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Empowering Student Teachers to teach Technology with a sustainability edge: Crucial aspects to address in Teacher Education

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Abstract

Technology education in primary schools must integrate sustainable development to provide young learners with the basic knowledge, skills, and values to understand, appreciate and contribute to a sustainable future. This integration prepares them for the challenges of a rapidly changing world, promotes responsible use of technology and fosters a sense of environmental responsibility from an early age. However, for this to happen, teacher education needs to adopt strategies that empower student teachers to seamlessly integrate sustainable development into technology education and equip them with environmentally and socially responsible attitudes. The aim of this study is to explore what needs to be addressed in teacher education to prepare student teachers to teach technology integrated with sustainability. The study is part of a project where to develop a teaching module that will prepare student teachers to teach technology in primary schools, with special attention to how student teachers develop relationships between technology education and sustainable development. The study includes 12 student teachers enrolled in a science and technology course. Data were collected in several steps, including focus group interviews, and written individual reflections by student teachers. Based on thematic analysis, we identified what student teachers experience as crucial to being able to teach technology with a sustainability edge. The results show that preparing student teachers to teach technology with a sustainability edge requires a multifaceted approach that integrates knowledge of technology and sustainable development with personal values, pedagogical competence, critical thinking competency, and the adoption of transformative teaching practices.

Keywords

Technology education, Sustainable development, Teacher education, Student teachers, Primary school

Introduction

Technology education has an important role to play in developing pupils' understanding of the technology they encounter in their everyday lives. Today, technology education includes raising pupils' awareness of sustainability issues related to the use and design of technology. The integration of sustainable development in technology education is crucial for pupils as it equips them with future-oriented skills, environmental awareness, and ethical considerations. It promotes critical thinking, informed decision-making, and global citizenship, and prepares pupils to be the agents of change needed for a sustainable future (Leicht et al., 2018). Therefore, there is a need for education to reflect on pedagogies and strategies to equip pupils with sustainability knowledge to meet the promises and challenges of the future. However, a study by Dahl (2019), based on data from seven European countries, shows that teachers feel

less prepared when it comes to teaching about sustainability and sustainable lifestyles. An important step in preventing such problems in technology education is to provide student teachers with both theoretical and practical knowledge of technology and to help them transform this into teaching technology in which sustainability is more explicitly integrated (Dahl, 2019; Pavlova, 2013; Pegalajar-Palomino et al., 2021). Further, research on student teachers' perspectives on teaching technology emphasises the need for a better understanding of how student teachers perceive the technology content they are expected to teach and suggests that teachers develop a significant portion of their subject matter knowledge during teacher education (see, for example, Courtney et al., 2017; Hallström & Klasander, 2017; McGlashan & Wells, 2013).

In a larger project, we are addressing these issues through a collaboration between teacher educators and a Municipal Technology Resource Facility (MTRF) that offers a variety of hands-on technology activities for pre-service teachers, in-service teachers, and other interested parties. The aim of the project is to develop a teaching module that can increase student teachers' competence in teaching technology with a sustainability edge, as well as to gain knowledge about what transformative processes are taking place, where expansion and development efforts can be more precisely designed in teacher education. In this project, we see the potential to both develop a teaching module that will provide high-quality training for student teachers and to contribute with research related to technology teacher education and education for sustainable development (ESD).

In this paper, we present a study carried out as part of the larger project. The aim of the study is to identify the aspects that student teachers experience as crucial to being able to teach technology with a sustainability edge. The results will contribute to knowledge of what needs to be addressed in teacher education to better prepare student teachers to integrate sustainability into technology education. The question guiding our research is: What aspects do student teachers experience as crucial to being able to teach technology with a sustainability edge?

Background

Technology Education and the Preparation of Future Technology Teachers

The Swedish compulsory education and teacher education are interrelated tasks, pupils are to be educated toward curriculum goals, and teachers must be prepared through teacher education to be the facilitators of learning for their pupils to achieve curriculum goals (Åstrand, 2023). Consequently, teacher education needs to present education that is in line with the school curriculum, as well as to prepare student teachers with relevant knowledge for them to be able to teach specific subjects.

The Swedish curriculum for the compulsory school includes technology as a mandatory subject for pupils in grades 1–9. In the curriculum, there is defined core content divided into three main areas: Technology, man, society and the environment; Technological solutions; and Working methods for developing technological solutions. These areas cover a broad content such as materials, construction, strength theory, electronics, programming, mechanics, technological development work and documentation, technological systems, the history of technology, and the consequences of technology for humans, society, and the environment (Curriculum for the

compulsory, school, preschool class and school-age educare [Lgr 22], 2022). The abilities and knowledge that pupils are expected to develop are as follows:

- the ability to reflect on different choices of technological solutions, their consequences for the individual, society and the environment as well as how technology has changed over time.
- knowledge of technological solutions and how constituent parts work together to achieve appropriateness and function.
- the ability to carry out technology development work and construction work.

(Curriculum for the compulsory, school, preschool class and school-age educare [Lgr 22], 2022).

The teacher's approach to how technology teaching should be conducted has decisive importance for the extent to which pupils learn in and about technology. However, there is a great variation in technology teachers' understanding of what teaching technology implies in terms of purpose, subject content, and teaching methods (Norström, 2014). The Swedish School Inspectorate (Skolinspektionen, 2014) carried out a review of primary school teaching in technology. The report showed several shortcomings, such as teachers feeling unsure of what the content of the curriculum represents in terms of technological knowledge, as well as which approaches and methods characterise the subject of technology. Norström (2014) suggests that it is of utmost importance that technology teachers are able to interpret what the content in the syllabus of technology represents in terms of technological knowledge as well as in teaching methods, for being able to present high-quality technology education. Further, this is also important for providing an equivalent assessment and grading of pupils (Jones et al., 2013).

Teachers develop a significant proportion of their subject knowledge during teacher education (Courtney et al., 2017; Hallström & Klasander, 2017; McGlashan & Wells, 2013). That is, teacher education has an important purpose to guide and prepare future teachers on what and how to teach technology. However, the changing world is reshaping technology education, emphasising the need for up-to-date skills, fostering a global perspective, adapting to digital transformations, embracing interdisciplinary approaches, stressing soft skills, considering ethical implications, promoting inclusion and diversity, and integrating concepts of environmental sustainability. This place demands on teacher education to keep up to date and ensure that student teachers are equipped with the necessary knowledge and skills to teach technology. Teacher educators should not only focus on preparing student teachers with technological knowledge and skills but also on the ability to adapt to a rapidly evolving technological landscape and to contribute meaningfully to a complex world where education for sustainable development is at the forefront.

Transformations in Technology Teacher Education and ESD

In ESD it is highly relevant to ensure that all learners can contribute to global sustainability, in line with the global sustainable development goals (SDGs). However, the efforts made so far have not been sufficient (Dahl, 2019; Pegalajar-Palomino et al., 2021; UNESCO, 2017; 2018). The results of a systematic review by Pegalajar-Palomino et al. (2021) showed that teachers are less prepared, i.e. they lack the necessary professional competencies, to teach about sustainability and sustainable lifestyles.

There have been several calls within the research community for new and diverse ways of designing education (Bencze et al., 2020; Holbrook, 2009; O'Brien et al., 2013; Lönngren et al., 2021; Pavlova, 2013). Based on a review of how related strands of research in science and technology education (SAQ, SSI, and STSE) share commonalities, Bencze et al. (2020) promote contextual and holistic approaches. Hence, more authentic approaches in interaction with society. O'Brien and Sygna (2013) suggest the need for transformation in higher education from both the "outside-in" and the "inside-out", a revolution that "must be unconventional and bold" (p.57). Key competencies such as knowledge, skills ("what"), values, beliefs, and worldviews ("why") and pedagogical competencies ("how") need to be included in teacher preparation to facilitate the implementation of ESD. Similarly, Holbrook (2009) and Pavlova (2013) argue that transformations in teaching are crucial in science and technology education. Technology education can for instance equip individuals with problem-solving skills and foster innovation. This is critical to addressing sustainability challenges as it enables the development of creative solutions to environmental, social, and economic issues. This includes educating individuals about the impact of technology on the environment and promoting a holistic understanding of the interrelationships between environmental, social, and economic systems. Important areas include how to reduce waste, conserve resources, and minimize environmental degradation, as well as how to promote clean energy and reduce dependence on non-renewable resources to help individuals make responsible and sustainable choices in the use and design of technologies. However, for sustainable development to be adopted, it must be relevant to individuals or communities, include practical solutions, and involve value-based social science decision-making (Holbrook, 2009; Pavlova, 2013). Furthermore, Pavlova (2013) states that there is a lack of research in technology education that addresses transformative teaching and learning.

Critical Thinking Competency in Technology Teacher Education and ESD

Achieving significant progress in sustainable development demands a deliberate shift in our mindset and behaviour. To tackle sustainability challenges effectively, individuals must evolve into agents of change for sustainability (Leicht et al., 2018). This transformation necessitates equipping them with the requisite knowledge, skills, values, and attitudes to actively advance sustainable development. Axell (2019) suggests that today's learners need to develop critical thinking competency to be able to make informed decisions about issues related to technology and its impact on people, society and the environment, and therefore need to be emphasised in technology education.

The SDGs serve as a framework for integrating ESD, with critical thinking recognised as a fundamental competency within this educational approach (UNESCO, 2017). Critical thinking entails an individual's ability to engage in higher-order cognitive processes that encompass analysis, synthesis, problem recognition, problem-solving, reasoning and evaluation (Taimur & Sattar, 2019). This means that to foster critical thinking, education must cultivate learners' ability to analyse, synthesise and evaluate information, and to use these cognitive skills to make informed judgements. Critical thinking also involves the ability to reflect on one's values, perspectives, and behaviours. Nonetheless, as noted by Taimur and Sattar, engaging in critical thinking during problem-solving isn't an innate skill. Developing critical thinking requires self-awareness and other necessary traits that enable individuals to articulate their analyses, interpretations, and evaluations of judgments made. In addition, Facione et al. (1995) suggested that individuals who lack openness may have difficulty accepting perspectives that

differ from their own, thus hindering their ability to explore different viewpoints before reaching conclusions.

Since individual agency is crucial for sustainable development, both from a learner and a teacher perspective, inner qualities and capacities for transformation have gained attention (Ivanova & Rimanoczy, 2021; O'Brien et al., 2013; O'Brien & Sygna, 2013; Wamsler, 2020; Wamsler et al., 2021; Wamsler, et al., 2022). Inner qualities relate to the "why" in ESD and the transformation of personal beliefs, values and worldviews is considered the most powerful source to transform actual outcomes in practice (O'Brien & Sygna, 2013; Wamsler et al., 2021). Consequently, sustainability education requires more than "business as usual" to promote changes. In a review by Wamsler et al. (2021) it is put forward that the lack of individual agency is consistent, mainly due to structural constraints. However, a transformation of learners' mindset can be achieved in different ways, both as an end and means (e.g. Ivanova & Rimanoczy, 2021; Wamsler, 2020; Wamsler et al., 2022). In such processes, inner qualities must be addressed by giving opportunities for learners to include self-awareness, empathy, sense-making, a sense of purpose, and a sense of empowerment (Wamsler et al., 2021).

In the context of technology teacher education and ESD, transformative teaching and learning are considered essential for fostering the knowledge, skills, attitudes, and values needed to address complex sustainability challenges (Pavlova, 2013). It equips student teachers with the capacity to critically analyse environmental issues, make informed decisions, and actively participate in shaping sustainable futures. However, as highlighted by Taimur and Sattar (2019), numerous teachers have yet to receive education on ESD during their teacher training. Integrating ESD into teacher training programs is crucial, as it provides teachers with the opportunity to acquire the essential knowledge and skills needed to actively engage in sustainable development initiatives.

Method

This study is part of a larger project including researchers and teacher educators at a university in Sweden, and teachers at a MTRF, where a new teaching module in technology was developed. This paper presents the first iteration of a Design-Based Implementation Research (DBIR) on the teaching module. In the module, activities and assignments were oriented towards technology teaching with pedagogical considerations about sustainable development (SD), the development of professional knowledge and the integration of both conceptual and practical aspects of technology teaching.

The DBIR Approach

DBIR involves multiple stakeholders in the research design, merging design-based research (DBR) focused on classroom contexts with implementation research (IR) centred on organisational settings (Fishman & Penuel, 2018; Fishman et al. 2013). DBR, or educational design research (EDR) (McKenney & Reeves, 2018), explores new educational concepts in their intended settings, while IR examines the rollout of programs or policies (Century & Cassata, 2016). DBIR aims to study stakeholder interactions during implementation to improve both design and implementation processes.

Our project incorporates several design principles from technology and sustainable development education literature to identify study outcomes. A critical principle is using DBIR

as a methodology to bridge the gap between innovative educational practices and sustained change in classrooms. This requires iterative and collaborative design efforts among stakeholders. Another principle emphasises cooperation to foster integration across different educational layers. Policy documents and curricula often mandate SD in education, a challenging goal for teachers. Our approach includes practical and value-based considerations of SD, urging the integration of personal values into pedagogical strategies. Lastly, in technology education, there is a need to balance practical benefits with conceptual understanding. Our project seeks to enrich pupils' comprehension of technology, integrating both theoretical and practical knowledge to better meet societal demands.

In summary, our design principles are shaped by the need for collaborative and iterative methodologies, integration of stakeholder cooperation, alignment with sustainable development values, enhancement of teacher professional development, and a balanced educational approach in technology education. These principles guide our DBIR approach to create meaningful and sustainable educational changes.

The Educational Context of the Study

The educational context of this study was based on a course module within a Science and Technology course of 30 credits, which includes the subjects chemistry, physics, technology, and biology. The student teachers enrolled in the course were preparing to become teachers in primary school, grades 4–6. The student teachers took the course during their sixth semester of eight in total.

In this study, our aim is to explore what aspects student teachers experience as crucial to being able to teach technology with a sustainability edge. Focusing on this single group of student teachers, this study can be considered as a DBIR case study which delves into the student teachers' experiences from taking part in the teaching module in technology. Typically, the research design in a case study involves qualitative methods such as semi-structured interviews or observations, enabling a detailed examination of the case (Bryman, 2016; Flyvbjerg, 2006). The case aligns with the research question and is anticipated to yield profound insights into the pedagogical implications of designing and integrating technology and sustainable development in the teaching module, and what aspects become necessary to bring forward in developing student teachers' pedagogical competence.

Description of the Technology Course Module Design

The content of the technology course module focuses on teaching and learning about conceptual and procedural technological knowledge. Hence, it includes learning to work with technology pedagogically, in practical activities in combination with theoretical knowledge. In the course module, it is emphasised that to be able to teach technology, teachers need both content knowledge and pedagogical knowledge. The module was set up through collaborative planning by the involved teacher educators and researchers, and teachers at the MTRF. The module includes lectures, seminars, and workshops, both at the University campus and at the MTRF. In total, the course module includes 12 sessions which were divided into two theoretical blocks, one practical block, and one synthesising block (see Table 1). In the synthesising block, the student teachers were planning and enacting technology teaching using knowledge captured from the previous blocks.

Table 1. The technology course module

Block	Content	Activities	Organisation
Block 1 Theoretical Session 1–4	The epistemology of technology History of technology Design and technological documentation. Construction techniques, strength theory and materials.	Literature seminars with discussions Group works on lesson plans. Workshops on technological development work, technological documentation, construction techniques, strength theory and construction materials.	Four seminars, 180 min each
Block 2 Practical Session 5–8	MTRF: Work practically with technology - Mechanics and Digital Models w. TinkerCad, everyday mechanics and programming w. micro:bit.	Introduction to the MTRF. Practical technology sessions – workshops.	Four workshops, 180 minutes each
Block 3 Theoretical Session 9	Technology, human, society and technological systems.	Seminar on technological systems, sustainability, safety, ethical considerations, Life cycle analysis. Workshop with a debate on sustainable issues/technology, and discussions on ethical dilemmas.	Workshop 180 min
Block 4 Synthesizing Session 10–12	The planning and teaching of technology at the MTRF with pupils.	Student teachers plan a lesson based on one of the themes from the MTRF, i.e. mechanics, TinkerCad, programming, electronics, which they present and get feedback from other student teachers and teachers on their lesson plan. They revise and conduct the lesson at the MTRF with pupils.	Two Workshops, 180 min each + 240 min incl. 90 min lesson with pupils/group

Participants

The study includes a cohort of primary school student teachers. In relation to the introduction of the technology course module, we informed the student teachers about our study and asked whether some of them might consider participating. In total 12 student teachers gave their consent. In addition, eight municipal school teachers, 42 4th-grade pupils and 38 5th-grade pupils provided authenticity in the student teachers' (training) performances at the MTRF (see Table 1, Block 4).

Data Collection

Multiple data sources were collected in several phases of the module to develop a rich and detailed picture. Initially, student teachers' individual written reflections on technology education and sustainable development were captured. After the student teachers performed lessons at the MTRF, semi-structured group interviews were conducted using an interview guide. This included questions such as: What do you think are important aspects of successful technology education? What knowledge does a teacher need? What is your perspective on the integration of sustainability issues in relation to technological knowledge? What impact can it

have on pupils' learning? What is required of you as a teacher? Each interview lasted about 45 minutes. After the module was ended, student teachers' individual written reflections on technology education and sustainable development were captured a second time.

Thematic Analysis

In this study, the analysis involved a thorough comparison of information derived from both semi-structured group interviews and student teachers' individual reflections to uncover prevalent patterns and common themes. Employing a thematic analysis with an inductive approach as outlined by Braun and Clarke (2006), the analytical process focused on describing and carefully organising the data.

The initial step aimed at familiarising ourselves with the extensive body of data. This included transcribing the semi-structured group interviews and engaging in repeated readings of the transcripts and the individual reflections for comprehensive understanding. Subsequently, transcripts and individual reflections were systematically coded and segmented into units, with the beginning and end of each unit determined by the content emphasised by the student teachers. Coding was complemented by identifying patterns in what aspects student teachers experience as crucial to being able to teach technology with a sustainability edge. The subsequent step involved a comparative examination of similarities and differences among coded units, leading to the tentative organisation of these units into themes. This process also entailed the compilation of relevant excerpts associated with each identified theme. Following this, a review of the themes concerning the collected excerpts took place to ensure that the themes accurately reflected the entire dataset. In the next last step, the characteristics of each theme were defined, and a logical naming and organisation of the themes were established. Finally, in the last step, excerpts were carefully selected to represent the identified themes, forming the basis of the analysis that addresses the research question posed in this study.

Results

In this section, we present the results in terms of what aspects of the student teachers' experiences were seen as crucial to their ability to teach technology with a sustainability edge. The findings are presented as themes, including excerpts, based on the analysis of the individual written reflections (R) and the semi-structured group interviews (G). The themes are:

- Knowledge in technology and its relationship to SD.
- Critical thinking competency.
- Inner qualities.
- Pedagogical knowledge of how to teach technology with an SD edge.

Knowledge in Technology and its Relationship to SD

All student teachers expressed that it is crucial to have deep technological knowledge as well as to be able to see the relationship between technology and sustainable development. For example, Kim suggests in the written reflection that knowledge in both areas is necessary to be able to teach pupils technology with sustainable development.

> *Good knowledge of technology and sustainable development...you need a solid knowledge base in the whole area to be able to communicate this effectively and appropriately to your pupils. (Kim, R)*

In the group interviews too, the student teachers could describe how important it is to have specific content knowledge about technology as it relates to sustainability, and how a lack of this can lead teachers to avoid important content in the classroom because they are unsure of what it is and how to include it.

> *[...] we organise the structure of the lesson based on the knowledge we have. We might not have chosen to talk about the recycling ladder [Lansink's ladder] if we didn't know anything about it. So, you kind of actively choose what to focus on based on your prior knowledge [...]. (Kris, G)*

Most student teachers emphasise the importance of understanding the relationship between technology and sustainable development in order to plan lessons that promote pupils' understanding of this relationship. Several of the student teachers described how they had never been taught about technology related to sustainable development. In the group interviews, the student teachers describe the transformation they have undergone during the course and how it has affected their way of thinking about the relationship between technology and sustainable development. For example:

> *I wasn't taught how to think about sustainability in technology before [...]. So, it has become sort of a bigger part of how to think about it. It's usually okay, we should include sustainable development, but how do I include it? So, I gained more insight into how to integrate it into my teaching. (Rene, G)*

Many of the student teachers emphasise that both knowledge of technology and knowledge of sustainable development are necessary to make informed decisions and take positions on technology in different situations. Content knowledge of technology facilitates taking a stand on issues of sustainable development and what the consequences might be. This needs to be considered not only in a local context but also in a global context. For some student teachers, integrating sustainability and technology was a new way of thinking and now it seems obvious that teaching technology should always be linked to sustainability. In her written reflection, Jackie suggests that to understand the impact of technology on society, the environment, and people, one needs to know about the technology itself, and in Jackie's own words:

> *This will reduce the risk of making uninformed and irresponsible choices that may seem exciting and revolutionary at first but turn out to have devastating consequences and hinder sustainable development. (Jackie, R).*

Additionally, for some student teachers, it is important to see the impact of technology from different perspectives, supported by knowledge of the technology itself. That is, you need some basic knowledge to be able to critically analyse technology, share experiences, and discuss technology with others.

Critical Thinking Competency

The student teachers describe critical thinking as an important competency for understanding and teaching technology in the context of sustainability. Critical thinking is described as being underpinned by both technological knowledge and knowledge of sustainable development, as well as the ability to see the relationship between technology and sustainable development. Concerning critical competency, student teachers mention necessary skills such as problem identification and problem-solving, as well as the ability to observe, analyse, evaluate, take different perspectives, draw conclusions, and collaborate. First, as Kit puts it, one has to have the facts and information, i.e., knowledge of technology as well as an understanding of sustainable development:

> *Once the information and facts have been gathered, they need to be organised, and this is where both evaluation and analysis skills are important. (Kit, R)*

Second, skills such as observation and analysis of what you see are necessary to be able to make decisions. This includes having analytical skills that help the teacher to take the subject knowledge to a higher level, which also promotes reflection, widens perspectives, and encourages decision-making on issues of technology in relation to sustainable development. All in all, this serves critical thinking skills. But being able to analyse, pose questions, and make decisions is not enough. As Charlie suggests, you also need to be able to identify problems and find and present sustainable solutions related to technology.

> *[...] As a teacher, developing the ability to analyse information and evaluate different perspectives is crucial. The ability to question claims and draw conclusions. Another good quality is the ability to solve problems. The ability to identify and solve problems is an important aspect of technology and sustainable development. This means finding sustainable solutions to challenges such as environmental impact and social aspects. (Charlie, R)*

Third, critical thinking skills include both the ability to think individually and to collaborate with others. That is, student teachers need to be able to understand other people's perspectives and ways of thinking to develop new ideas and solutions.

Inner Qualities

Many of the student teachers expressed inner qualities such as a sense of self-esteem, confidence, courage, creativity, empathy, and a sense of empowerment. All of these are put forward by the student teachers as important aspects of the role of a teacher. These kinds of inner qualities fuel the student teachers' engagement and interest in teaching technology and help them deliver lessons that, in turn, can lead their pupils to learn about and evaluate sustainability issues related to technology. The inner qualities can be rooted in both deep content knowledge and an established critical thinking competency that make student teachers confident in their role as teachers. As Robin expresses it, deep content knowledge fosters confidence in teaching technology. It keeps a teacher engaged and motivated, which translates to her pupils:

> *Having a deep knowledge of the subject increases my confidence as a teacher and I am not afraid to face questions from pupils because I feel confident in the subject. (Robin, R)*

The student teachers also describe that knowledge of the subject promotes a sense of confidence in understanding what sustainability is in relation to technology, and this confidence helps when it comes to analysing and making decisions on sustainability issues. Alva adds that the most important aspect for a teacher is to have the courage to implement technology lessons integrated with sustainability. If the teacher lacks this, it will affect the learning:

> *[...] The most important component in my opinion is that you as a teacher have the courage and the knowledge to actually implement these things. [...] If the teacher lacks this, the pupils will lack this knowledge and it will be a negative cycle. (Alva, G)*

Kit mentions that empathy, along with curiosity, are important aspects. She suggests that curiosity is important to learn more about issues related to sustainability and technology. Empathy is necessary to understand how technology affects others besides oneself. The lack of these qualities makes it difficult to understand the relationship between technology and sustainable development.

> *If you can't empathise and understand how your actions affect other people's lives and quality of life, it can be difficult to understand the connections that are necessary for sustainable development. [...] (Kit, R)*

Among the student teachers, there are accounts for the necessity to think outside the box and to find new approaches, especially in the classroom. Several of the student teachers also mention motivation and engagement as important, as well as the desire to influence the evolution of our world toward sustainable development. They feel empowered when they have enough content knowledge about technology and sustainable development, and this makes them more engaged and motivated to teach pupils in this area.

> *If I, as a teacher, have good knowledge, it is also easier to be committed and motivated, which in turn leads to more successful teaching and can also increase the motivation of the pupils when they see that their teacher is committed. (Robin, R)*

Some students suggest that it is important to create a learning environment in which pupils can engage with and become involved in issues related to technology and sustainable development. This is linked to the student teachers' aptitude and empowerment is present in their descriptions. If they are empowered to teach from a sustainability perspective, not only in technology but also in other subjects, this will show a real commitment to the pupils. They, in turn, will experience that it is important to learn, and they are likely to become more interested.

Pedagogical Knowledge of How to Teach Technology with an SD Edge

Several of the student teachers expressed that it is not enough to have content knowledge about technology and to understand how it relates to sustainability. They need to have pedagogical knowledge of how pupils understand the content and how to translate that knowledge into something their pupils can understand. This includes knowledge of what content needs to be addressed and knowledge of what classroom activities might be appropriate to make the content understandable. One example is as follows:

> *[...] You should also take into account the group of pupils you are dealing with by observing their interests and prior knowledge in the field to select the knowledge that the pupils need to develop and work on based on the social, economic and environmental aspects of sustainable development. (Jackie, R)*

The importance of both being confident in the subject and being able to find the right level for pupils, both in terms of teaching activities and what they need to learn, is also suggested by student teachers. Sometimes this is emphasised as the need to be able to handle situations that may be difficult for pupils, such as how to interpret a particular sustainability issue. In addition, a teacher needs to be able to transform his or her knowledge of technology and SD and know how to address it in terms of both conceptual and procedural knowledge related to sustainability issues. Teachers also need to be able to plan and implement classroom activities that develop critical thinking skills, such as the ability to analyse and reflect:

> *[…] For teaching to be successful, it is important to work on the skills that develop pupils' analytical abilities, so you need to plan your teaching to develop these skills. (Alva, R)*

This includes implementing activities that make pupils aware of the relationship between technology and sustainable development. In such situations, content related to technology and sustainable development can be complex to understand, which requires specific teaching methods to engage pupils' interest and develop their critical thinking skills.

> *It's not just about transferring knowledge, it's about teaching pupils to think and act as problem solvers. You should also encourage them to question and develop their critical thinking skills. (Kim, R)*

Summary of the Results

The four themes identified indicate interwoven aspects that are necessary for student teachers to develop in order to be able to teach technology integrated with sustainability. Technological knowledge and knowledge of SD, as well as understanding the relationship between them, are necessary to develop and enable critical thinking competency. This competency includes skills such as problem identification and problem-solving, as well as the ability to observe, analyse, evaluate, take multiple perspectives, and draw conclusions. By having these skills and abilities, student teachers become more knowledgeable and can take positions on technology in relation to sustainability. In addition, technological knowledge, SD knowledge, and critical thinking competency promote student teachers' inner qualities such as a sense of self-esteem, confidence, courage, creativity, empathy, and a sense of empowerment. These are important aspects of the role of a teacher. Inner qualities drive the student teachers' engagement and interest in teaching technology. It adds to the planning and implementation of lessons that can guide their pupils to learn about and take positions on different issues where SD and technology are related. However, student teachers also need pedagogical knowledge about how to teach technology integrated with SD. They need to have knowledge of pupils' conceptions and misconceptions of the content and be able to use this knowledge when planning lessons to make the content understandable to their pupils. This includes knowledge of what content is appropriate for the age group and knowledge of instructions and activities that can be used to teach technology with a sustainability edge.

Discussion

The results of this study show that preparing student teachers to incorporate technology with a sustainability edge requires a multifaceted approach that encompasses both personal and pedagogical dimensions. The evolving landscape of technology education necessitates that student teachers possess up-to-date skills, a global perspective, and an understanding of ethical implications, including environmental sustainability. Teacher educators must equip student teachers not only with technological knowledge and skills but also with the ability to adapt to a rapidly changing technological environment and contribute meaningfully to sustainable development. This underscores the importance of integrating sustainability principles into technology education to prepare students for the challenges of the future. Taimur and Sattar (2019) have previously suggested that numerous teachers have yet to receive education on ESD during their teacher training. In our study, the results also reveal a gap in student teachers' preparedness to teach about sustainability when entering the course. Similar findings were presented by Pegalajar-Palomino et al. (2021) which underscores the gap in preparedness to teach about sustainability, indicating a lack of necessary professional competencies. However, the student teachers involved in the study describe the transformation they have undergone during the course and how it has affected their way of thinking about the relationship between technology and sustainable development. They now realise that both technological knowledge and an understanding of sustainable development are crucial to making informed decisions and taking a stand on sustainable development issues and understanding what the consequences might be. Thus, the content and activities covered in the limited time available during the course seem to bridge this gap to some extent. However, the results indicate that there is more to be done. According to the results, this implies developing student teachers' knowledge of the relationship between technology and sustainable development. This knowledge enables critical thinking competency, which promotes inner qualities like engagement and interest. This necessitates a holistic approach (Bencze et al., 2020) focusing on various technological content and skills including the ethical and pedagogical dimensions of sustainable development.

Fostering Student Teachers Critical Thinking competency

Critical thinking is identified as a fundamental competency within the framework of ESD (UNESCO, 2017). This involves engaging in higher-order cognitive processes such as analysis, synthesis, problem-solving, reasoning, and evaluation. Moreover, critical thinking entails self-reflection on one's values, perspectives, and behaviours. The results show that the student teachers emphasise critical thinking as crucial for grasping and teaching technology in relation to sustainability. They highlight its reliance on both technological and sustainable development knowledge, along with the capacity to discern the connection between technology and sustainability. Key skills mentioned by the student teachers include problem identification, problem-solving, observation, analysis, evaluation, perspective-taking, and drawing conclusions. This is similar to what previously has been suggested by Taimur and Sattar (2019) concerning critical thinking and an individual's ability to engage in higher-order cognitive processes that encompass analysis, synthesis, problem recognition, problem-solving, reasoning and evaluation. The results indicate that critical thinking also involves the ability to reflect on one's values, perspectives, and behaviours which is important for value-based social science decision-making (Holbrook, 2009; Pavlova, 2013). Nonetheless, as noted by Taimur and Sattar (2019), engaging in critical thinking during problem-solving isn't an innate skill. Developing critical thinking skills requires self-awareness and other traits that enable student teachers to articulate analyses, interpretations, and evaluations, particularly in problem-solving contexts.

Thus, nurturing critical thinking competency in relation to teaching technology and sustainable development requires a deep understanding of both these areas and pedagogical strategies that promote critical thinking. That is to integrate sustainable development principles into teaching, considering ethical implications and fostering interdisciplinary connections, as well as to integrate personal values.

Integration of Personal Values into Pedagogy

Inner qualities and capacities for transformation have previously gained attention in relation to individual agency and sustainable development (see Ivanova & Rimanoczy, 2021; O'Brien et al., 2013; O'Brien & Sygna, 2013; Wamsler, 2020; Wamsler et al., 2021; Wamsler et al., 2022). The results of this study show that several of the student teachers voiced the possession of inner qualities such as self-esteem, confidence, courage, creativity, empathy, and a sense of empowerment, all of which constitute crucial aspects of the teacher's role. These intrinsic qualities propel their involvement and enthusiasm in teaching technology and aid in the delivery of lessons that, consequently, can prompt their pupils to engage with and formulate positions on sustainability issues related to technology. Rooted in both substantial content knowledge and cultivated critical thinking competency, these inner qualities instil confidence in student teachers regarding their role as teachers. Accordingly, the results indicate the importance of incorporating personal values related to SD into pedagogical considerations. This integration serves as a guide for student teachers to understand sustainability themselves and effectively promote pupils' interest and understanding. This has previously been suggested as the "why" in ESD and the transformation of personal beliefs, values and worldviews which is considered the most powerful source to transform actual outcomes in practice (O'Brien & Sygna, 2013; Wamsler et al., 2021). However, challenges persist in fully integrating these values into pedagogy, indicating a need for further attention to inner qualities and capacities to facilitate the development of individual agency. In essence, student teachers must not only grasp technology and sustainability concepts but also internalise them deeply to effectively impart them to their pupils.

Embracing Transformative Teaching and Learning

In the context of technology teacher education and ESD, Pavlova (2013) has previously suggested that transformative teaching and learning can be considered essential for fostering the knowledge, skills, attitudes, and values needed to address complex sustainability challenges. This approach emphasises the importance of creating learning environments that encourage critical reflection, active engagement, and the application of knowledge to real-world sustainability issues. By embracing transformative teaching practices, student teachers can empower their pupils to become agents of change in building a more sustainable future.

In the initial iteration of the designed course module, provisions were made for student teachers to contemplate their beliefs, values, and worldviews, aligning with the perspectives of O'Brien and Sygna (2013) and Wamsler et al. (2021). Our data reveal numerous instances supporting the transformation of student teachers' mindsets, such as an increase in expressions demonstrating empathy towards both people and nature. However, there remains a need for further emphasis on inner qualities and capabilities to assist student teachers in addressing internal dimensions crucial for nurturing individual agency (Wamsler, 2020).

The results highlight design principles within the initial iteration of the teaching module that warrant further scrutiny. That is to advocate for developing student teachers' critical thinking competency and the integration of personal values of SD as a framework for pedagogical deliberations concerning sustainable development. While student teachers have undergone personal transformations in their perspectives on sustainability in relation to technology, challenges persist in effectively integrating activities aimed at fostering pupils' comprehension. This enduring challenge has been documented in previous research (Holbrook, 2009; Pavlova, 2013; Wamsler et al., 2021), and needs to be further investigated.

In conclusion, preparing student teachers to teach technology with a sustainability edge requires a multifaceted approach that integrates knowledge of technology and sustainable development with personal values, pedagogical competence, critical thinking competency, and transformative teaching practices. Teacher educators play a pivotal role in equipping student teachers with the necessary knowledge, skills, and attitudes to effectively integrate sustainability principles into technology education and contribute to a more sustainable future.

Limitations of the Study

A common criticism of case studies is the inability to draw general conclusions from a single case (Bryman, 2016; Flyvbjerg, 2006) and thus we acknowledge that this is the first iteration of our DBIR approach as advocated by Fishman et al. (2013). However, while the sample size is limited for drawing general conclusions, the qualitative data offers richness and depth, providing a detailed insight into what student teachers experience as crucial to being able to teach technology with a sustainability edge. The study can as such serve as an exemplifying case for the group of student teachers who may participate in similar courses. Further, the findings contribute to the collective process of knowledge accumulation in the research field (Fishman et al., 2013; Flyvbjerg, 2006). This in-depth knowledge is expected to guide further investigations on SD and guide teacher educators in what to address in technology teacher education.

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