacturing Planning)	Testing and Assessment	Test	Test
Purpose of the Stage	Evaluate the test results, choose an appropriate product proposal, and plan the manufacturing process.	Test prototypes/solution proposals with users, get their feedback, evaluate them, and improve the prototypes.	Test the prototypes with other students’ groups/users to get feedback and improve prototypes.	Reach a final design by iterative testing and receiving user feedback about the prototype.
Method Name		<ul style="list-style-type: none"> • User testing • Feedback capture grid • Empathy map (for second prototype) • Dig deeper 	<ul style="list-style-type: none"> • Live prototyping (User testing) • Peer review • Feedback capture grid • Make a presentation • Test scenario • Online polls or surveys 	<ul style="list-style-type: none"> • Level 1: Make a presentation • Level 2: Feedback capture grid • Level 3: Test scenario • Level 4: Live prototyping, Online polls or surveys <ul style="list-style-type: none"> • User testing • Feedback capture grid <p>Methods to be used in the “Define” stage</p> <ul style="list-style-type: none"> • Empathy map
Stage	Prototype (Low/High-fidelity prototype production & Presentation)	Presentation and Dissemination		
Purpose of the Stage	Create low/high-precision prototypes, and prepare posters/presentations for project presentations.	Develop strategies for marketing the product to introduce, deliver, and disseminate the product/prototype to users (logo design, creating media content for promotion, preparing presentations/websites/online exhibitions, etc.), and, if appropriate, make the necessary applications for patent/utility model acquisition & national/international project competitions.		

Discussion and Conclusion

Discussion

The purpose of this paper is to compare and evaluate the books on DT in education published by public institutions in Türkiye to gain an understanding of the DT approach and how it is applied. This study is considered significant because the information gleaned from comparing the books, as well as the following recommendations for implementing the DT approach, can assist teachers in implementing the DT approach in K-12 education, particularly in the *Technology and Design* course.

According to the literature, the DT-based learning process is given in three different ways: a learning process based on an existing DT process, a learning process based on a single DT stage, and a learning process with a DT approach customized for different teaching purposes (such as for developing students' 21st-century skills, etc.) (Lin et al., 2025). This finding in the literature is consistent with the finding that the application of the DT approach in the reviewed books is based on the Stanford d.school DT process, an existing DT process. The reviewed books also benefit from some stages of IDEO's DT approach (Kaygan et al., 2025a), HPI's mindsets, and IDEO methods in the problem-solving process (Aksoy et al., 2020).

According to the findings, DT is perceived as an interdisciplinary and human-centered problem-solving process that necessitates a set of skills and mindsets. Although described as a holistic approach in some books, all books focus on the physical problem-solving process in which students design, build, test, and receive feedback. The issue of how to develop a designer's mindset and skills in non-designers – teachers and students – is generally under-emphasized in the books. For this reason, the DT approach in education isn't comprehended and practiced as a holistic approach that requires the interaction between mindsets, processes, and tools.

The iterative nature of the DT approach allows for revisiting previous stages or even the first stage of the problem-solving process if deemed necessary, if the proposed solution proves ineffective, or if no solution is found. Although the findings indicate that the DT approach is perceived as an iterative process, its iterative nature is only emphasized in the *Prototype* and *Test* stages, where prototypes are revised based on feedback from users/students. Even though the core of this method is to think and act like a designer in the problem-solving process, this way of implementation appears to be a simplified version of "design thinking" that consists of stages (Li, & Zhan, 2022). This finding aligns with literature criticizing non-design educators' application of the DT approach as a linear process or their simplification of complex design processes (von Mengersen, 2023).

The OECD points out that social/emotional skills or moral/ethical values (such as a sense of belonging to school/environment, healthy social relationships, etc.) should be the focal point of the education curriculum along with academic achievement (OECD, 2018). Research has revealed that some OECD social/emotional skills coincide with DT mindsets, including optimism, empathy, collaboration, creativity, embracing ambiguity, and experimentation (Aksoy et al., 2020). It has been noticed that some of the strategies proposed for the implementation of prototyping or teamwork encompass values that are intended to be

developed in Turkish students (such as time management, trust, respect for the other party, etc. (Kaygan et al., 2025a). Accordingly, the essence of the DT approach and its implementation in activities naturally involves the implicit instruction of specific skills and values. Implicit teaching strategies integrated into activities using the DT approach can effectively develop social/emotional skills and values, compared to direct instruction. Consequently, the DT approach can be used to support the development of social/emotional skills and integrate societal values with 21st-century skills, as aimed by both the Turkish MONE and the OECD.

Except for three books (Kaygan et al., 2025b; Avcı et al., 2023; Tasarım Beceri Atölyeleri Öğretmen El Kitabı, n.d.), the target audience of other books is secondary school students and teachers/educators. The examination of the books reveals no substantial difference in the presentation and execution of the DT process based on students' educational levels. Although being released as two distinct volumes for high school and secondary school by Kaygan et al. (2025a, 2025b), the DT approach, narrative, and process are implemented nearly similarly in both books within the same project framework. Literature underscores the need to differentiate design education in secondary and high school (Choi, & Hyun, 2025). Accordingly, the presentation and implementation of the DT approach can be differentiated by taking into account the grade levels of the students.

Strategies for Integrating the Design Thinking (DT) Approach into Technology and Design Education

In the *Technology and Design* textbook in Türkiye, the course aims to teach and raise awareness of processes and concepts related to different technology and design disciplines, and collaboration with other disciplines is recommended. In the book, technology is used as a tool and to facilitate the problem-solving process within the units. The DT approach is not included in a single topic or unit. It is additionally posited that attaining these objectives may be unfeasible with a practical course offered for two hours weekly only in the 7th and 8th grades at the K-12 level, taught by teachers from various disciplines in schools with limited resources.

In the books investigated, there is the use of technology at any stage of the problem-solving process within interdisciplinary activities, or as a tool in this process, or in teaching technological content/skill related to problem solving within the DT process. Although the purpose of the books doesn't explicitly state that the DT approach is used for technology teaching/integration, the activities in the books demonstrate that the DT approach can be used for this purpose. The literature supports this suggestion that the DT approach is stated to be employed as a tool to establish a context for the use of technological tools for teaching a subject (González & Mella, 2021).

In the 2033 Türkiye Education Policies Strategy Document, it is stated that some of the 21st-century skills are lacking in teachers and students in secondary school education in Türkiye (Akgündüz, & Yület Yılmaz, 2023). According to Dikpınar (2024), Türkiye's exam-focused educational system cannot give students 21st-century skills. In Türkiye, there is an absence of undergraduate programs specifically designed to train *Technology and Design* teachers,

resulting in instructors from diverse academic backgrounds teaching this subject. Similarly, Technasium (secondary school) in the Netherlands includes Research and Design course whose teachers have graduated from diverse disciplines and do not have prior knowledge about design (De Haan-Topolscak, Ebskamp, & Vos-de Tombe, 2024). Dikpinar (2024) recommends teaching *Technology and Design* teachers the DT approach to both enhance students' and teachers' 21st-century skills and facilitate design-based activities. Therefore, in countries without access to teacher education in the fields of technology and design or related ones, teachers can receive training in the DT approach to help them learn about design-related concepts and easily incorporate such interdisciplinary courses.

Technology is a multidisciplinary subject that merges scientific knowledge from different disciplines with creativity. Technology also means designing and producing, and using manual skills (Hanson, & Lucas, 2020). Design in technology education is perceived as a process used to identify problems (with empathy), design creative solutions, and gather information from interdisciplinary sources (ibid). Addressing the complex, multifaceted challenges of the 21st-century, such as the climate crisis, and rapid technological advancements, requires multidisciplinary, collaborative research. In this context, collaboration among teachers from diverse disciplines in the *Technology and Design* course is crucial for offering students an interdisciplinary viewpoint in the problem-solving process. At that point, the DT approach in *Technology and Design* education can help establish interdisciplinary connections and address problems from a holistic perspective (Dikpinar, 2024).

Considering the findings and the literature review, some recommendation is made to be employed in *Technology and Design* education implemented not just in Türkiye, but also in similar countries where there are exam-focused education systems and/or no subject-specific teachers.

Technology and Design courses may be delivered in a hybrid format, provided that students and schools have reliable internet access.

The use of non-location-based teaching methods that include digital technologies, such as blended or hybrid learning (online and face-to-face instruction together) or flipped learning (using pre-recorded audio, video, or reading digital teaching materials to prepare students for class with the teacher), in technology education can allow students to access information at their own learning pace (Winn, 2023). Given problems in technology integration in schools and the skills students are expected to acquire within a two-hour weekly *Technology and Design* course, this course may be implemented in a hybrid way at schools. The theoretical part of the course can be delivered online, supported by pre-recorded informative videos, while the practical part can be delivered in a two-hour course, more effectively through in-class practices. With the DT approach integrated into the course content, an interdisciplinary course that reinforces and teaches technology and design processes through practice and thus helps the development of certain content and skills, accessible to everyone, can be delivered. This way of approach can also facilitate the contribution of instructors/experts from different disciplines to the course in an online environment.

Modifications can be introduced to the stages of the design thinking (DT) approach applied in the Technology and Design course.

According to the literature, there is no single design process; rather, design processes may be specific to different fields or problems. For this reason, teachers may need to adapt the DT model or tools applied according to the problem to be solved, the grade level of the students, or different teaching objectives (Lin et al., 2025; Li, & Zhan, 2022).

The rise of data science has transformed design research and practice through the use of large language models like ChatGPT and rendering generators like Midjourney in the context of research, data collection/analysis, design prototyping, and development. Accordingly, this course, provided in a hybrid learning environment, can be planned to utilize AI technologies and tools, which both the Turkish MONE and UNESCO encourage for use in education (Sevil, 2025; Miao, & Holmes, 2023). The AI-assisted DT approach can accelerate the problem-solving processes in conducting user research, data collection, analysis, idea generation, visualization and testing, and facilitate the delivery of this course in both online and hybrid formats. This approach can also help students adapt to the changing working and design processes associated with AI technology, starting in secondary school.

Within the scope of findings and literature review, some differentiations in the stages of the DT approach can be made for the *Technology and Design* course. At first, theoretical or hands-on training can be given to students about tools used in the problem-solving process (such as AI tools, prototyping tools, or methods) before starting to apply the DT process. Then, the DT process can be taught and reinforced through practice within the problem-solving process. Secondly, the methods applied at each DT stage can be modified by taking into account the difficulty level of the methods, the experience of students and teachers using the DT approach, and the educational objectives. Thirdly, a stand-alone activity that concentrates on one stage or one tool can be implemented due to the benefits it provides to students and the convenience it provides in time management and application. Lastly, the DT approach integrated in this course can include the following stages: Empathize, Define, Ideate, Prototype, Test, Evolution, Presentation and Dissemination.

Empathize and Define Stages.

In these stages, two different approaches can be included in the problem-solving process: creating a new need in addition to finding a need and iterating the data collection and processing.

In recent years of rapid technological change, new products, technologies, and services are being invented to address needs people hadn't previously considered, or even knew, or realized they needed. Instead of designing products and services based on identified needs, as in the past, new products and services are being designed to create new needs or to address hidden needs. For example, 20 years ago, no one would have imagined that everyone would need a smartphone small enough to carry in their pocket, capable of communicating anywhere, with a camera, internet access, or e-mail (Barak, 2020).

Accordingly, in the DT process to be taught in design and technology courses, an *Empathize* stage can be designed that addresses the issue of how to create new needs as well as the

need identification using the DT approach. This approach allows students to explore the ways to imagine/invent new digital products by creating new needs/uses.

Every user interaction with the product/system is a source of data that will enhance AI's learning, leading to more personalized and efficient design solutions. Therefore, the data-driven design process involves a cyclical, ongoing process of collecting data, analyzing it, making design decisions, and collecting more data after each new interaction (Cain, & Pino, 2023). At that point, generating a new product in the context of machine learning and artificial intelligence needs iterative data collection/capturing and interpreting/analyzing the data. Along with the iterative prototyping and testing stages, a continuous iteration in the *Empathize* and *Define* stages of the DT approach can be employed to prepare students for a data-driven future.

Ideate Stage.

At this stage, in addition to applying traditional brainstorming methods by pairing with other students, students can also apply brainstorming methods and produce multiple ideas together by working in partnership with AI to generate ideas. Furthermore, within the scope of this stage, the meaning of the word "product" should be explained to students to make them understand the types of products and their variations in different disciplines (such as tangible, digital, interior, exterior, building, software, system, or service products). In that way, they can see their options while developing ideas in the problem-solving process.

Prototype Stage.

This stage includes the production of low-fidelity prototypes and testing the concepts with students before user testing. In this stage, along with the d.school prototyping methods, prototyping with digital tools (software prototype) can be included as an option to develop digital/mobile/web products or systems. With the help of AI tools, students can easily build software designs even without having coding experience. Software/digital prototyping can also facilitate technology integration in education under three categories: for example, creating software with Raspberry Pi (technology as a tool) to solve a traffic signaling problem (technology to facilitate the problem-solving process) and developing algorithmic thinking skills (technology to teach technological contents or skills) (Avcı et al., 2023).

Test and Evolution Stages.

In the *Test* stage, the results of the tests conducted with students are evaluated, and low-fidelity or, if possible, high-fidelity prototypes of the selected concepts are produced and iteratively tested with real users. The *Evolution* stage includes evaluating the test results, improving them if necessary, and then planning the production process for the selected design. For this purpose, specialists from diverse disciplines, including engineering, manufacturing, or marketing, can be invited to the class to get feedback from them and to learn the real manufacturing planning process.

Presentation and Dissemination Stage.

In this stage, students are encouraged to prepare presentations, logos, media content, or websites for introducing and marketing their products to users/students and for applying for

patent/utility model acquisition and for participating in national/international project competitions. This way of approach can increase students' motivation in the problem-solving process.

Certain stages and tools of the Design Thinking (DT) approach can be emphasized in this course, as they offer pedagogical benefits for students and support effective time management and implementation.

In a data-driven design approach, certain mindsets and strategies are crucial for designers to interact with and manage data. Accordingly, the designer has a facilitating and integrating role between technology, design, and other disciplines; therefore, *collaboration with human and non-human (datasets, AI tools) stakeholders* is essential. Due to the constant changes and evolution of data, it's also crucial to embrace the complexities and uncertainties inherent in the design process. Therefore, *navigating uncertainty* (also called embracing ambiguity (Hanson, & Lucas, 2020)) remains a crucial mindset for designers (Cain, & Pino, 2023).

The literature also points to the importance of certain mindsets considered important in technology education and development, which also exist within DT mindsets: these are, critiquing (includes getting feedback and taking risks in the problem-solving process), imagining (includes creativity, embracing ambiguity, and reflective thinking in the problem-solving process), making (consists of the design process from sketching to prototyping, and learning from failure), and human-centered designing (empathizing with people to understand them and collaborating with diverse disciplines) (Hanson, & Lucas, 2020).

Given the findings, some recommendations are made for implementing the DT as a holistic approach in education. Instead of implementing 5 or 6 stages of the DT approach, teachers can design a stand-alone activity that concentrates on one stage (*Empathize* or *Test* stages) or one tool (implementing a *brainstorming* activity). Teachers can make incremental progress toward gaining students' acceptance of the DT process and mindsets (Zielezinski, 2017).

The literature suggests that individual DT stages can be flexibly integrated into any part of a course to emphasize DT's non-linear, flexible process (Lin et al., 2025). The DT skills that need to be developed most in both teachers and students emerge in the *Empathize*, *Prototype*, and *Test* stages (Watkins et al., 2020; Zielezinski, 2017). Empathy-focused DT instruction is considered to foster understanding of user needs and finding human-centered solutions (Lin et al., 2025). These activities can also help students engage in iterative prototyping and user testing and develop empathy, experimentation, and collaboration skills (Goldman et al., 2017; Zielezinski, 2017).

Encouraging students to reflect on each implemented DT stage and method can improve long-term retention of students' learning. Teachers' specific feedback and reflection at various points throughout the learning process can also lead students to self-assess their approach to problem-solving and experiment with different approaches to completing their tasks. Activities centered on the iterative prototyping process can be carried out for this

purpose. DT training, focusing on prototyping activities, can be easily integrated into existing learning processes, enables concrete creative ideas, and teaches students to receive and evaluate feedback, as well as to learn from failures through iterative practices in prototyping and testing processes (Lin et al., 2025). This way of approach also encourages students to adopt experimental, risk-taking, and collaborative mindsets (Watkins et al., 2020; Zielezinski, 2017). Practicing a design-based activity can help students tolerate challenging problem-solving processes and adopt a mentality of embracing ambiguity (Watkins et al., 2020).

Conclusion

While many studies examine DT in general education settings, this article's analysis of government-published materials offers insight into how a national education system approaches and disseminates modern pedagogical concepts. This article also makes a significant contribution by providing concrete suggestions for directly applying DT to *Technology and Design* education.

To improve the incorporation of DT into *Technology and Design* education, several strategies can be employed, considering the educational level of students. First, *Technology and Design* courses can be offered in a hybrid format, provided schools and students have dependable internet access. This approach offers greater flexibility in learning environments and enables the effective use of both physical and digital resources. Second, modifications can be made to the stages of the DT approach implemented in the course. These adaptations will better align the structure of the DT process with course objectives, learning outcomes, and classroom conditions. Finally, specific stages and tools of the DT approach can be highlighted in this course because they provide pedagogical benefits for students and support effective time management and implementation.

Analyzing DT books has the potential to inform educational practice and curriculum development. In future research, researchers can undertake systematic comparisons of basic DT books to find shared themes, methodological discrepancies, and theoretical evolution. Future reviews can also incorporate an examination of both books and research articles to provide a more comprehensive understanding of the evolution of DT.

References

- Akgun, O. (2013). Technology in STEM project-based learning. In: R. M. Capraro, M. M. Capraro, & James R. Morgan (Eds.), *STEM project-based learning: An integrated science, technology, engineering, and mathematics (STEM) Approach* (2nd ed., pp. 65-75). Rotterdam, Netherlands: Sense Publishers.
- Akgündüz, D., Kurt, A. A., & Seferoğlu S. S. (2023). 2023-2033 eğitim teknolojileri. In: D. Akgündüz (Ed.), *2033 Türkiye eğitim politikaları strateji belgesi* (pp. 482-504). İstanbul: İstanbul Aydın Üniversitesi
- Akgündüz, D., & Yulet Yılmaz, T. (2023). 2023-2033 Ortaokul Eğitimi. In: D. Akgündüz (Ed.), *2033 Türkiye eğitim politikaları strateji belgesi* (pp. 213-244). İstanbul: İstanbul Aydın Üniversitesi
- Aksoy, B. D., Balçık, E., Uykun, E., Erdemli, E., Yıldırım, F. A., Kaya, F., Biçer, G., Gökdağ, K., Demir, K., Kızanlık, M., Öztürk, M., Eynel, Ö., & Sarıkoç, Z. (2020). *Eğitimde inovasyon*

- için tasarım odaklı düşünme*. Ankara: Türkiye Ministry of National Education, General Directorate of Teacher Training and Development.
- Aspelund, K. (2017). *The Design Process*. 3rd Edition. USA: Bloomsbury Publishing.
- Bowen, G. A. (2009). Document analysis as a qualitative research method. *Qualitative Research Journal*, 9(2), 27-40.
- Barak, M. (2020). Teaching problem-solving in the digital era. In: P. J. Williams, & D. Barlex (Eds.), *Pedagogy for technology education in secondary schools: Research informed perspectives for classroom teachers* (pp. 245-266). Switzerland: Springer Nature.
- Bruce, B. C., & Levin, J. A. (1997). Educational technology: Media for inquiry, communication, construction, and expression. *Journal of Educational Computing Research*, 17(1), 79-102.
- Cain, J. & Pino, Z., 2023. Navigating design, data, and decision in an age of uncertainty. *she ji: The Journal of Design, Economics, and Innovation*, 9(2), 197-212.
- Choi, S., & Hyun, E. (2025). What drives design education in Korean classrooms? The history of South Korea's national curriculum and some proposals for design education in its current iteration. *International Journal of Art & Design Education (iJADE)*, 44(1), 177-190.
- Corbin, J., & Strauss, A. (2008). *Basics of qualitative research: Techniques and procedures for developing grounded theory*. Thousand Oaks, CA: Sage Publications, Inc.
- De Haan-Topolscak, J., Ebskamp, M., & Vos-de Tombe, P. (2024). Research and design teachers', and students' frame of reference around the concept of 'model'. *Design and Technology Education: An International Journal*, 29(2), 173-187.
- Deneyap (n.d.). Retrieved January 15, 2021, from <https://www.deneyapturkiye.org/>
- "Design Thinking Bootleg" (n.d.). Stanford University d.school. Retrieved August 18, 2017, from <https://dschool.stanford.edu/resources/the-bootcamp-bootleg>
- Diefenthaler, A., Moorhead, L., Speicher, S., Bear, C., & Cerminaro, D. (2017). *Thinking & acting like a designer: How design thinking supports innovation in K-12 education*. WISE and IDEO.
- Dikpinar, B. (2024). *Endüstriyel tasarım meslek disiplini kapsamında ilköğretim teknoloji ve tasarım dersine yönelik öğretim programı önerisi* (Master's thesis), Türkiye: Marmara University, Institute of Fine Arts
- Doğan, B., & Robin, B. (2015). Technology's role in STEM education and the STEM SOS model. In: Sahin, A. (Ed.), *A practice-based model of STEM teaching* (pp. 77-94). Rotterdam, Netherland: Sense Publisher.
- Ellis, J., Wieselmann, J., Sivaraj, R., Roehrig, G., Dare, E., & Ring-Whalen, E. (2020). Toward a productive definition of technology in science and STEM education. *Contemporary Issues in Technology and Teacher Education*, 20(3), 472-496
- Fields in Teacher Appointments, (n.d.). Retrieved August 20, 2025, from <https://pbs.meb.gov.tr/kaynak-okul/Giris/Index>
- Gerken, S., Uebernickel, F., & de Paula, D. (2022). *Design thinking: A global study on implementation practices in organizations. Past - Present - Future*. Potsdam: Universitätsverlag Potsdam.
- Goldman, S., Zielezinski, M. B., Veal, T., Bachas-Daunert, S., & Kabayadondo, Z. (2017). Capturing middle school students' understandings of design thinking. In: S. Goldman, &

- Z. Kabayadondo (Eds.), *Taking design thinking to school: How the technology of design can transform teachers, learners, and classrooms* (pp. 76-93). New York: Routledge.
- González, E. J., & Mella, J. M. (2021). Technological tools in teaching the EU: A design thinking proposal. In: A. Visvizi, M. Field, & M. Pachocka (Eds.), *Teaching the EU: Fostering knowledge and understanding in the Brexit age (Emerald Studies in Higher Education, Innovation and Technology)* (pp. 85-101). Emerald Publishing Limited.
- Guha, M. L., McNally, B., & Fails, J. A. (2017). Design partners in schools: encouraging design thinking through cooperative inquiry. In: S. Goldman, & Z. Kabayadondo (Eds.), *Taking design thinking to school: How the technology of design can transform teachers, learners, and classrooms* (pp. 53-66). New York: Routledge.
- Hanson, J., & Lucas, B. (2020). The case for technology habits of mind. In: P. J. Williams, & D. Barlex (Eds.), *Pedagogy for technology education in secondary schools: Research informed perspectives for classroom teachers* (pp. 45-64). Switzerland: Springer Nature.
- Hoonard, W. (2008). Inter- and intracoder reliability. In: L. M. Given (Ed.), *The SAGE encyclopedia of qualitative research methods* (Vol. 1, pp. 445-446). SAGE Publications, Inc.
- HPI. (n.d.). Retrieved May 18, 2020, from <https://hpiacademy.de/en/design-thinking/what-is-design-thinking.html>
- IDEO (Design Thinking for Educators Toolkit) (2012). IDEO + Riverdale Country School. Retrieved September 06, 2016, from <http://www.designthinkingforeducators.com/toolkit/>
- IDEO methods (n.d.). Available at: <https://www.designkit.org/methods>
- Karataş, S., Kılıç Çakmak, E., & Üstündağ, M. T. (2021). *Different approaches in STEM trainers' training*. Ankara: Türkiye Ministry of National Education, General Directorate of Teacher Training and Development. Retrieved January 20, 2025, from <https://cdn.eba.gov.tr/kitap/steam/EN/mobile/index.html>
- Kaygan, P., SÜNER Pla-Cerda, S., Akkuş Çakır, N., Karadoğaner, A., Eren, G. H., Kapkın, E., & Yılmaz, T. (2025a). *Deneyap Türkiye: Tasarım ve Üretim-Ortaokul*. Ankara: TÜBİTAK Yayınları. Retrieved February 20, 2025, from https://yayinlar.tubitak.gov.tr/themes/classic/assets/img/dummies/pdf/1_Tasar%C4%B1m_ve_Tasar%C4%B1m_ve_uretim_Ortaokul_17_1_2025.pdf
- Kaygan, P., SÜNER Pla-Cerda, S., Akkuş Çakır, N., Karadoğaner, A., Eren, G. H., Kapkın, E., & Yılmaz, T. (2025b). *Deneyap Türkiye: Tasarım ve Üretim-Lise*. Ankara: TÜBİTAK Yayınları. Retrieved February 20, 2025, from https://yayinlar.tubitak.gov.tr/themes/classic/assets/img/dummies/pdf/2_Tasar%C4%B1m_ve_Tasar%C4%B1m_ve_Uretim_Lise_13_01_2025.pdf
- Kaygan, P., SÜNER Pla-Cerda, S., Akkuş Çakır, N., Karadoğaner, A., Eren, G. H., Kapkın, E., & Yılmaz, T. (2021). *Deneyap Türkiye: Tasarım ve Üretim-Ortaokul*. Ankara: TÜBİTAK Yayınları.
- Kimbell, L. (2011). Rethinking design thinking: Part I. *Design and Culture*, 3(3), 285-306.
- Kimchi, J., Polivka, B., & Stevenson, J. S. (1991). Triangulation: Operational definitions. *Nursing Research*, 40(6), 364-366.
- Li, T., & Zhan, Z. (2022). A systematic review on design thinking integrated learning in K-12 education. *Applied Sciences*, 12, 8077.

- Lin, L., Shen, S., Shadiev, R., & Yu, M. (2025). Review of research on design thinking in K-12 education. *Educational Research Review*, 47.
- Miao, F., & Holmes, W. (2023). *Guidance for generative AI in education and research*. United Nations Educational, Scientific and Cultural Organization. <https://unesdoc.unesco.org/ark:/48223/pf0000386693>.
- OECD (Organisation for Economic Cooperation and Development). (2018). *Social and emotional skills for student success and well-being: Conceptual framework for the OECD study on social and emotional skills*. Retrieved November 12, 2022, from https://www.oecd.org/en/publications/social-and-emotional-skills-for-student-success-and-well-being_db1d8e59-en.html
- Öztürk, A. (2022). What Does Design Thinking Mean in Turkey? Analysis of DT-related Books Published by Public Institutions. *EDUCONGRESS 2022 (International Education Congress) Conference Abstract Book* (pp. 424-426), 17-19 November 2022, Antalya, Türkiye: Akdeniz University. ISBN: 978-605-72845-0-1.
- Öztürk, A., & Korkut, F. (2022). Design Thinking Customized to Support STEM Teachers: Co-Developing and Implementing STEM Activities for Fifth Graders in Turkey. *International Journal of Technology and Design Education, Advance Online Publication*. <https://doi.org/10.1007/s10798-022-09790-x>
- Peng, F. (2022). Design thinking: From empathy to evaluation. In: D. Herath, & D. St-Onge (Eds.), *Foundations of robotics: A multidisciplinary approach with Python and ROS* (pp. 63-81). Springer.
- Weekly Course Schedule (n.d.). Retrieved August 20, 2025, from <https://ttkb.meb.gov.tr/www/haftalik-ders-cizelgeleri/kategori/7>
- Sameti, A., Koslow, S., & Mashhady, A. (2022). Are product design researchers and practitioners on the same page? The way professional product designers view creative design. *Journal of Product & Brand Management*, 31(6), 951-970.
- Sarıkoç, Z., Baydar, S., Sarıça, S., Ekici, T., Kurnaz, K. T., & Torun, I. G. (2021). STEM projeleri ve tasarım odaklı düşünme. In: İ. Saralar-Aras (Ed.), *Okul öncesinden ortaöğretime farklı disiplinlerde STEM eğitimi uygulamaları* (pp. 355-370). Ankara: Türkiye Ministry of National Education, General Directorate of Teacher Training and Development.
- Sevil, Ş. (2025). *Yapay Zekâ ve Eğitim: Öğretmenler için Uygulamalı Prompt Mühendisliği ve Üretken Araçlarla Yenilikçi Öğrenme Stratejileri*. Ankara: Türkiye Ministry of National Education, Innovation and Educational Technologies General Directorate. Retrieved August 11, 2025, from chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://yegitek.meb.gov.tr/meb_iys_dosyalar/2025_07/08125530_yz_ve_egitim_promt_rhbri_guncell.pdf
- Tasarım Beceri Atölyeleri Öğretmen El Kitabı (n.d.). Ankara: Türkiye Ministry of National Education, General Directorate of Secondary Education.
- The Field Guide to Human-Centered Design. (2015). Retrieved November 01, 2019, from <https://www.designkit.org/resources/1/>
- The P21 Framework for 21st Century Learning (2009). Retrieved October 01, 2025 from chrome extension://efaidnbmnnnibpcajpcglclefindmkaj/<https://files.eric.ed.gov/fulltext/ED519462.pdf>
- Turan, A., Soysal, M. T., Dümbüllü, T., & Çelikkol, Ö. (2021). Teknoloji, tasarım odaklı düşünme, mühendislik tasarım süreci ve STEM projeleri. In: İ. Saralar-Aras (Ed.), *Okul*

- öncesinden ortaöğretime farklı disiplinlerde STEM eğitimi uygulamaları (pp. 99-130). Ankara: Türkiye Ministry of National Education, General Directorate of Teacher Training and Development.
- Turkish Technology and Design Education Curriculum (2018). Retrieved May 06, 2018, from <http://mufredat.meb.gov.tr/ProgramDetay.aspx?PID=380>
- Türel, Y. K., Şimşek, A., Vautier Şengül, C. G., Şimşek, E., & Kızıltepe, F. (2023). *21. yüzyıl becerileri ve değerlere yönelik araştırma raporu*. Ankara: Türkiye Ministry of National Education, Board of Education.
- Türkiye's Education Vision 2023 report. (n.d.). Ankara: Türkiye Ministry of National Education. Retrieved February 2, 2020, from http://2023vizyonu.meb.gov.tr/doc/2023_VIZYON_ENG.pdf
- Ulrich, K., Eppinger, S., & Yang, M.C. (2019). *Product Design and Development*. 7th Edition. McGraw Hill.
- von Mengersen, B. (2023). Thinking: Nurturing independent design thinking and decision-making. In: D. Gill, D. Irving-Bell, M. McLain, & D. Wooff (Eds.), *The Bloomsbury handbook of technology education* (1st ed, pp. 101-121). Bloomsbury Academic.
- Watkins, C., Treviranus, J., & Roberts, V. (2020). *Inclusive Design for Learning: Creating Flexible and Adaptable Content with Learners*. Manual.
- Winn, D. (2023). Digital learning: The role of digital technologies in technology education. In: D. Gill, D. Irving-Bell, M. McLain, & D. Wooff (Eds.), *The Bloomsbury handbook of technology education* (1st ed., pp. 288-303). Bloomsbury Academic.
- Zielezinski, M. B. (2017). Finding your fit: Empathy, authenticity, and ambiguity in the design thinking classroom. In: S. Goldman, & Z. Kabayadondo (Eds.), *Taking design thinking to school: How the technology of design can transform teachers, learners, and classrooms* (pp. 195-203). New York: Routledge.

Recurriculation of Engineering, Technology, and Technical Education Programmes for the adoption of Industry 5.0

Sunkanmi Afeez Yekinni, University of Nigeria, Nsukka, Nigeria

Theresa Chinyere Ogbuanya, University of Free State, South Africa

Abdifatah Ahmed Ali Afyare, Salaam University, Somalia

Abstract

Industry 5.0 is a new emergent industrial revolution that admits and promotes mutual and coordinated interaction of industrial workers' cognitive and creative skills, and artificial intelligence machines' qualities to maximize production in industries. Thus, the advent of Industry 5.0 demands new skills, knowledge, attitude and responsibilities/roles from workers to enable them to fit the positions. Consequently, Industry 5.0 has significant implications for engineering, technology and technical education programs. These programs need to be reshaped for the purpose of producing worthwhile graduates that can easily be absorbed into Industry 5.0. However, this article focuses on the 'recurriculation' of engineering, technology and technical education programs for adopting Industry 5.0. The article is anchored on a literature review. Specifically, the article dwells briefly on the pre-industrial revolution, Industry 1.0, Industry 2.0 and Industry 3.0. The article explicates on Industry 4.0 and Industry 5.0. Similarly, the article identifies problems that emanated during the Industry 4.0 era. It explains the importance of human beings in industries. Also, this article explains the needs for improving the knowledge, skills and attitude of industrial workers during Industry 5.0. Being a program where knowledge, skills and attitude needed in industry 5.0 can be acquired, the article briefly conceptualizes engineering, technology and technical education. Furthermore, the article explains the concept of recurriculation of engineering, technology and technical education programs. Finally, the chapter explains the phases for the recurriculation of engineering, technology and technical education programs.

Keywords

Industry 5.0, Engineering Education, Technology Education, Technical Education, Recurriculation

Introduction

Technology and its development is as old as human beings. Kozí (2015) agreed that human beings were, are and will be the main initiators of any technological innovations and changes that increasingly enter the professional and private lives of adults as well as children. Thus, the source of technological change and its development is responsible for the fulfilment of the needs and wants of individuals and society at large (Graube & Theuerkauf, 2005). This is because human beings, in the process of satisfying basic and essential needs and wants, continue to think and engage in problem-solving activities, hence discovering new technologies which serve as means for the attainment and satisfaction of the needs and wants. The eagerness and zeal to increase human and societal satisfaction of wants and needs that upholds

evidence of popular economics theory, “human wants are insatiable” (Bianchi, 2002; Lebergott, 1993; Witt, 2001) has transformed into the continuous development and improvement of technology globally which, by an extension, led to the continuous emergence of industrial revolutions ranging from pre-industrial revolution through Industry 1.0, Industry 2.0, Industry 3.0 and Industry 4.0. Currently, Industry 5.0 is progressing.

By implication, technological and industrial changes will have influence on education. This is because educational institutions such as schools, colleges of technology, polytechnics, and universities train and produce prospective industrial workers (engineers, technologists and technicians) for effective and efficient application of technology for individual, industrial and societal benefit. Every change in the industry will make educational processes and content change. Similarly, changes in industries will call for constant review and renewal of the document guiding the educational curriculum (Yekinni & Ogbuanya, 2025) to keep up with the industrial revolution and changes in society.

Thus, this article examines the trend of industrial revolutions from pre-industrialization through Industry 1.0 to Industry 4.0. It establishes the concept of Industry 5.0 and Industry 5.0 technology and investigates the skills required by workers to adapt with Industry 5.0. The article establishes the concept of engineering education, technology education and technical education and the concept of recurriculation. Finally, the article investigates phases of recurriculation of engineering, technology and technical education programs toward Industry 5.0. Methodologically, this article is anchored on a literature review: existing scholastic empirical reports, theories and opinions.

Industrial Revolutionary Trends

Before the year 1750 which marks the pre-industrial revolutionary period in Europe, people of that age were characterized by their use of hand tools, simple implements and animals to practice subsistence farming and to process and produce essential items, primarily agricultural products, for their proliferation purposes. The period was overshadowed by a poor standard of living and poor economic growth (Durlauf & Blume, 2010; Kent & Kopacek, 2019). Nahavandi, (2019), Odo et al. (2017) and Durlauf and Blume (2010) submitted that between the 1750-1780s, the first Industrial Revolution (Industry 1.0) started in England with the discovery of mechanical power from water, steam, and fossil fuels. The revolution was characterized by different innovations and discoveries viz; coke blast furnaces in 1710 by Abraham Darby, atmospheric engines in 1712 by Thomas Newcomen, steam engines in 1776 by James Watts, flying shuttle in 1773 by John Kay, spinning jenny in 1770 by Hargreaves and water frame in 1771 by Richard Arkwright (Macon-Cooney, 2019). This revolution favored high productivity growth and by extension an increase of GDP per capita, as well as the real wages of people of that period (Macon-Cooney, 2019). Similarly, the revolution led to the liberation of humans from dependence on animal power, and a move from agrarian to industrial and rural to urban societies (Özdemir & Heim, 2018). Second revolutionary changes (Industry 2.0), which began in 1870s, featured the discovery of electricity. Electrical energy coupled with electrically driven machines favoured manufacturers with assembly lines and mass production (Kent & Kopacek, 2019; Nahavandi, 2019). The third Industrial Revolution (Industry 3.0) emanated during the second half of the 20th Century, specifically in the 1970s. The revolution was characterized by computerization and automation in the manufacturing field, hence, giving rise to the application of personal computers, the Internet and ICTs in industries (Ikenga & van der Sijde,

2024; Özdemir & Heim, 2018). During this revolutionary period, automation allowed humans to assign the large number of tasks to machines, leaving supervising and monitoring functions to human beings (Graube & Theuerkauf, 2005). Further advancement and development in information and communication led to the advent of Industry 4.0.

Industry 4.0

Industry 4.0 - The fourth industrial revolution - was an initiative from the German Government in 2011 (Demira et al., 2019, Oeij, et al., 2024). Industry 4.0 includes smart and innovative manufacturing systems where manufacturing is done through the integration of the internet of things (IoT), cyber-physical systems, smart/intelligent machines, artificial intelligence and cloud and cognitive computing (Haleem & Javaid, 2018; Ozdemir & Hekim, 2018; Lu & Xu, 2019). According to Jardine (2020) and Rossi (2018), the objective of Industry 4.0 includes bring together robots, interconnected devices, machines, processes and systems, and fast networks of data within the factory environment, basically to make the factory more productive and execute the routine tasks that can be best done by robots more efficiently and effectively than by humans. The fourth industrial revolution is characterized by the high level of automation, use of cloud technology, big data, more precision as well as miniaturization of products (Cojocariu, 2019; Lewis, 2016; Patches et al., 2019; Ustundag & Cervical, 2018). Industry 4.0 was technologically deterministic (Oeij, et al., 2024). Industry 4.0 dedicated most industrial activities, tasks and operations to the robots (machines), causing larger percentages of industrial workers to become redundant, but created new jobs that required new and emerging knowledge and skills. Correspondingly, Cojocariu (2019) and Vanderborcht (2018) claimed that the advent of Industry 4.0 came along with some drawbacks: the complexity of system, expensive software, industrial workers being replaced by machines, security leaks, the need for highly skilled people to operate intricate processes, loss of innovation and creativities and loss of jobs and unsustainable jobs. Also, Acemoglu and Restrepo, (2017), Ford (2015), Kent and Kopacek (2019), Frey and Osbourne (2013) and World Bank (2016) predicted that approximately 47% and 57 % of US jobs and jobs in the OECD countries respectively, will be vulnerable to automation which will in turn have a knock-on effect of reducing customer spending and could result in a secondary wave of job losses affecting all occupations. Correspondingly, evidence upheld that automation technologies replaced workers in both low- and high-skill jobs causing many workers to lose their jobs (Bazylik & Gibbs, 2022; Filippi et al., 2023; Spencer, 2018; Wajcman, 2017). Meanwhile, the situation is unsatisfactory, indicated by reactions in a number of articles dedicated to Industry 4.0 globally (Skobelev & Borovik, 2017).

Humans and Robots

Since the year 2000, computers and machines have been increasingly replacing workers instead of making them more valuable and useful in the developing and developed world (Ken & Kopacek, 2019). The proliferation of robotic automation is inevitable (European Economic Social Committee, EESC, 2018), but Tesla CEO, Elon Musk, admitted that excessive automation in most industries is a mistake, claiming that humans are underrated in industries (Domonoske, 2019; Jardine, 2020). Similarly, Jardine (2020) stated that though robots are much more consistent than humans and better at precision work, robots are inflexible and incapable of adapting to and engaging in critical thinking that is naturally endowed in humans. Thus, by working together with people in industries, robots can fulfill their designated purpose of providing assistance and making lives better (Jardine, 2020). Also, bringing back human workers to the factory floors will pair humans and machines to utilize human brainpower and creativity

to increase process and production efficiency by combining workflows with intelligent systems (Ken & Kopacek, 2019; Nahavandi, 2019). Manufacturers who understand the value of human intuition and problem-solving capabilities are positioning themselves to thrive (Anang et al., 2024; Jardine, 2020). Correspondingly, Phill Cartwright, executive chairman of the “Centre for Modelling & Simulation”, commented that pairing humans and machines in the manufacturing sector leads to the creation of higher-value jobs than ever before because freedom of design and the associated responsibility is handed back to engineers, technologists and technicians (Kent & Kopacek, 2019). Thus, advocating for the reintroduction of human workers (human intelligence) alongside machines (robots) and collaborative robots (Faccio et al., 2023; Huang et al., 2022; Nahavandi, 2019; Pluchino et al., 2023; Rossato et al., 2021) bring about Industry 5.0.

Industry 5.0

Industry 5.0 is a transformative shift in manufacturing processes that emerged in response to accusations that Industry 4.0 was technologically deterministic, and recognition of industrial workers as substitute or subordinate to machines led to job displacement and removal of human workers from manufacturing processes (Gamberini & Pluchino, 2024, Huang et al., 2022; Leng et al., 2022; Oeij, et al., 2024, Xu et al., 2021). Global Electronic Service (2020), Jardine (2020), Javaid and Haleem (2002), Haleem and Javaid (2019), Ozdemir and Hekim (2018), Rossi (2018), and Skobelev and Borovik (2017) proclaim that the Fifth Industrial Revolution, Industry 5.0, was introduced in 2015. The objective of Industry 5.0 is to continue with the digital transformation of Industry 4.0 with the inclusion of human active roles (Oeij, et al., 2024). European Economic and Social Committee (EESC) (2018), and Patches et al., (2019) described Industry 5.0 as the amalgamation of human creativity and craftsmanship qualities with the speed and consistency of robots. Similarly, Carr and Haslam (1980), Kopacek (2018), Kent and Kopacek (2019), Nahavandi (2019), Patches et al., (2019), and Shelzer (2017) explained that Industry 5.0 is a new industrial change where reliable automation of robots are intertwined with the human brain in a joint operation as human intelligence works in harmony with cognitive computing to increase production efficiency and works as a collaborator and supervisor. Combining the speed and accuracy endowed in automation with the cognitive skills and critical thinking of humans ensures the success of Industry 5.0 (Kent & Kopacek, 2020; Grabowska et al., 2024; Yordanova, 2021). Kent & Kopacek (2019), Demira et al., (2019), Lu (2017), Korcomptenz (2019), Reinhardt et al., (2020) stated that in Industry 5.0, robots rigorously prepare products with high precision, meeting high specification and standards while humans take over to add the value and finishing touches to the product. Machines take over all monotonous, repetitive, error-prone and mundane tasks while humans take creative, artistry, and the research and development side, taking on more responsibilities and increased supervision of systems to elevate and improve the quality of production across the board (Patches et al., 2019; Demira et al., 2019).

Putting humans back into industrial production with collaborative robots will provide humans with bigger opportunities to engage in value-added tasks in production, leading to the personalization of customer needs (Rossi, 2018). Cojocariu (2019); Kent and Kopacek (2019); Ozdemir and Hekim (2018); Østergaard (2018); Patches et al., (2019) state that Industry 5.0 proceeds from mass customization to personalization of customers' needs, where clients/customers are allowed to get products and services by giving them maximum opportunities to state their preferences and requirements based on their needs at the design phase and the production line, instead of choosing from existing options. The most essential

benefits of Industry 5.0 include increased productivity, agility and profitability, improved adaptability, change-readiness, a responsive working environment and overall cost reduction (Patches et al., 2019; Kospanos, 2017; Rada, 2018). Industry 5.0 brings improvement to industrial design, process, operations, speed and accuracy of industrial automation through the application of human cognitive and critical thinking capability, which was not previously possible, hence, provides a flexible approach to continuous improvement in manufacturing sectors to solve problems of the future and produce personalised products of high value (Kent & Kopacek, 2019; Ozdemir & Hekim, 2018). Furthermore, Industry 5.0 leads to the attainment of business goals, an exceptionally efficient and value-added production process, flourishing and trusted autonomy and associated costs (Xu et al., 2014; Xu et al., 2018; Haleem & Javaid, 2019).

Technology of Industry 5.0

Global Electronic Service (2020) submitted that the tendency of Industry 5.0 to affect the manufacturing processes and supply chain, among others, depends on quick adoption and the willingness to implement technologies necessary to bring the Industry 5.0 revolutionary features and components to the plant floor. Thus, Burrus (2014), Chattopadhyay (2020), Cojocariu (2019), Nahavandi (2019), Ozdemir and Hekim (2018), Ustundag and Cervical (2018), and Patches, et al., (2019) express that Industry 5.0 technologies, which can be used across diverse professions such as medical science and healthcare, education, sport, entertainment and engineering among others, include customized software/application, network of smart and intelligence sensors, programmable machines and devices, collaborative robotics (cobo), 3D printing, artificial intelligence, internet of things (IoT), cloud technology, blockchain technology and data analytics. Society 5.0 is a society where advanced information technologies (IT), IoT, robots, artificial intelligence (AI) and augmented reality (AR) are actively used in human's everyday life, in industry, health care and other spheres of activity for the progress, benefit and convenience of every human being (Graube & Theuerkauf, 2005; Skobelev & Borovik, 2017). Meanwhile, any change in industries and technologies have severe implications on the qualification, knowledge, skill and attitude of industrial workers. This is because handling these new technologies in industry sectors requires new qualifications and responsibilities and, by extension, new knowledge, skills, attitudes and competencies from industrial workers and management (Saniuk, et al., 2021). Oranu (2010) and Magaji (2015) report that factors responsible for the rising demand for knowledge and skills in industries and labour markets include technological and organizational/industrial change, deregulation of key industrial sectors, and the decline of unions.

Need for knowledge

Industry 5.0 will create new jobs in human-machine interaction and human computational factors (Saniuk & Grabowska, 2022), which may span across intelligent systems, artificial intelligence and robotics, machine programming, machine learning, maintenance, training etc. (Madesn & Berg, 2021; Martynov, et al., 2019). Ikenga and van der Sijde, (2024) and Li (2020) posited that the combined power of humans and machines generates new possibilities and competencies.

This is because, industrial change and rapid changes and developments in technology are progressing globally and in Africa are accompanied by new roles, expectations, activities and tasks. Hence, industries are demanding for managers, workers and graduates with higher and

quality education and training standards, multi-skilled graduates and people with new knowledge, skillsets, technical aptitude, attitude, specific and generic skills, in the ever-changing business environment and manufacturing industries (Board of Engineers, Malaysia, 2003; Brunhaver, et al., 2017; Jobs for the Future, 2007; Hernandez-Gantes, 2016; National Academy of Sciences, 2007; National Academies of Sciences, Engineering, and Medicine, 2018). Evidence upheld that employers in the US and other parts of the world began to report problems concerning finding competent workers in high-tech, high-wage fields in science, technology, engineering, and mathematics (STEM), with adequate preparation underlined by basic academic skills, technical skills, and complementary skills associated with teamwork and problem-solving (Carnevale et al., 2010; Hernandez-Gantes, 2016; Hernandez-Gantes & Fletcher, 2013; Ibanga, 2015; Kim, 2011; Otokunefor; 2011). Ikenga and van der Sijde (2024) and Wang, Yu and Han (2021) argued that many workers lack the knowledge and technical expertise to work with new technologies of Industry 5.0 such as artificial intelligence and robotics applications, resulting in a skill gap. Evidence from Demira, Dövena and Sezenb (2019) and Kelly (2015) upheld that people losing jobs in industries are unlikely to possess the education, training, and skills to assume the responsibility of employment requiring creativity in the industrial sector. Similarly, the World Economic Forum (2012) and Spang (2014) reported that it is estimated that there are 10 million jobs in manufacturing companies that remain unfilled due to the skills gap and that the ability to access the right talent will increasingly become a matter of competitive advantage.

According to Hadgraft (2017) and the Institute for the Future (2015), lists of the key skills of the future workforce includes: sense-making, trans-disciplinarity, design mindset, novel and adaptive thinking, virtual collaboration, cross-cultural competency, social intelligence, new media literacy and computational thinking. Demir and Ercan (2019), de Oliveira (2024), Ikenga and van der Sijde, (2024), Kent and Kopacek, (2019), Ramadhani, (2017), Saniuk and Grabowska (2022). Saniuk and Grabowska (2023) identified technical or STEM skills such as understanding of automated systems, robotics, artificial intelligence (AI), the Internet of Things (IoT) and data management software, ability to design, operate and maintain complex equipment and skill to analyse large quantities of data to optimize production processes, and soft skills such as problem-solving, creativity and innovation, flexibility, communication and collaboration, leadership and team management, empathy, emotional intelligence, analytical thinking and innovation, ecological awareness, ethics and social responsibility and knowledge of safety and regulatory compliance, as employee skills needed in Industry 5.0. Similarly, Demira, Dövena and Sezenb (2019); Cojocariu (2019); Alpaslan, et al., (2017); Felder, et al., (2000); Kelly (2015); McCrone et al., (2015); OECD (2015) claimed that job and occupational skills, technical skills, cognitive skills, social and emotional skills, problem-solving, creativity and critical thinking skills are the vital range of skills, demanded by employers in the Industry 5.0 era, and which existing and prospective industrial workers needed to collaborate with smart machines, programme the robots, or manage them.

Thus, Industry 5.0 created new types of work and introduced new technologies which require workers with highly developed knowledge and set of skills and proficient in the use of these technologies (Greenwood, 1997; Kent & Kopacek, 2019; Kopacek, 2018). Global Electronic Service (2020) stated that the birth of Industry 5.0 requires new manufacturing roles such as Chief Robotics Officer (CRO) and experts who are knowledgeable, skilful, specialized, and focused on human-machine connectivity and responsible for making decisions on which

machines or devices can be added to the plant floor to improve strategies for optimizing the production line. Similarly, Ramdass (2012) reported that the most significant demand of any industry are highly skill workers who possess the strong ability to apply new knowledge and technologies, and who can bring about business improvement methodologies and ultimately add value to industrial output. Correspondingly, Özdemir and Hekim (2018) expressed that both industrial personnel and students (prospective industrial workers) in the field of technology and engineering ought to be exposed to and experience the emerging concepts and knowledge of the IoT, AI, smart factories, and how they might transform and implement the knowledge within Industry 5.0 in the near future. Meanwhile, these skills are indisputably lacked by most serving and prospective industrial workers (Akinyemi et al., 2012; Ibanga, 2015; Otokunefor, 2011; Ogbuanya & Onele, 2018). Nahavandi (2019) claimed that essential skill/role gaps which exist as a result of Industry 5.0 emergence must be addressed.

Evidence upheld that Industry 5.0 changes career and professional development, emphasising the need for new skills, continuous learning, and adaptability in a rapidly evolving labour market (Huang et al., 2022; Tomaseic, 2023). Consequently, there is an urgent need to focus on the role of education and training as a lever for a competitive, innovative, sustainable and inclusive labour market and economy (Oeij, et al., 2024). This is because the design and implementation of quality education and training for industrial workers (engineers, engineering technologists and engineering technicians) are pivotal for personal, national and international development (Board of Engineers, Malaysia, 2003).

Technology is continuously playing a considerable role in Industry 5.0, there is corresponding increase in the need for up-skilling and re-skilling the workforce with a background in STEM-soft skilled training (Ikenga & van der Sijde, 2024) to enable them adapt to Industry 5.0's changing requirements and help businesses succeed in this new era of production (Demir & Ercan, 2019; Güğgerçin & Güğgerçin, 2021). Ramdass (2012) expressed that the essential skills, knowledge, attitudes and capabilities needed to excel in industries globally and, in Africa, are developed and learned through the institute or faculty of engineering and technology in higher education. This is because an educational/training institution is an institution of learning devoted to the discovery, examination, production, appraisal, dissemination and transmission of knowledge (Erguder, 2010; Steyn, et al., 2012) to develop the human potential that supports the social, economic, cultural, and intellectual life of a rapidly changing society, and ensure high-level skills training and development of personal abilities that would support national development (Federal Republic of Nigeria, 2013; Ramdass, 2012). Building these knowledge and skills requires human solid capital foundations and lifelong learning because human capital is positively correlated with the adoption of advanced technologies (Kent & Kopacek, 2019). Similarly, Jonathan and Monday (2017), Koretsky and Magana (2019) and Parashara & Parashar (2012) reported that there is a need for a higher level of skills and knowledge of technology used in engineering practice to be taught as advanced learning, before workplace entry, to cope with and manage rapid changes in technology and industrial changes, uncertainty and complexity in the workplace.

Graube and Theuerkauf (2005) expressed that the emerged developments in engineering and technology have significant implications and impacts on engineering, technology and technical education. Educational institutes such as universities, polytechnics, institute of technology and technical colleges play a significant role in preparing a potential workforce (engineers,

technologists and technicians) who can fulfil an ambassador's role in Industry 5.0 (Oeij, et al., 2024). Scholars upheld that knowledge, skills and attitudes needed to cope with the advent of Industry 5.0 are offered primarily at educational institutions' classrooms and workshops/laboratories purposely to meet national developmental goals and global demands, support critical discourse and creative thinking, and support the advancement of all forms of knowledge (Department of Education, 1997; Lange, 2012; Resale, 2019). However, educators and policy makers have come to a consensus that the ability of engineering, technology and technical education to provide such training needs to be promoted and improved (Katehi et al., 2009; Parashara & Parashar, 2012). This study focuses on development of technical, technology and engineering education in universities, polytechnics, institute of technology and at technical college level for the purpose of producing competent engineers, technologists and technicians who work at industries in Nigeria.

Engineering Education

Conceptually, the Board of Engineers, Malaysia (2003) and Sönmez (2014) proclaimed that engineering education programs are expected to instil in students the ability to apply mathematics, science and engineering science in the design, operation and improvement of systems, machines and processes to meet desired needs; conduct experiments; analyse and interpret data; identify, formulate and solve engineering problems; understand and resolve the environmental, economic, societal implications of engineering work; engage in lifelong learning and professional development, and act under the ethical principles of the engineering profession. According to the Board of Engineers, Malaysia (2003) and Cheshier (1998), engineering education focuses on the conceptual and theoretical aspects of science and engineering which is aimed at preparing potential graduates for the practice of engineering in research, development, and conceptual design functions. Though scientific and technological knowledge and skills are available in engineering educational programs, engineers are expected to be equipped with the capability necessary to participate in research, develop functional devices, structures or processes, design work, production and testing, sales, management, consulting and teaching and also framing the curricula of engineering programs (Eide et al., 2008; Sönmez, 2014; Wickert, 2006). Similarly, participation in engineering programs at university and college level helps to improve a student's level of ability to apply mathematical reasoning within the design process (Akins & Burghardt, 2006; Gomez-Zwiep, 2016). Meanwhile, an educational program similar to engineering education is technology education.

Technology Education

Technology education programs at university and college level are designed to prepare students in grasping knowledge of system and their components, technical operations and actions, functions of technical systems and processes, consequences for the individual, and the history and development of technology (Graube, 2005, Lindstrom, 2005). Technology education aims to develop in students the creative, imaginative, technical and practical expertise needed to solve real and relevant problems confidently, and to participate effectively in technological world; build and apply a collection of knowledge and skills via manipulation of materials and tools with techniques to design and make high-quality prototypes and products for a wide range of users; and critique, evaluate and test their ideas and products (Ankeli, 2019, Department for Education, 2013, James et al., 2015). Generally, technology education instils in students the ability to know and understand technical systems and processes (structural,

functional, societal, historical, ecological, economic, aesthetic qualities of a system etc.), ability to manage technical systems (including all forms of operations: design, production, management, removal from operation, recycling technical systems), and ability to assess and evaluate the social, human and environmental impact of technical products, systems and processes (Schlagenhauf, 2005). Graube and Theuerkauf (2005) stated that technology education is designed to enable students be part of the process in which a world undergoing technical change has to be given shape, be capable of responsible technical action, cope with technological /practical requirements encountered in our daily lives and on the job, understand the principles of technical systems, and be able to use their basic technical understanding to decide in favour of technical professions. Technology education primarily emphasises the analysis, application, implementation, and improvement of existing technologies and is aimed at preparing prospective graduates (technologists) for the practice of engineering closest to product improvement, manufacturing and engineering operational functions (Board of Engineers, Malaysia, 2003; Cheshier, 1998). Similarly, technology education aims at producing graduates (technologists) who understand how conditions of production, society, the physical environment, and the requirements of life are changing (Blomdahl, 2005).

Technical Education

The Federal Government of Nigeria, FGN, (2004), Jonathan and Monday (2017), Magaji (2015), McCrone et al., (2015) and Winer (2000) define technical education as the study of technologies and related sciences and acquisition of practical skills, attitudes, understanding, work habits and knowledge that enables the learners to gain employment and perform effectively in employment on a valuable and productive basis. Okoye and Arizona (2016) and Uwaifo (2009) submitted that technical education is the training given to students to become technically oriented personnel who are to be the initiators, facilitators and implementers of the technological development of a nation. The purpose of technical education is to prepare youth and adults for careers in a wide array of high-wage, high skill, high-demand fields (Association for Career and Technical Education (ACTE), 2014; Hernandez-Gantes, 2016). Technical education prepares people for entry into recognized occupations at a higher level but usually lower than the first degree (Okoye & Arizona, 2016).

Engineering, technology and technical education are designed to train students in classrooms and workshops/laboratories for their specific career major (Altalbe, 2018; Yekinni and Ogbuanya, 2025). Specifically, engineering, technology and technical education are typically offered at the institutes of technology, polytechnics, universities, local community colleges, trade centres or technical colleges (Odo et al., 2017), leading to the turning out of engineers, who design the system and process, technologists, who use scientific and practical knowledge to implement design and change design into product, and artisans and technicians who install and maintain the product and are conversant with engineering related ethics (Felder et al., 2000; Ogbuanya & Yekinni, 2019; Zambwa et al., 2018) and who can gain employment mostly in industries, an establishment or become an entrepreneur (The Institution of Engineers, Australia, 2002; Okoye & Arizona, 2016; Momo, 2012).

The training given to engineers, technologists and technicians can either be on-the-job/ in-service training, which implies current and existing industrial service personnel undergo further training; placements; mentoring activities; attending trade shows; visits; competitions), manufacturer training (for better performance and career/professional growth and

development) or off-the-job/pre-service training, learning at college or with the learning provider. (Lucas & Spencer, 2015; McCrone et al., 2015; Ciraso-Calı et al., 2016). By implication, professional engineers focus on the design and development of products, or systems; engineering technologists are inclined to apply engineering output in manufacturing and production line (Board of Engineers, Malaysia, 2003; Cheshier, 1998; Sönmez, 2014). Meanwhile, engineering technicians are expected to have relatively practical understanding of theoretical principles and be proficient in applying relevant skills and techniques for carrying out installation, maintenance and repair activities in industries or an establishment (Francois, 2005; Ibezim, 2011; Ogbuanya & Yekinni, 2019; Ohanu & Ogbuanya, 2014; Zambwa, 2018).

Challenges Facing Engineering, Technology and Technical Education Institutions

Engineering, technology and technical education graduates of the present day are commissioned to solve the problems of a future world that faces a rapidly increasing and more critical than ever set of challenges (Atman et al., 2010; Korkmaz et al., 2018). Okoye and Arizona (2016) and Umunadi (2013) explained that training of engineering and technical personnel in most institutes of technology, polytechnics, universities, local community colleges, trade centres or technical colleges in Africa, including Nigeria, have witnessed many challenges such as a curriculum that has little or no relationship with workplace and social needs, inadequate facilities and poor staff training among other things. Similar evidence upheld that Zimbabwe, Malawi and Tanzania have identified inadequate learning facilities, absence of school-industrial synergies and ineffective curricula among other constitute problems facing educational institutions struggling to produce competent graduates (Lemo & Olakotan, 2016; Olakotan & Lemo, 2019; Woyo, 2013; Anangisye, 2008). Similarly, Chattopadhyay (2020) expressed that educational institutions globally, including Nigeria, face significant challenges - a function of tectonic shifts and technological disruption in the techno-socio-economic landscape and digital revolution frequenting in industries which causes professionals to find themselves becoming irrelevant in their career, professional and occupational areas.

Meanwhile, experts claimed that educational changes must be kept up with new technologies and changes in industrial requirements (Kline, 1992; National Academy of Sciences, 2005). Similarly, experts asserted that educational institutions through their academia should work with industries to produce and align curricula with real-world needs, up-skill workforce and ensure engagement with ongoing changes (Carminati et al., 2025; Yoto, 2017). To cultivate and synergize Industry 5.0 knowledge and skills into education and training programmes, there is need to revise current teaching and training programs (Carminati et al., 2025) and incorporate technologies such as artificial intelligence and machine learning etc. into Industry 5.0 applications to tailor the educational experience for learners in education programmes (Ikenga & van der Sijde, 2024). Scholars expressed that amidst the ever-changing work milieu, there is a need for educational reforms focusing on improved career readiness nationally and internationally (Hernandez-Gantes, 2016; Stone, 2013) in which schools have to provide learning experiences in areas like digital skills, numerical competencies, scientific and technological know-how, entrepreneurship, machine learning, data analysis, artificial intelligence, programming among others that can make students fit in their occupational area after graduation (Galvao et al., 2017; European Parliament and Council, 2006; Ramadhani, 2017). Engineering, technology and technical education graduates are naturally expected to possess a number of integrated skills (Korkmaz et al., 2018). Therefore, there should be a cordial relationship between the quality of graduates produced and supplied by educational

institutions and the need/demands of the industries for the purpose of bridging the need gap of skill labour (Priowirjanto, 2001; Yoto, 2017). Thus, experts highlighted urgent needs to re-skill professionals such as engineers, technologist and technicians in the Industry 5.0 era and to make the transition of students from school to industry smoother and less traumatic by re-booting and making the curriculum, pedagogy of teaching/learning and faculty members more relevant to the world of industry and commerce (Chattopadhyay, 2020; Moss, 1990; National Academies of Sciences, Engineering, and Medicine, 2018). Thus, this article focuses the development of a model for redesigning the academic program of study in the Nigeria educational institutions (institutes of technology, polytechnics, universities, local community colleges, trade centres or technical colleges) for the production of competent engineers, technologists and technicians who are proficient to adapt to an Industry 5.0 technological shift.

Curriculum would include components such as the rationale for the program, conceptual and contextual knowledge structures, learning outcomes, teaching and learning activities, assessments, level descriptors and graduate attributes etc, that would address the knowing, doing and being imperatives of a graduate (Scholtz, 2013). Nkomo (2000), Scholtz (2013) and Wattanbarger and Skaggs (1979) proclaimed that curriculum is virtually every aspect of the full education system. If the curriculum becomes obsolete and antediluvian due to technological and industrial changes, it must be revised. Similarly, experts upheld that to keep pace with the rapid evolution of technology and knowledge explosion, to cope with shifting social expectations, to make students relevant and provide them with the current development in practices and theories, to produce self-directed learners, critical thinkers and workers who will be able to work in a team and contribute to the entire development, it is imperative that the curricula of the discipline are reviewed and renewed regularly (Carew & Cooper, 2008; McNerney, 1998; Ramadhani, 2017; Resane, 2019). This is because experts expressed that curriculum needs regular revision, reform and renewal to ensure that the needs of learners are adequately addressed (Meliani et al., 2021; Resale, 2019; Supriani et al., 2022), meet the constantly changing training needs that keep up with technological change and industrial development in every engineering, technology and technical educational institution, maintaining the current quality of educational programs and meet up with the current demands of culture, society, industries and the expectations of the population it is serving (Carew & Cooper, 2000; Johnson, 2001; Subasubani, 2016).

Thus, the fundamental step for the development of engineering, technology and technical education programs in the Industry 5.0 era, is the revision and improvement of a curriculum to make it more relevant, current and improve the supply base of employable candidates to industry (Ramdass, 2012). Guan and Lu (2012) and Lu et al., (2013) expressed that it is essential to understand industrial needs, design a curriculum that has qualities to bridge the need gaps, and cultivate human resources to meet these needs. Changes in technology and industrial expectations, due to the advent of Industry 5.0, called for urgent recurriculation and overhauling of engineering, technology and technical education qualification framework with the view of meeting the needs of 21st century educational programs that are more responsive to the socio-economic development of our society (Forbes, 2006; Johnson et al., 2012; Lu et al., 2013; Okoye & Arizona, 2016; Ramdass, 2012; Schultz, 2013). This will also respond to the demands of national and global policies, goals and objectives and to the requirements of higher educational institutions, industries, professional bodies and general economy (Schultz, 2013). Similarly, Sönmez (2014) opined that engineers, engineering technologists and engineering

technicians should acquire more comprehensive trainings that will enable them to adapt to and adopt technological innovations, and to successfully participate in a globally competitive business world via restructuring engineering, technology and technical education programs and curriculum. Thus, the process of restructuring the curriculum, is Recurriculation.

Recurriculation of Engineering, Technology and Technical Education Programs

It is good to acknowledge that nearly all the studies consulted online or offline on recurriculation of academic programs were conducted and reported from South African educational institutions. Conceptually, recurriculation is a curriculum transformation which represents a strategic effort to advance technical, technology and engineering education programs with an aim to prepare graduates who are proficient to adapt with Industry 5.0 technology (Harden, 2001). Recurriculation of engineering, technology and technical education programs, which are synonymous with curriculum revision, refers to modification or re-adjustment of existing curriculum to produce modern and appropriate objective, content, and process driven curricular that support the maintenance of the quality of engineering, technology and technical education programs and production of graduates who can flourish in their chosen profession (Burgess, 2004; Carew & Cooper; 2008, Ramdass, 2012; Schultz, 2013). Recurriculation is the establishment of a new curriculum that addresses the number of weaknesses of the existing curriculum (Council on Higher Education, 2013) and refining the curriculum to better address the needs of industry and society at large (Van As et al., 2016). Recurriculation includes the introduction of a new learning experience in which its purpose, outcomes, field of study, mode or site of delivery have changed significantly to comply with both industrial, technological and societal demands (Resale, 2019). Pressure exerted on institutions of learning to enhance students' learning and train future workers who possess necessary skills and knowledge needed to engage actively in industry, adapt to new technology such as robots in industries and necessitate recurriculation of engineering, technology and technical education programs in Nigerian institutions (Prochario-Foley, 2017; Resane, 2019).

Recurriculation of engineering, technology and technical education qualifications frameworks will undoubtedly translate to the production of highly qualified and competent graduates - engineers, technologists, artisans and technicians - who are better prepared to meet the challenges of a constantly changing workforce in Nigeria and by extension promote rapid industrialization and economic growth of national and global society (National Academy of Sciences, 2005; Okoye & Arizona, 2016). Recurriculation is necessitated by the need for genuine curriculum change that demands a deeper enquiry into the kinds of knowledge, skills, values, attitudes and beliefs that can meet and respond to Industry 5.0 demands in Nigeria (Jansen, 2012; Resane, 2019). Evidence upheld that key drivers of the Future Work Skills in engineering and technology, especially in Nigeria, include a computational world of AI and big data, super structured organization, increase of smart machines and systems, new media ecology, and a globally connected world (Institute for the Future, 2015; Hadgraft, 2017). Thus, the advent of mechatronics, smart/innovative technology, Nano-technology and sustainable development (greening) technology which are the components of Industry 5.0, have forced experts in the field of engineering and technology – Electrical/Electronic Engineering (Technology), Mechanical Engineering (Technology), Building and Civil Engineering (Technology), Chemical Engineering (Technology), etc. - to embark in the universities and colleges on the revitalization of their curriculum. Specifically, metalwork, auto mechanic technology and mechanical engineering are introducing elements of mechatronics into the program of undergraduate and

postgraduate students. This is helping mechanical engineering students to gain more knowledge and skills relating to the design, development and application of robots in industries. Electrical/Electronic engineering accepts programming languages, cyber security, nanotechnology and its application, and greening technology into the program. Similarly, chemical engineering introduces students to the application of nanotechnology, chemical plant design and fractionating columns, and application of electronic equipment and devices in the chemical engineering laboratories, such as spectrophotometer (for microbial counting), centrifuge machines (for the separation of liquid components), electronic ampoule/ampule (ceiling of chemical sample for storage and preservation purpose etc). These changes bring about the rearticulation of academic program in the field.

Postmodern Curriculum Theory

Globally, technology and industry are undergoing post-modernisation – an idea for referencing a world without stability, where knowledge is constantly changing and change is the only constant (Boboc, 2012; Nădrag & Buzarna-Tihenea, 2015). Thus, William Doll, the prominent American curriculum theorist proposed a postmodern curriculum theory to address the continuous changes in knowledge and skills demanded by employers due to industrial revolution and technological changes to equip the prospective workforce of industries. The article adopted postmodern theory since the article focused on the changes in knowledge and skill that may exist as a result of migration from Industry 4.0 to Industry 5.0.

Postmodernists (Doll, 1993; Gang, 2015; Lau, 2001; Lixin, 2004; Negroponte, 1995) suggested the 4R's - Richness, Recursion, Relations, and Rigor - as criteria for the rearticulation of engineering, technology and technical education programs. Conceptually, Richness of curriculum entails quality of curriculum instead of quantity (Lixin, 2004). Lixin (2004), and Whitehead (1967), argued that curriculum content should be few and crucial. Richness according to Smitherman (2005), and Schultz (2013), stands on the premise that curriculum is revised to enrich its content, knowledge, skill and attitude and to be inculcated to make it fit, be relevant and pertinent to technological and industrial changes in the Industry 5.0 era. Recursion here revealed that rearticulation of an existing academic program (curriculum) occurs to transform and change the existing curriculum to one that can promote and support new/current experience, skills and knowledge and, by extension, foster genuine creativity in students iteratively by using the current curriculum as a basis for the formation of a new curriculum (Smitherman, 2005; Schultz, 2013). Here, the existing curriculum is revised and changed considerably to produce new curricula to maintain the stability of the existing patterns but with changes in variables (Doll, 2013; Godden, 2014). This includes those elements within the new curriculum – the matrix or network which gives new curriculum richness and, those outside school, a large matrix within which the curriculum is embedded (Doll, 2013; Doll, 1993). Lau (2001), Doll (1993) and Doll (2013) stated that relationships might be pedagogical relationships (interactions among the curriculum structure) or cultural relationships (interactions among the curriculum with the local as well as global context). Technology and industry are ever-changing, ever-shifting and dynamic, hence, affecting how curriculum is constantly shaped and structured. Finally, Rigour means that rearticulation must involve critical analysis and examination of content, knowledge, skills, attitude and competence to be embedded in a new curriculum to determine its relevancies and fitness, and address technological and industrial change (Smitherman, 2005; Schultz, 2013).

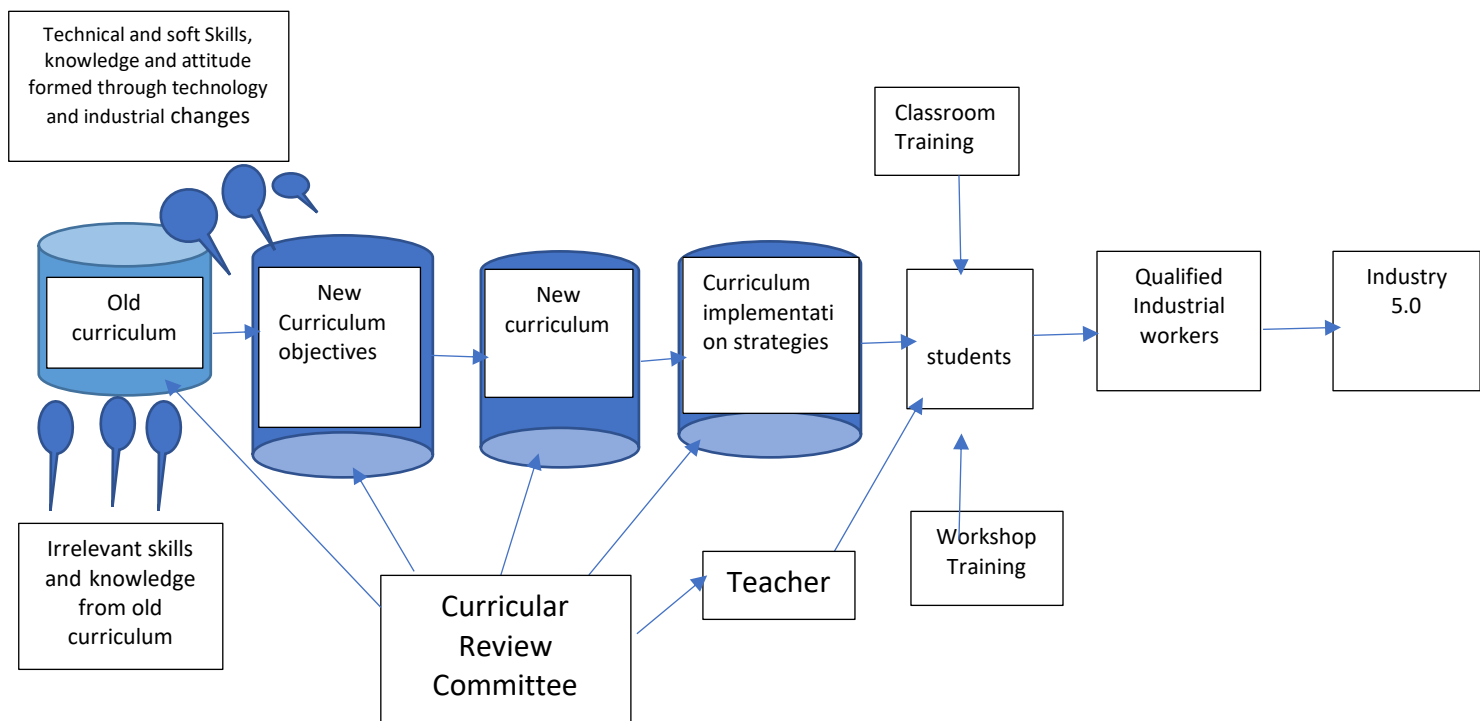


Figure 1: Recurriculation model

The model above depicts that for appropriate recurriculation to occur, curriculum Review Committees are formed, which include engineering educators, policymakers, industrial employers- educational researchers, etc who are responsible to extract and use some of the relevant knowledge, skills and attitude from the old/existing curriculum, and technical or STEM skills, soft skills, occupational skills, and cognitive skills, knowledge and attitude due to technological and industrial changes as input for stating the objectives of new curriculum and for producing new curriculum for institutes of technology, polytechnics, universities, local community colleges, trade centres or technical colleges. Thus, the new curriculum will be used to train the students in the classroom and well facilitated workshops/laboratories through qualified teachers using appropriate pedagogical methods. This is mainly to produce qualified and competent graduates who will conveniently work in Industry 5.0.

Phases for the Recurriculation of Engineering, Technology and Technical Education Programs.

The process of recurriculation, as reported by Aguokogbuo (2000), Katehi et al., (2009), Okeke (1981), Starbuck (2016) and Supriani, (2022), includes: constant brainstorming, reviewing, analysis and evaluation of existing engineering, technology and technical education programs and societal needs, identification of aspects of the program to be revised, involving all concerned with the planning, development and interpretation and implementation of curriculum, development of curriculum content, skills, tasks and trade, and production of actual curriculum materials and production of curriculum packages. Thus, after reviewing a number of published works, the phases of recurriculation of engineering, technology and technical education programs is addressed in the chronological order as follows.

Senior management brainstorming and reviewing Industrial's needs

Openness to Change

In deciding to embark on curriculum renewal, innovation or review in engineering, technology and technical educational programs, it is vital to consider the readiness of the academics, instructors and other actors for change (Carew & Cooper, 2008). Here, academics should willingly accept the changes to prevail or accept the changes to take place in the educational system before any curriculum review can be successfully done in engineering, technology and technical education programs. Experts revealed that the ultimate requirement for curriculum innovation is the creation of a culture of openness to change and wiliness to adapt to new technology and work process (Jackson, 2002; Ikenga & van der Sijde, 2024; Schultz, 2013; Wattanbarger & Skaggs, 1979). Academics and other actors who have undertaken recent curriculum change may be suffering from change fatigue and have inadequate resources of patience and enthusiasm to participate in more change (Carew & Cooper, 2008). The openness to change will create more eagerness to participate in the recurriculation process. Similarly, changes in educational structure and individual functions and responsibilities are likely to occur if curriculum changes are accepted among academics in educational institutions. Openness to change includes the willingness to be part of a curriculum review committee, readiness on the part of engineering, technology and technical educators to take part in professional development that may enable them to teach new courses/subjects in the classroom or workshops/laboratories effectively, and readiness, on the part of engineering, technology and technical education workshop instructors to undergo training on how to operate new equipment and carry out new task/activities in the laboratories/workshops. For instance, automobile lecturers and instructors may be trained on how to use automobile diagnostic scanners while mechanical engineering lecturers and instructors may be trained on how to handle Finite Element Analysis (FEA) software, Computer-aided design, and Computer Numerical Control machine among others.

Formation of Curriculum Revision/Recurriculation Committee

Aguokogbuo (2000), Beane, Toepfer and Alessi (1986), Irons, Holm and Annandale (2017), Johnson (2001), Katehi, Pearson and Feder (2009), Özdemir and Heim (2018), Schneider and Rivet (2000), Spang (2014), Ilkiw et al. (2017), Isabel and Stewart (1935), Wattanbarger and Skaggs (1979) expressed that the task of recurriculation is conducted by and committed to the hand of various concerned experts and stakeholders of a Curricular Review Committee. This committee includes engineering/technology educators, policymakers, industrial employers-financial investors, industrial engineers, smart factory entrepreneurs, content experts and information and communication technology (ICT) experts- educational researchers, curriculum experts and cognitive scientists and others concerned about the development of the country's technical workforce will also find much to ponder. Committees consist of an assortment of field-relevant work representatives and the academic staff of a department who decide upon curriculum issues so that the academic courses are more closely aligned with what work wants, and to changes that are occurring in the industry (Garraway, 2007). Curriculum review/recurriculation committees are charged with the responsibility to conducts a series of workshops to identify new institutional goals, aims, objectives and philosophical statements, technical and non-technical skill sets, deliberate on the lack and needs of the existing curriculum, determine the extent of changes to be done on existing curriculum by determining and selecting the irrelevant knowledge, skills and competences to be removed or identify the

new skills that could be added to the curriculum and come out with new curriculum that is in alignment or matches with the latest technological and industrial development (Aguokogbuo, 2000; Irons et al., 2017; Spang, 2014; Thanikachalam, 2015). The function of this committee also includes the identification of problems, issues, and concerns of the previous engineering/technology-related curriculum and use the information obtained to come up with a better curriculum that addresses the needs of fast-growing industries (Ilkiw et al., 2017). The committee of experts will identify the trades in engineering and technology fields, roles/job description, activities and tasks required in each trade and competences, skills and knowledge needed to perform the tasks. Committees will set the time limit for knowledge and skill acquisition and decide on orderliness of skill acquisition and its arrangement on the curriculum.

Development of Outcome Statement

Program Outcome Statements are statements that accurately describe what students from a engineering, technology and technical education academic program will be able to do at the point of graduation (Carew & Cooper, 2008). This phase includes the establishment of rationale, philosophical, general and institutional outcome statements, core values, guiding principles, and learning outcome statement that addresses core and specific knowledge, competencies, skills and attitude that are relevant and fit for the industry 5.0 (Aguokogbuo, 2000, Beane, Toepfer & Alessi, 1986; Ilkiw et al., 2017; Taba, 1962). Golby (1977) and Beane, Toepfer and Alessi (1986) stated that curriculum goals imply statements of preferences, values and judgments about the directions which engineering, technology and technical education activities might focus. Meanwhile, specific objectives reflect short or immediate purpose involved within a particular classroom/laboratory teaching and learning activities (Beane et al., 1986). Irons, Holm and Annandale (2017) stated that at this stage, curricular review committees finalize the general and specific objectives and outcomes of the engineering, technology and technical education academic programs. The sample of program outcomes could include, at the end of an academic program, graduates should be able to:

1. demonstrate knowledge, understanding, and proficiency regarding the selection and choice of appropriate smart tools, equipment and materials in design and construction of functional electronic circuits safely,
2. select and use appropriate electronic tools, equipment and material in the repairing and maintenance of electronic equipment and appliances,
3. design a functional miniature circuit
4. write a functional algorithm for the design of robot.
5. design simple robot using appropriate materials and equipment
6. carry out crystallization, filtration and evaporation processes safely using appropriate methods, materials and equipment.
7. use Finite Element Analysis (FEA) software to perform structural analysis on stresses and deflections in complex structures.
8. handle Computer-aided design for the creation, modification, analysis, or optimization of design.
9. design roads for light vehicular traffic, taking into account vehicular loading, existing ground properties, local environmental conditions, and local availability of road building materials, machinery, labour and expertise (Carew & Cooper, 2008).

Development of content

Curriculum committees reflect on the contents of a curriculum to ensure that it meets the demands posed by technological and industrial changes, and the unique context of the country - Nigeria (Council on Higher Education, 2006; Steyn et al., 2012). Here, the curriculum committee decides on what should form the learning experience of engineering, technology and technical education students and how such can be arranged, structured or mapped using program outcome statements as a guide. This involves identification and definition of required experience that can help to develop the required skills, knowledge, behaviour, competencies and attitude needed to gain employment in industries (Beane et al., 1986). Colin (2009), and Walker (2003) argued that curriculum should include content that may be depicted in terms of concept maps, topics and themes. Golby (1977), Olaitan (2003), World Health Organization (2019), Starbuck (2016) stated that this stage includes the addition and formation of relevant programs, topics, course structure and method, scope, sequence, or modules to suit the ideas, knowledge, skills, attitudes and competencies expected from engineering, technology and technical education graduates to gain employment, and function productively in industries. This also includes the establishment of laboratories/workshops, tasks/activities, classroom tasks/activities, library, specification of kits, resource units, text and other teaching and learning materials that support the knowledge and skills to be acquired by students of engineering, technology and technical education programs (Aguokogbuo, 2000; Golby, 1977). Hlavac (2023), The Government of Western Australia (2025) and Thanikachalam (2015) claimed that every industry publishes the desired knowledge skills and competencies required from the employees from time to time, hence, these should be considered as standards by the trainers for the re-curriculation of engineering, technology and technical education programs. Specifically, the Government of Alberta (2024) identified Interpret drawings, Interpret specifications, layout projects using drawings and/or specifications; apply applicable standards, regulations, and codes; demonstrate safety awareness and safe work practices; select, use, and maintain personal protective equipment; select, use, and maintain hand and power tools; demonstrate start-up and shutdown procedure of oxyfuel equipment, use oxy-fuel equipment when cutting metals, and use oxy-fuel equipment when heat straightening metals among others as competencies required to train an Ironworker Metal Building Systems Erector.

Pedagogy

Pedagogy is the art of arranging teaching and learning processes to achieve specific learning outcomes among learners (Coral, 2009). This involves an arrangement of learning methods and techniques that engineering and technology teachers, trainers and instructors adopt during teaching and learning situations in classrooms and laboratories/workshops. This is the implementation period where skills, knowledge and attitude are arranged and taught to students both in the classroom and workshops/laboratories. The teacher, before training, states achievable and specific objectives. Then, teachers use objectives as a guide in delivering the contents of instruction in the classroom and laboratory using appropriate methods and techniques and teaching aids. The methods that are often used by engineering and technology educators and instructors during classroom and workshop teaching and learning activities includes: bringing an expert to teach in the classroom or workshop, guiding students to practice specific tasks inside the workshop, hands-on learning, feedback which promotes learning, real-world problem solving, one-to-one coaching and mentoring, competing against the clock, and seamless blending of online and face-to-face learning (Lucas & Spencer, 2015; McCrone et al., 2015).

Professional Development

Engineering, technology and technical education teachers and instructors educate and train male and female youths within the institutes of technology, polytechnics, universities, local community colleges, trade centres or technical colleges level, who are or will become employees of industries in Nigerian society (National Academy of Sciences, 2005). The knowledge and skills that teachers/ laboratory instructors require to carry out their duties change with new challenges and shifts of technology and industrial revolutions (Okeowo, 2009). Thus, as educational programs evolve to meet the changes in technology, markets, and societal needs, faculty members must be trained on new teaching and learning techniques as well as new technology and essential professional skills that their students will encounter in the workplace (National Academies of Sciences, Engineering, and Medicine, 2018). This is because, Chai et al., (2017), Göksün and Kurt (2017), Kennedy et al., (2022) and Wagiran et al., (2019) stated that improving the skills for teaching and learning processes among teachers are vital for improving the integration of new technologies in technical, technology and engineering education programs to enhance the attainment of educational objectives. Aguokogbuo (2000), Golby (1977) and Subasubani (2016) reported that the need for continuous pedagogy and didactic training and retraining of engineering, technology and technical educators could not be underestimated, because delivery methods of lessons are as critical as the level of knowledge of the subject the trainer has. A lack of teacher preparedness and further training among technical, technology and engineering education teachers and instructors poses a serious challenge on them to shifting from traditional teaching methods to modern ICT-based teaching methods (Edwin & Stela, 2016; Carr et al., 2018; Kennedy et al., 2022). Thus, experts supported that the educators and instructors who are tasked with the responsibility of implementing curriculum in Nigeria need to attend professional development sessions to teach engineering, technology and technical education related subjects efficiently (Katehi et al., 2009). This makes them continuously fit and relevant in the implementation of new changes in curriculum and by extension, makes them qualify to foster genuine creativity in students (Okeowo, 2009) and produce graduates that will be accepted in industries.

Eggen and Kauchak (2006), Kipper and Rüttemann (2013), Gess-Newsome (1999) and Shulman (1987), reported that during professional development, at least four different forms of knowledge are essential for technical, technology and engineering educators while teaching for understanding:

Knowledge of content – this means a thorough understanding of the topics and subjects taught by teachers in all content areas. Foster (2020) stated that Subject Content Knowledge include understanding the substantive and syntactic structures of concepts, principles and, ultimately, facts of any given subject area. For instance, electrical/electronic engineering/technology/ trade teachers should have deep knowledge of electrical/electronic components, have ability to use measuring devices and equipment such as multimeters, oscilloscopes, clamp meters, vectorscopes, tachometers, and chronometers, and build a circuit among others.

Pedagogical content knowledge – this includes the ability of teachers to create examples, understanding of ways to represent subjects that make it understandable to students and knowledge of what makes the learning of specific topics easy or difficult (Atkins, 2025; Shulman, 1986; Shing et al., 2015). It also includes ‘blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and

adapted to the diverse interests and abilities of students and presented for instruction. This includes appropriate adoption of teaching techniques and strategies to deliver content of instruction. For instance, engineering/technology/trade teachers or instructors may use demonstration method in teaching product design, construction and analysis in laboratories/workshops. However, explanation method may be applied to clarify the concepts theories and principles of particular topics.

General pedagogical knowledge – this implies understanding of general principles of instruction and classroom management that transcends individual topics or subject matter areas. Similarly, teachers with this knowledge should be able to communicate clearly, provide effective feedback, and use other strategies that make teaching in classrooms and laboratories more meaningful. The knowledge may help the engineering/Technology/trade teacher to arrange the classroom and laboratories appropriately prior to the commencement of the teaching and learning instruction, have background understanding of students and adopt appropriate strategies to assess students' level of instructional achievement (Weyers et al., 2024).

Other categories of teacher knowledge include curriculum knowledge, knowledge of educational contexts, and knowledge of educational ends, purposes and values. (Shulman, 1987).

Implication of the study

This article synthesized the scholastic opinions and reports of the previous studies on re-curriculation of engineering, technology and technical education programs for adopting Industry 5.0. The article has implications on educational stakeholders, specifically STEM educators, school administrators, policy makers and governments. The article exposes educational stakeholders - educators, school administrators and policy makers to historical trends of industries. The article informs the educators, policy makers and government of the current industrial era that these are features and qualities of the era. This will help the educators to engage in training that will make them fit for the changes, encourage government to offer necessary supports and adequate funds to equip the schools and training the teachers to cope with changes appropriately, and stimulate policy makers to enact favorable policies that will promote adequate adjustment to the current industrial era. The article will inform teachers, school administrators and government on the needs for the re-curriculation of existing/current educational programs and inform them of steps/phases of re-curriculation of existing/current educational programs. This will help them to understand the roles expected of them during the re-curriculation process.

Conclusion

The advent of Industry 5.0 was accompanied by new requirements, new roles and new tasks. These make the knowledge and skills possessed by industrial workers stand obsolete and, by extension, make them irrelevant and unfit for industrial jobs in this era. This is because the old knowledge and skills they possessed could no longer be useful in industries these days. However, this article presents Industry 5.0 in a holistic form, establishing the need for knowledge and skills in the Industry 5.0 era. The article conceptualized engineering, technology and technical education, and the challenges they are facing in addressing Industry 5.0. The article conceptualised re-curriculation of engineering, technology and technical education and finally, detailed phases of re-curriculation in engineering, technology and technical education.

The re-curriculation, if accepted by engineering, technology and technical education administrators in the universities and colleges of engineering and technology globally, will promote the turning out of graduates who are competent and qualified to work conveniently with robots in industries.

References

- Acemoglu, D. & Restrepo, P. (2017). *Robots and jobs: evidence from US labor markets*. NBER Working Paper Series. Retrieved from: <http://www.nber.org/papers/w23285>
- Aguokogbuo, C. N. (2000). *Curriculum development and implementation for Africa*. Nsukka: Mike Social Press.
- Akins, L. & Burghardt, D. (2006). Work in progress: Improving K-12 mathematics understanding with engineering design projects, in *Frontiers in education conference, 36th Annual, San Diego, CA, 27–31 October 2006*. New York, NY: IEEE. pp. 13–14
- Akinyemi, S., Ofem, I. B., & Ikuenomore, S. O. (2012). Graduate turnout and graduate unemployment in Nigeria. *International Journal of Humanities and Social Science*, 24: 257–265.
- Alpaslan, D. K., Cayman, E. & Eli, M. (2017). Issues in Integrating Robots into Organizations. *The 12th International Scientific Conference on Defence Resources Management in the 21st Century*, November 09-10, 2017, Brasov, Romania.
- Altalbe, A. (2018). *Virtual laboratories for electrical engineering students: student perspectives and design guidelines* [PhD Dissertation, University of Queensland, Brisbane, QLD, Australia.
- Anang, A. N., Obidi, P. O., Mesogboriwon, A. O., Obidi, J. O., kuubata, M. & Ogunbiyi, D. (2024). The role of Artificial Intelligence in industry 5.0: Enhancing human-machine collaboration. *World Journal of Advanced Research and Reviews*, 2024, 24(02), 380–400. <https://doi.org/10.30574/wjarr.2024.24.2.3369>
- Anangisye, W. A. L. (2008). Developing quality teacher professionals: A reflective inquiry on the practices and challenges in Tanzania. *Africa-Asia University Dialogue for Education, CICE Series*, 137-154
- American Management Association. (2010). *Critical skills survey*. Retrieved from: [http://www.amanet.org/news/AMA-2010-critical skills survey.aspx](http://www.amanet.org/news/AMA-2010-critical%20skills%20survey.aspx)
- Ankeli, G. O. (2019). Science and technology education development and the Nigerian child: challenges and prospects. *BSUJEM*, 1 (2): 58-66.
- Atkins, G. (2025). *What Is Pedagogical Content Knowledge?* Retrieved from: <https://www.hmhco.com/blog/what-is-pedagogical-content-knowledge?srsId=AfmBOoqowp4aV96pUeBhwKIsVZRu1maSjlG5fsWGC8rp0RqnmMOTmc71>
- Association for Career and Technical Education (ACTE) (2014). *ACTE Today Fact Sheet*. Retrieved from <https://www.acteonline.org/CTETodayOct14>
- Atman, C. J., Sheppard, S. D., Turns, J., Adams, R. S., Fleming, L. N., Stevens, R., Streveler, R. A., Smith, K.A., Miller, R.L., Leifer, L.J., Yasuhara, K. & Lund., D. (2010). Enabling Engineering Student Success, *The Final Report for the Center for the Advancement of Engineering Education*. Retrieved from: <http://files.eric.ed.gov/fulltext/ED540123.pdf>.
- Bazylik, S. & Gibbs, M. (2022). *How is new technology changing job design?* IZA World of Labor. Retrieved from: <https://wol.iza.org/articles/how-is-new-technology-changing-job-design/map>

- Beane, J. A., Toepfer, C. F. & Alessi, S. J. (1986). *Curriculum planning and development*. London: Allyn and Bacon, Inc
- Bianchi, M. (2002). The insatiability of human wants: economic and aesthetics in market society (review). *History of political economy*, 34 (4): 811-814.
<https://doi.org/10.1215/00182702-34-4-811>
- Blomdahl, E. (2005). Towards a Philosophy of Technology Education Based on Heidegger and Dewey. In L. Lindstrom (Ed), *Technology Education in New Perspectives Research, assessment and curriculum development*. Stockholm: Stockholm Institute of Education Press
- Board of Engineers, Malaysia (2003). *The Engineering Technology Path Blueprint for a highly competent engineering technical workforce*. Retrieved from:
https://www.academia.edu/6087653/The_Engineering_Technology_Path_2003_Report
- Boboc, M. (2012). The Postmodern Curriculum in a Modern Classroom. *International Journal of Education*, 4(1): 142-152. URL: <http://dx.doi.org/10.5296/ije.v4i1.1167>
- Brunhaver, S. R., Korte, R. F., Barley, S. R. & Sheppard, S. D. (2017). Bridging the gaps between engineering education and practice. In: US engineering in the Global Economy, eds Freeman R, Salzman H. Cambridge, MA: National Bureau of Economics Research.
- Burgess, H. (2004). Redesigning the curriculum for Social Work Education: Complexity, conformity, chaos and creativity. *Social Work Education* 23(2): 163–183.
- Carew, A. L. & Cooper, P. (2008). Engineering curriculum review: processes, frameworks and tools. SEFI - Annual Conference of European Society for Engineering Education (pp. 1007-1016). Aalborg, Denmark: SEFI.
- Carminati, L., Lagorio, A., Cimini, C., Pirola, F., Jurczuk, A. & Boucher, X. (2025). Integrating skills frame for industry 5.0: insight from a systematic literature review and European survey study. *Journal of environment management*, 394: 127425.
<https://doi.org/10.1016/j.jenvman.2025.127425>
- Carnevale, A. P., Smith, N., Stone, J. R., Kotamraju, P., Steuernagel, B. & Green, K. (2011). *Career Clusters: Forecasting Demand for High School through College Jobs, 2008– 2018*. Washington, DC: Georgetown University Center on Education and the Workforce.
- Carr, E. H. & Haslam, J. (1980). *From Napoleon to Stalin and Other Essays*. London, UK: Macmillan London.
- Carr, A., Balasubramanian, K., Atieno, R., & Onyango, J. (2018). Lifelong learning to empowerment: Beyond formal education. In: *Distance Education Journal*, 39 (1), 69-86.
- Chattopadhyay, A. (2020). *Curriculum 4.0 for Industry 4.0*. Retrieved from:
<https://globalfocusmagazine.com/curriculum-4-0-for-industry-4-0>
- Cheshier, S. R. (1998). *Studying Engineering Technology*. Los Angeles: Discovery Press, pp. 36-37.
- Ciraso-Cali', A., Quesada-Pallares, C. & Rebollar-Sanchez, E. M. (2016). In-service teacher training for VET institutions: the challenge of evaluation in *Comunitat Valenciana (Spain)*. In Eicker, F. Haseloff, G., Lennartz, B. (Eds). *Vocational Education and Training in Sub-Saharan Africa: Current Situation and Development* Germany: W. Bertelsmann Verlag GmbH & Co. KG. <https://doi.org/10.3278/6004570w>
- Cojocariu, O. (2019). *Industry 5.0 opportunities and challenges: bring your factory into the future*. Retrieved from: <https://digitalya.co/blog/industry-5-opportunities-and-challenges/>
- Coral, J. S. (2009). *Engineering education for a sustainable future*. Barcelona.

- Council on Higher Education (2013). *A proposal for undergraduate curriculum reform in South Africa: The case for a flexible curriculum structure*. Pretoria: Council on Higher Education.
- Council on Higher Education. (2006). *Academic Freedom, Institutional Autonomy and the Corporatised University in Contemporary South Africa*. (CHE HEIAAF No.3) Pretoria: CHE.
- Demir, S. & Ercan, F. (2019). The effect of a self-awareness and communication techniques course on the communication skills and ways of coping with stress of nursing students: An interventional study in Ankara, Turkey. *J. Pak. Med. Assoc.*, 69, 659–665.
- Demira, K. A., Dövena, G. & Sezenb, B. (2019). Industry 5.0 and Human-Robot Co-working. *Procedia Computer Science*, 158: 688–695. <https://doi.org/10.1016/j.procs.2019.09.104>
- de Oliveira, A. (2024). *Upskilling Your Workforce for Industry 5.0 (Benefits + Strategies)*. Retrieved from: <https://blog.proactioninternational.com/en/upskilling-employees-for-industry-50>
- Department of Education (DOE). (1997). *White Article on Higher Education 3: A Programme for the transformation of higher education*. Retrieved from: http://www.gov.za/sites/default/files/gcis_doc
- Department for Education (2013). *Design and technology programmes of study: key stages 1 and 2 National curriculum in England*. Retrieved from: https://assets.publishing.service.gov.uk/media/5a7ca43640f0b6629523adc1/PRIMARY_national_curriculum_-_Design_and_technology.pdf
- Doll, W. (2013) The Four R's – An Alternative to the Tyler Rationale. In: D. J. Flinders & S. J. Thornton (Eds.), *Curriculum Studies Reader (4th ed.)*. New York, NY: Routledge Falmer, pp. 215–222.
- Doll, W. E. (1993). *A Postmodern Perspective on Curriculum*. New York: Teachers College Press. Ducker
- Domonoske, C. (2019). Even In the Robot Age, Manufacturers Need the Human Touch. NPR.
- Doyle-Kent, M., Kopacek, P. (2020). Industry 5.0: Is the manufacturing industry on the cusp of a new revolution? In: N. Durakbasa, M. Gençyılmaz (Eds.), *Proceedings of the International Symposium for Production Research 2019* (pp. 432–441). Seria: Lecture Notes in Mechanical Engineering. Cham: Springer.
- Durlauf, S. N. & Blume, L. E. (2010). *Economic Growth | Industrial Revolution*. 148–160. doi:10.1057/9780230280823_22
- Gess-Newsome, J. (1999). Secondary teachers' knowledge and beliefs about subject matter and their impact on instruction. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge: The construct and its implications for science education* (pp. 51–94). Kluwer Academic Publishers.
- Edwin, O.M., & Stella, K.O. (2016). E-Learning in TVET: An Opportunity for Developing Countries. *IRA International Journal of Education and Multidisciplinary Studies*, 3(3), 54-66.
- Eggen, P. D. & Kauchak, D. P. (2006). *Strategies and Models for Teachers Teaching Content and Thinking Skills*, 5th edition, Pearson Education Inc.
- Eide, A. R., Jenison, R. D., Northup, L.L., Mickelson, S.K., (2008). *Engineering Fundamentals and Problem Solving*, (6th ed.), McGraw-Hill, NY, pp.1-51.
- European Parliament and Council (EP& C). (2006). *Recommendation of the European Parliament and of the Council on key competences for lifelong learning*. Official Journal of European Union.

- Faccio, M., Granata, I., Menini, A., Milanese, M., Rossato, C., Bottin, M., & Rosati, G. (2023). Human factors in the cobot era: a review of modern production systems features. *Journal of Intelligent Manufacturing*, 34(1), 85–106. <https://doi.org/10.1007/s10845-022-01953-w>
- Federal Republic of Nigeria (2004). *National Policy on Education*. Lagos: Federal Government Press.
- Federal Republic of Nigeria (2013). *National Policy on Education*. Lagos: NERDC Press.
- Felder, R. M., Woods, D. R., Stice, J. E. & Rugarcia, A. (2000). The future of engineering education ii. teaching methods that work. *Chem. Engr. Education*, 34(1): 26–39.
- Filippi, E., Bann`o, M. & Trento, S. (2023). Automation technologies and their impact on employment: A review, synthesis and future research agenda. *Technological Forecasting & Social Change* 191: 122448. <https://doi.org/10.1016/j.techfore.2023.122448>
- Forbes, B. E. (2006). *Programme Design and Quality Management for Work-Integrated Learning in a Co-operative Education Partnership*. Cape Peninsula University of Technology
- Ford, M., 2015. *Rise of the Robots: Technology and the Threat of a Jobless Future*. Basic Books.
- Foster, P. (2020). What do teacher need to know? Retrieved from: <https://curriculumteamleader.wordpress.com/2020/08/30/what-do-teachers-need-to-know-part-1-subject-content-knowledge/>
- Francois, C. (2005). *Computer Technicians: Occupational Outlook Handbook*. USA: Graw Hill Publishers.
- Galvao, C., Claudia, F., Sofia, F., & Monica, B. (2017). Curriculum Conception, Implementation and Evaluation: An Experience, in Ben Akpan (Ed.), *Science Education: A Global Perspective*. Switzerland: Springer International Publishing.
- Gang, X. (2015). Doll's Pedagogical Theory and Its Enlightenment on British and American Literature Teaching. *English Language Teaching*, 8(3):104-10
- Garraway, J. (2007). Processes and Patterns of Responsiveness to the World of Work in Higher Education Institutions. *PhD thesis University of Western Cape*, south Africa.
- Global Electronic Service (2020). *What Is Industry 5.0 — and How Will It Affect Manufacturers?* <https://gesrepair.com/industry-5-0-will-affect-manufacturers/>
- Godden, P. (2014). Curriculum Theory: Doll's four R's—An alternative to the Tyler rationale. Retrieved from: <https://talkcurriculum.wordpress.com/2014/09/30/doll-w-2013-the-four-rs-an-alternative-to-the-tyler-rationale-in-d-j-flinders-s-j-thornton-eds-curriculum-studies-reader-4th-ed-pp-215-222-new-york-ny-routledge/>
- Golby, M. (1977). Curriculum Studies and Education for Teaching. *Journal of Further and Higher Education*, 1:1, 68-77, <https://doi.org/10.1080/0309877770010110>
- Gomez-Zwiep, S. (2016). *Science, Technology, Engineering and Math (STEM) Curricula in the US and Other Contexts*. In Wyse, D., Hayward, L. & Pandya, J. (Eds). *The SAGE Handbook of Curriculum, Pedagogy and Assessment*. Washington DC: SAGE Publications Ltd
- Government of Alberta (2024). *Ironworker Metal Building Systems Erector: apprenticeship education program curriculum guide*. Retrieved from: chrome-extension://efaidnbmninnibpcapjpcglclefindmkaj/https://tradesecrets.alberta.ca/SOURCE/S/PDFS/CURRICULUM_GUIDES/0404_OUTLINE.PDF
- Grabowska, S., Sługocki, W & Aleksandra Saniuk, A. (2024). Industry 5.0 – directions of business action and knowledge of technology in the context of surveys of employees of manufacturing companies. *Scientific Papers of Silesian University of Technology Organization and Management Series NO. 202*: 139-152. <http://dx.doi.org/10.29119/1641-3466.2024.202.9>

- Graube, G. (2005). Proposal of a Model of Competence for Technological Education. In L. Lindström (Ed.) *Technology Education in New Perspectives Research, assessment and curriculum development*. Stockholm Library of Curriculum Studies Vol. 14. Stockholm: Stockholm Institute of Education Press (HLS Förlag).
- Graube, G. & Theuerkauf, W. E. (2005). Technological Development and Development of Technology Education. In L. Lindström (Ed.) *Technology Education in New Perspectives Research, assessment and curriculum development*. Stockholm Library of Curriculum Studies Vol. 14. Stockholm: Stockholm Institute of Education Press (HLS Förlag).
- Greenwood, J. (1997). *The third industrial revolution: Technology, productivity, and income inequality* (No. 435). American Enterprise Institute.
- Guan, S-S. & Lu, L-S. (2012). A study on curriculum structure and industry requirement of design education in Taiwan. *International Journal on New Trends in Education and Their Implications*, 3(3):27-37.
- Güçerçin, S. & Güçerçin, U. (2021). How Employees Survive in the Industry 5.0 Era: In-Demand Skills of the Near Future. *Int. J. Discip. Econ. Adm. Sci. Stud.*, 7, 524–533.
- Hadgraft, R. G. (2017). New curricula for engineering education: experiences, engagement, e-resources. *Global Journal of Engineering Education*, 19(2): 112-117.
- Haleem, A., & Javaid, M. (2018). Industry 5.0 and its applications in orthopaedics. *Journal of clinical orthopaedics and trauma*, 10(4), 807–808.
<https://doi.org/10.1016/j.jcot.2018.12.010>
- Harden, R. M. (2001). AMEE Guide No. 21: Curriculum mapping: a tool for transparent and authentic teaching and learning. *Medical teacher*, 23(2), 123-137.
- Hernandez-Gantes, V. M. (2016). College and Career Readiness for All: The Role of Career and Technical Education in the US 674. In D. Wyse, L. Hayward, & J. Pandya (Eds), *The SAGE Handbook of Curriculum, Pedagogy and Assessment*. Washington DC: SAGE Publications Ltd.
- Hernandez-Gantes, V.M. and Fletcher, E. (2013). The need for integrated workforce development systems to broaden the participation of underrepresented students in STEM-related fields. in R. Palmer & L. Wood (eds.), *Community College and STEM: Examining Underrepresented Racial and Ethnic Minorities*. New York, NY: Routledge.
- Hlavac, J. (2023). Knowledge, skills and abilities (KSAs) as a metric to re-conceptualise aptitude: a multi-stakeholder perspective. *The Interpreter and Translator Trainer*, 17(1).
<https://doi.org/10.1080/1750399X.2023.2170052>
- Huang, S., Wang, B., Li, X., Zheng, P., Mourtzis, D., & Wang, L. (2022). Industry 5.0 and society 5.0—Comparison, complementation and co-evolution. *Journal of Manufacturing Systems*, 64, 424–428. <https://doi.org/10.1016/j.jmsy.2022.07.010>
- Ibanga, F. D. A. (2015). Solving the problem of poor quality of university graduates in Nigeria – A proposed holistic approach. *British Journal of Education*, 3(7), 43–49. Ibezim. N. E. (2011). Social networking skill needed by technicians of computer hardware maintenance for effective entrepreneurship. *Nigeria Vocational Association Journal* 16(1): 102-117.
- Ikenga, G.U. & van der Sijde, P. (2024). Twenty-First Century Competencies, about Competencies for Industry 5.0 and the Opportunities for Emerging Economies. *Sustainability*: 16, 7166. <https://doi.org/10.3390/su16167166>
- Ilkiw, J. E., Nelson, R. W., Watson, J. L., Conley, A. J., Raybould, H. E., Chigerwe, M. & Boudreaux, K. (2017). Institutional Experiences with Curricular Renewal Curricular

- Revision and Reform: The Process, What Was Important, and Lessons Learned. *JVME*, 44(3): 480-489. 2017 AAVMC <https://doi.org/10.3138/jvme.0316-068R>.
- Institute for the Future. (2015) *Future Work Skills 2020*. Retrieved from: <http://www.iftf.org/futureworkskills/>
- Institution of Engineers, Australia, IEAust, (2002). *Australian Engineering Technology Programmes Accredited by the Institution of Engineers Australia*.
- Irons, P. C., Holm, D. E. & Annandale, C. H. (2017). Institutional Experiences with Curricular Renewal Curricular Renewal at the Southern Tip of Africa: The 2016 Veterinary Curriculum at the University of Pretoria. *JVME* 44(3):440-449. <https://doi.org/0.3138/jvme.0316-062R>
- Isabel, M. & Stewart, R. N. (1935). Curriculum revision an essential step in the reconstruction of nursing education. *The American Journal of Nursing*, 35(1): 58-66. <http://www.jstor.org/stable/3412556>.
- Jackson, N. (2002). *Pressures for curriculum change*. UK: LTSN Generic Centre.
- James N. O., Isaac, B. E. & Joseph, E. B. (2015). Technology education and development in Nigeria beyond 2020. *Knowledge Review*, 33(3):1-6.
- Jansen, J.D. (2012). Can the theological leopard change its spots? On the transformation of university knowledge. In Venter & Tolmie (Eds.) 2012. *Transforming theological knowledge: Essays on theology and the university after apartheid*. 9-19. SunMedia, Bloemfontein.
- Jardine, J. (2020). *Industry 5.0: Top 3 Things You Need to Know*. Retrieved from: <https://www.mastercontrol.com/gxp-lifeline/3-things-you-need-to-know-about-industry-5.0/>
- Javaid, M. & Haleem, A. (2019). Critical components of Industry 5.0 towards a successful adoption in the field of manufacturing, *Journal of Industrial Integration and Management*, <https://doi.org/10.1142/S2424862220500141>
- Jobs for the Future (2007) *The STEM Workforce Challenge: The Role of the Public Workforce System in a National Solution for a Competitive Science, Technology, Engineering, and Mathematics Workforce*. Washington, DC: US Department of Labor, Employment and Training Administration.
- Johnson, J. A. (2001). Principles of Effective Change: Curriculum Revision That Works. *The Journal of Research for Educational Leaders*, 1(1):5-18.
- Jonathan C. N. & Monday, M. E. (2017). Technical and Vocational Education and Training as a Tool for National Sustainable Development in Nigeria. *The International Journal of Social Sciences and Humanities Invention* 4(9): 3983-3988. <https://doi.org/10.18535/ijsshi/v4i9.14.c>
- Katehi, L., Pearson, G. & Feder, M. (2009). *Engineering in K-12 Education: Understanding the Status and Improving the Prospects*. Washington, D.C. The National Academies Press.
- Kelly, S. (2015). *Raising Productivity by Improving Higher Technical Education: Tackling the Level 4 and Level 5 Conundrum (HEPI Occasional Article 11)*. Oxford: Higher Education Policy Institute [online]. Retrieved from: <http://www.hepi.ac.uk/2015/07/16/raising-productivity-improving-higher-technical-education-tackling-level-4-level-5-conundrum/>
- Kennedy, G. W., Ekong, M. O. & Okorie, M. N. (2022). Digital Technological Tools for Technical Vocational Education and Training Interactive Learning: Availability and Utilization in Nigerian Universities. *Rivers State University Journal of Education* 25 (2):85-95
- Kent, M. D. & Kopacek, P. (2019). *Industry 5.0: Is the Manufacturing Industry on the cusp of a new revolution?* https://doi.org/10.1007/978-3-030-31343-2_38

- Retrieved from: <https://www.researchgate.net/publication/336819748>
- Kim, Y. M. (2011). *Minorities in Higher Education: Twenty-Fourth Status Report, 2011 Supplement*. Washington, DC: American Council on Education.
- Kipper, H. & Rüttemann, T. (2013). Special Focus Article: Teaching for Understanding in Engineering Education. *IJEP*. 3(1): 55-63. <http://dx.doi.org/10.3991/ijep.v3iS1.2402>
- Kline, R. R. (1992). *Steinmetz: Engineer and Socialist*. Baltimore, Md.: Johns Hopkins University Press.
- Kopacek, P., (2018). Development Trends in Cost Oriented Production Automation. *IFAC-Articles Online*, 51(30), pp.39-50.
- Korcomptenz (2019) *Korcomptenz.com*. Retrieved from: <https://www.korcomptenz.com/blog/industry-5-0>
- Koretsky, M. D. & Magana, A. J. (2019). Advances in engineering education: Using Technology to Enhance Learning and Engagement in Engineering. *American society for engineering education, spring*.
- Korkmaz, O., Kösterelioğlu, M., Kara, M. (2018). A Validity and Reliability Study of the Engineering and Engineering Education Attitude Scale. *IJEP* – (8). 5:44-57.
- Kospanos, V. (2017). *Industry 5.0 – far from science fiction (pt. 2)*. Retrieved from: <http://www.pnmsoft.com/industry-5-0-far-science-fiction-pt-2/>
- Kozí, T. (2015). The Importance of Technical Education for the Development of Society. *Acta Technologica Dubnicae*, 5(3):48-72. <https://doi.org/10.1515/atd-2015-0070>
- Lange, L. (2012). Knowledge, curriculum and transformation. In Venter & Tolmie (Eds) *Transforming theological knowledge: Essays on theology and the university after apartheid*. Sun Media Bloemfontein (Pty) Ltd. <https://doi.org/10.18820/9781920382261>
- Lau, D. C-M. (2001) Analysing the curriculum development process: three models. *Pedagogy, Culture and Society*, 9:1, 29-44. <https://doi.org/10.1080/14681360100200107>
- Lemo, O. O. & Olakotan, O. O. (2016). Strategies for enhancing the functionality of metalwork workshops in technical and vocational education institutions in Nigeria. *Nigeria Journal of Education, Health and Technology Research. NJEHETR*, 8(1): 111-119.
- Lewis, A., (2016) *Guide to Industry 4.0 & 5.0*. Retrieved from: <https://blog.gesrepair.com/category/manufacturing-blog/8>
- Leng, J., Sha, W., Wang, B., Zheng, P., Zhuang, C., Liu, Q., & Wang, L. (2022). Industry 5.0: Prospect and retrospect. *Journal of Manufacturing Systems*, 65, 279–295. <https://doi.org/10.1016/j.jmsy.2022.09.017>
- Li, L. (2020). Education supply chain in the era of Industry 4.0. *Syst. Res. Behav. Sci.* 2020, 37, 579–592.
- Lindstrom, L. (2005). Introduction. In L. Lindstrom (Ed), *Technology Education in New Perspectives Research, assessment and curriculum development*. Stockholm: Stockholm Institute of Education Press
- Lixin, L. (2004). Letter to my sister about Doll's 4R's. *Transnational Curriculum Inquiry*, 1(1): 28-42. <http://nitinat.library.ubc.ca/ojs/index.php/tci>
- Lu, L-S., Guan, S-S., Chang, W-S. & Huang, C-C. (2013). A Study on the Curriculum Structure and Industry Needs for Digital Media Design Education in Taiwan. *Procedia - Social and Behavioral Sciences* 83: 895 – 899. <https://doi.org/10.1016/j.sbspro.2013.06.167>
- Lu, Y. (2017), Cyber-physical system (CPS)-based industry 4.0: a survey. *Journal of Industrial Integration and Management*, 2(3), 1750014.
- Lucas, B. & Spencer, E. (2015). *Remaking Apprenticeships: Powerful Learning for Work and Life. Summary Report*. London: City and Guilds [online]. Retrieved from:

- <http://www.cityandguilds.com/~media/Documents/what-weoffer/apprenticeships/Remaking%20Apprenticeships%20pdf.ashx>
- Luo, L. (2004). Letter to my sister about Doll's 4R's. *Transnational Curriculum Inquiry*, 1(1) <http://nitinat.library.ubc.ca/ojs/index.php/tci>
- Macon-Cooney, B. (2019). *The state and technological revolution*. Retrieved from: <https://thefinancialexpress.com.bd/views/the-state-and-technological-revolution-1577031193>
- Madsen, D. & Berg, T. (2021). An Exploratory Bibliometric Analysis of the Birth and Emergence of Industry 5.0. *Appl. Syst. Innov.*, 4, 87, <https://doi.org/10.3390/asi4040087>.
- Magaji, M. (2015). The Role of Vocational and Technical Education for Improving National Economy for Sustainable Development: Curriculum Issues. *IOSR Journal of Research & Method in Education*, 5, (3): 12-18. <https://doi.org/10.9790/7388-05321218>
- Martynov, V.V., Shavaleeva, D.N., Zaytseva, A.A. (2019). Information Technology as the Basis for Transformation into a Digital Society and Industry 5.0. 2019 International Conference "Quality Management, Transport and Information Security, Information Technologies"(IT&QM&IS). *IEEE*, 539-543.
- McCrone, T., O'Beirne, C., Sims, D., & Taylor, A. (2015). *A review of technical education*. Slough: National Foundation for Educational Research (NFER)
- Meliani, F., Natsir, N. F. & dan Haryanti Erni, D. H. (2021). Sumbangan Pemikiran Ian G. Barbour Mengenai Relasi Sains Dan Agama Terhadap Islamisasi Sains. *JlIP-Jurnal Ilmiah Ilmu Pendidikan* 4(7): 673–88, <https://doi.org/10.54371/jiip.v4i7.331>
- Momo, O. A. (2012). Revitalization of Technical Education in Nigeria as Vehicle for Transformation. *Proceedings of COREN 21st Engineering Assembly*, Pp 53 – 81.
- McInerney, P. A. (1998). *Recurriculating to a problem-based learning curriculum: The WITS experience*. Curationis Report, 53-56.
- Nădrag, L. & Buzarna-Tihenea, A. (2015). From Modern to Postmodern Curriculum. The Annals of UOC: the Philology Series, 2/2015. Retrieved from: https://litere.univ-ovidius.ro/Anale/documente-z/art-rez-2015-2/10_Nadrag-Galbeaza%202-2015.pdf
- Nahavandi, S. (2019). Industry 5.0 - A Human-Centric Solution. *Sustainability*, 11, 4371, doi:10.3390/su11164371
- National Academy of Sciences. (2005). *Educating the Engineer of 2020: Adapting Engineering Education to the New Century*. Washington, DC: The National Academies Press. Retrieved from: <http://www.nap.edu/catalog/11338.html>
- National Academy of Sciences (2007). *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*. Washington, DC: The National Academies Press.
- National Academies of Sciences, Engineering, and Medicine. (2018). *Understanding the Educational and Career Pathways of Engineers*. Washington, DC: The National Academies Press. <https://doi.org/10.17226/25284>.
- Negroponte, N. (1995). *Being Digital*. London: Hodder & Stough.
- Nkomo, M. (2000). *The National Qualifications Framework and Curriculum Development*. Pretoria: South African Qualifications Authority.
- Nusche, D. (2016). Student Assessment and its Relationship with Curriculum, Teaching and Learning in the Twenty-First Century. In Wyse, D., Hayward, L. & Pandya, J. (Eds), *The SAGE Handbook of Curriculum, Pedagogy and Assessment*. Washington DC: SAGE Publications Ltd

- Odo, J. U., Okafor, W. C., Odo, A. L., Ejikeugwu, L. N. & Ugwuoke, C. N. (2017). Technical Education – The Key to Sustainable Technological Development. *Universal Journal of Educational Research*, 5(11): 1878-1884. <https://doi.org/10.13189/ujer.2017.051104>
- OECD (2015). *Skills Outlook 2015: Youth, Skills and Employability*. Paris: OECD Publishing.
- Oei, P.R.A., Lenaerts, K., Dhondt, S., Van Dijk, W., Scharinger, D., Sorko, S.R., Warhurst, C., (2024). A Conceptual Framework for Workforce Skills for Industry 5.0: Implications for Research, Policy and Practice, *Journal of Innovation Management*, 12(1), 205-233, https://doi.org/10.24840/2183-0606_012.001_0010
- Ogbuanyia & Onele (2018): Investigating the Effectiveness of Desktop Virtual Reality for Teaching and Learning of Electrical/Electronic Technology in Universities. *Computers in the Schools*. <https://doi.org/10.1080/07380569.2018.1492283>
- Ogbuanyia, T. C. & Yekinni, S. A. (2019). Advancing Electronic Waste Management Techniques among Electrical/Electronic Technicians' Workshops for Sustainable Healthy Society. *Insights Min Sci technol.*, 1(4): 555566. <https://doi.org/10.19080/IMST.2019.01.555566>
- Ohanu, I. B. & Ogbuanyia, T. C. (2014) Precautionary Measures Necessary in Liquid Crystal Display (LCD) Television Maintenance by Electronic Technicians. *Modern Economy* 5: 201-210.
- Okeke, E.A.C. (198 1). *The Dynamics of Curriculum Revision*. In Uga Qnwuka (Ed.) *Curriculum Development for Africa*. Onitsha: AMcana- FkP Publishers.
- Okeowo, O. (2009). The teacher in the school system. In K. Oyesiku, S. Ogunsaju, & J. Oni (Eds.), *Contemporary school administration in Nigeria*. Ijebu-Ode: Tai Solarin University of Education Press.
- Okoye, R. & Arizona, M. O. (2016). Technical and Vocational Education in Nigeria: Issues, Challenges and a Way Forward. *Journal of Education and Practice*, 7(3): 113-118.
- Olaitan, S. O. (2003). *Understanding Curriculum*. Nsukka: Ndudim Printing & Publishing Coy.
- Olakotan, O. O. & Lemo, O. O. (2019). Appraising fabrication and welding students' employability skills in Ogun state technical colleges. *International Journal of Education*, 11(2), 125-129. <https://doi.org/10.17509/ije.v11i2.11896>
- Oranu, R.N. (2010) *Vocational and technical education in Nigeria*. Retrieved from: <http://www.ibe.unesco.org/curriculum/AfricaPdf/lago2ora.pdf>
- Østergaard, E. H. (2018). *Welcome to Industry 5.0*. Retrieved from: https://www.researchgate.net/profile/Mohamed_Mourad_Lafifi/post/Industry_40_vs_Industry_50-Does_industry_50
- Otokunefor, T. (2011). Why Nigerian universities produce poor quality graduates. *Alpha Education Foundation Educational Monograph Series* (No. 3), 1–22. Retrieved from: https://issuu.com/skillsmagazine/docs/aef-quality_of_nigerian_univ_graduates
- Özdemir, V. & Heim, N. (2018). Birth of Industry 5.0: Making Sense of Big Data with Artificial Intelligence, 'The Internet of Things' and Next-Generation Technology Policy. *Journal of integrative biology*. <https://doi.org/10.1089/omi.2017.0194>.
- Parashara, K. & Parashar, R. (2012). Innovations and Curriculum Development for Engineering Education and Research in India Ashish. *Procedia - Social and Behavioral Sciences* 56: 685 – 690. <https://doi.org/10.1016/j.sbspro.2012.09.704>
- Pasenet L. L. (1993). *Structural economic dynamics*. Cambridge: Cambridge University Press.
- Patches, D., Moan, A. & Draghici, A. (2019). industry 5.0 – the expected impact of next industrial revolution. *International conference on technology, innovation and industrial management*, 15-17 May, Piran, Slovenia.

- Pluchino, P., Pernice, G., Nenna, F., Mingardi, M., Bettelli, A., Bacchin, D., Spagnolli, A., Jacucci, G., Ragazzon, A., Miglioranza, L., Pettenon, C., & Gamberini, L. (2023). Advanced workstations and collaborative robots: Exploiting eye-tracking and cardiac activity indices to unveil senior workers' mental workload in assembly tasks. *Frontiers in Robotics and AI*, 10, 104559. <https://doi.org/10.3389/frobt.2023.1275572>
- Priowirjanto, G. H. (2001). *Vocational Education Reposition toward 2020*. Jakarta: Depdiknas Dirjen Dikdasmen.
- Procario-Foley, C.B. (2017). Institutional mission education as a form of teaching. *Religious Education*, 112 (3) 255-263. <https://doi.org/10.1080/00344087.2016.1247320>.
- Rada, M. (2018). *Industry 5.0 definition*. Retrieved from: <https://medium.com/@michael.rada/industry-5-0-definition-6a2f9922dc48>
- Ramadhani, M. (2017). Curriculum and Competence Based Education Training (CBET) in Tanzania: A Critical Assessment of Public Administration and Management (PAM) Curricula at Tanzania Public Service College (TPSC). *HOLISTICA*, 8(2): 17-40 <https://doi.org/10.1515/hjbpa-2017-0010>
- Ramdass, K. (2012). Programme Re-curriculum: An Experience at the University of Johannesburg. *International Journal of Business and Social Science*, 3 (8): 204-210
- Reinhardt, I. C., Oliveira, J. C., & Ring, D. T. (2020). Current Perspectives on the Development of Industry 4.0 in the Pharmaceutical Sector. *Journal of Industrial Information Integration*, 18. 100131.
- Resane, K. T. (2019). Recurriculum: a pedagogical necessity for theological education at a post-apartheid public university. *Pharos Journal of Theology* 100: 1-10. Retrieved from: <http://www.pharosjot.com>
- Rossato, C., Pluchino, P., Cellini, N., Jacucci, G., Spagnolli, A., & Gamberini, L. (2021b). Facing with collaborative robots: The subjective experience in senior and younger workers. *Cyberpsychology, Behavior, and Social Networking*, 24(5), 349–356. <https://doi.org/10.1089/cyber.2020.0180>
- Rossi, B. (March 7, 2018). *What will Industry 5.0 mean for manufacturing?* Retrieved from: <https://www.raconteur.net/manufacturing/manufacturing-gets-personal-industry-5-0/>
- Saniuk, S., Caganova, D. & Saniuk, A. (2021). Knowledge and Skills of Industrial Employees and Managerial Staff for the Industry 4.0 Implementation. *Mobile Networks and Applications*. <https://doi.org/10.1007/s11036-021-01788-4>
- Saniuk, S. & Sandra Grabowska, S. (2022). Development of knowledge and skills of engineers and managers in the era of Industry 5.0 in the light of expert research. *Silesian University of Technology Publishing House Scientific Papers of Silesian University of Technology 2022 Organization and Management series no. 158*. <http://dx.doi.org/10.29119/1641-3466.2022.158.35>
- Saniuk, S. & Grabowska, S. (2023). Knowledge and Skills Development for Implementing the Industry 5.0 Concept. *Proceedings of the 24th European Conference on Knowledge Management, ECKM 2023*, 1188-1195.
- Schneider, R. & Rivet, A. (2000). Curriculum Revision as a Research Activity: Using Classrooms to Improve Curriculum. *Article presented at the National Association for Research in Science Teaching Annual Meeting New Orleans, LA April 2000*. Retrieved from: <http://www-personal.umich.edu/~krajcik/Becky.NARST.pdf>
- Schultz, D. (2013). Curriculum revision: Challenges in responding to change. *Progression*, 35 (2): 133–153.

- Shelzer, R. (2017). *What Is Industry 5.0 — and How Will It Affect Manufacturers?* Retrieved from: <https://blog.gesrepair.com/industry-5-0-will-affect-manufacturers/>
- Schlagenhauf, W. (2005). Perspectives on Technology Education in Germany and the situation today. In L. Lindstrom (Ed). *Technology Education in New Perspectives Research, assessment and curriculum development*. Stockholm: Stockholm Institute of Education Press.
- Shing, C. L., Saat, R. M., & Loke, S. H. (2015). The Knowledge of Teaching – Pedagogical Content Knowledge (PCK). *The Malaysian Online Journal of Educational Science*, 3(3): 40-55.
- Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, 15(2), 4-14.
- Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review*, 57(1), 1–23.
- Skobelev, P. O. & Borovik, S. Y. (2017). on the way from industry 4.0 to industry 5.0: from digital manufacturing to digital society. *International Scientific Journal*, II, (6): 307-311
- Skobelev, P. O. & Borovik, S. Y. (2017). On the way from Industry 4.0 to Industry 5.0: from digital manufacturing to digital society. *Int Sci J.*, 2(6):307-311.
- Smitherman, S. (2005). Chaos and Complex Theories. In, W. E. Doll Jr., M. J. Fleener, D. Truet & J. St Julien(eds.). *Chaos, Complexity, Curriculum and Culture: A Conversation*. New York: Peter Lang.
- Sönmez, M. (2014). The Role of Technology Faculties in Engineering Education. *Procedia - Social and Behavioral Sciences*, 141: 35 – 44. <https://doi.org/10.1016/j.sbspro.2014.05.009>
- Spang, D. I. (2014). Curriculum Design and Assessment to Address the Industry Skills Gap. 121st *American Society for Engineering Education (ASEE) Annual Conference and Exposition*, Indianapolis in June 15-18, 2014.
- Spencer, D.A., 2018. Fear and hope in an age of mass automation: debating the future of work. *N. Technol. Work. Employ.* 33 (1), 1–12. <https://doi.org/10.1111/ntwe.12105> .
- Starbuck, P. (2016). *What Makes a Quality Curriculum? Current and Critical Issues in Curriculum and Learning*, March, 2016, No.2IBE/2016/WP/CD/02IBE. Retrieved from: <https://unesdoc.unesco.org/ark:/48223/pf0000243975>
- Starbuck, P. (2016). *What Makes a Quality Curriculum? Current and Critical Issues in Curriculum and Learning*, March, 2016, No.2 IBE/2016/WP/CD/02IBE. Paris: UNESCO. Retrieved from: <https://unesdoc.unesco.org/ark:/48223/pf0000243975>
- Steyn, M., Schuld, N. & Hartell, C. (2012). A Bird's Eye View on the Status of the Module "Life Skills" in the Foundation Phase at Higher Education Institutions in South Africa. *South African Journal of Childhood Education*, 2(2): 158-176.
- Stone, J.R. (2013) 'Programs of study, college, and career readiness: career and technical education and making high school matter. *Article presented at the 2013 Annual Meeting of the American Educational Research Association*. Retrieved from: <http://www.aera.net/Publications/OnlineArticleRepository/AERAOnlineArticleRepository/tabid/12720/Default.aspx>
- Subasubani, J. K. (2016). Situation and Development of Vocational Education and Training (VET) and VET Science in Namibia. In Eicker, F. Haseloff, G., Lennartz, B. (Eds). *Vocational Education and Training in Sub-Saharan Africa: Current Situation and Development*, Germany: W. Bertelsmann Verlag GmbH & Co. KG. <https://doi.org/10.3278/6004570w>
- Supriani, Y., Meliani, F., Supriyadi, A., Qiqi, S. & Zaqiah, Y. (2022). The process of curriculum innovation: dimensions, models, stages, and affecting factors. *Nazhruna: Journal*

- Pendidikan Islam 5(2): 485-500 E-ISSN: 2614-8013
<https://doi.org/10.31538/nzh.v5i2.2235>
- Taba, H. (1962). *Curriculum Development. Theory and Practice*. New York: Harcourt Bruce.
- Thanikachalam, V. (2015). curriculum design for industry relevant and interdisciplinary postgraduate programmes in engineering and technology. *Journal of Engineering Education Transformations, Special Issue: Jan. 2015: 58-61*.
- The Government of Western Australia (2025). *Fact Sheet: Current Industry Skills and Knowledge*. Retrieved from: <https://www.wa.gov.au/government/publications/fact-sheet-current-industry-skills-and-knowledge>
- The World Economic Forum (2012). *The Future of Manufacturing Opportunities to Drive Economic Growth*. A World Economic Report in Collaboration with Deloitte Touche Tohmatsu Limited, April 2012.
- Tomasevic, A. N. (2023). Reshaping the Future of Work: Navigating the impacts of lifelong learning and digital competences in the era of 5.0 industry. *Social information journal*, 2(1), 1-6. <https://doi.org/10.58898/sij.v2i1.01-06>
- Umunadi, E. K. (2013). Functional vocational and technical education curriculum for sustainable youth empowerment in Nigeria. *British Journal of Education*, 1(1): 7-13.
- Ustundag, A. & Cevican, E. (2018). *Industry 4.0: Managing the Digital Transformation*. Switzerland: Springer Nature Switzerland AG.
- Uwaifo, V. O. (2009). Technical Education and its Challenges in Nigeria in the 21st Century. *International NGO Journal*, 5(2): 40-44.
- Van As, J., Fouché, I. & Immelman, S. (2016). Academic Literacy for Science: A Starting Point for Recurriculation. *Journal for Language Teaching*, 50(2):11 – 35.
<http://dx.doi.org/10.4314/jlt.v50i2.1>
- Vanderborght, B. (2018). *Industry 5.0: Combining strengths of humans and robots for better and healthier manufacturing*. Vrije Universiteit Brussels: Brussels Human Robotic Research centre.
- Walker, D. F. (2003). *Fundamentals of Curriculum, 2nd edition*. Mahwah, NJ: Lawrence Erlbaum.
- Wattanbarger, J. & Skaggs, S. (1979). Eicker, F. Haseloff, G., Lennartz, B. (Eds).. 1979:(25):1-10.
<https://doi.org/10.1002/cc.36819792503>
- Weyers, J., Ligtoet, R. & König, J. (2024). How does pre-service teachers' general pedagogical knowledge develop during university teacher education? Examining the impact of learning opportunities and entry characteristics over five time points using longitudinal models. *Journal of Curriculum Studies*, 56: 448-467,
<https://doi.org/10.1080/00220272.2024.2355923>
- Whitehead, A. N. (1967). *The aim of education and other essays*. London: Williams & Norgate Ltd. (Original work published 1929).
- Wickert, J., (2006). *An Introduction to Mechanical Engineering, (2nd ed.)*, Thomson, USA, pp. 1-25.
- Winer, R.K., 2000. Rung by up the health career ladder. *American Vocational J.*, 48(7): 18-27.
- Witt, U. (2001). Learning to consume – A theory of wants and the growth of demand. *Journal of Evolutionary Economic*, 11: 23–36
- World Health Organization (2019). *Best practices document and facilitators' guidance: Review and Revision of Laboratory Curricula*. Denmark: WHO Regional Office.
- Xu, L. D. He, W., & Li, S. (2014). Internet of Things in Industries: A Survey. *IEEE Transactions on Industrial Informatics*, 10(4), 2233-2248.

- Xu, L. D., Xu, E.L., & Li, L. (2018). Industry 4.0: State of the art and future trends. *International Journal of Production Research*, 56(8), 2941-2962.
- Xu, X., Lu, Y., Vogel-Heuser, B., & Wang, L. (2021). Industry 4.0 and Industry 5.0—Inception, conception and perception. *Journal of Manufacturing Systems*, 61, 530–535.
<https://doi.org/10.1016/j.jmsy.2021.10.006>
- Yekinni, S. A. & Ogbuanya, T.C. (2025). Mediating role of psychological adjustment ability on emotional intelligence-workshop/laboratory safety behaviour relationship among Electrical/Electronic Technology students. *Discov Educ* 4, 40.
<https://doi.org/10.1007/s44217-025-00427-4>
- Yoto (2017). Preparing Skilled Labor in Industry Through Production- Based Curriculum Approach in Vocational High School. *AIP Conference Proceedings*, 1887, 020002.
<https://doi.org/10.1063/1.5003485>.
- Wajcman, J. (2017). Automation: is it really different this time? *Br. J. Sociol.* 68 (1), 119–127.
<https://doi.org/10.1111/1468-4446.12239>.
- Wang, X., Yu, B. & Han, X. (2021). Industry 5.0: Concept, Characteristics, and Future Trends. *IEEE Access*, 9, 55183–55196.
- Woyo, E. (2013). Challenges facing technical and vocational education and training institutions in producing competent graduates in Zimbabwe. *Open Journal of Education*, 1(7), 182–189.
- World Bank (2016). *World Development Report 2016: Digital Dividends*.
- Zambwa, J., Makinde A. A., Samaila, Y. (2018). Competency Needs of Radio, Television and Electronics Works Teachers for Effective Teaching in Technical Colleges, Northern States of Nigeria. *Multidisciplinary Journal of Science, Technology and Vocational Education* 6(1): 20-31.