Insights from the implementation of the course "Development of an interdisciplinary STEM project via PBL approach" in an 'Integrative STEM Education' M.Ed. program

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ABSTRACT

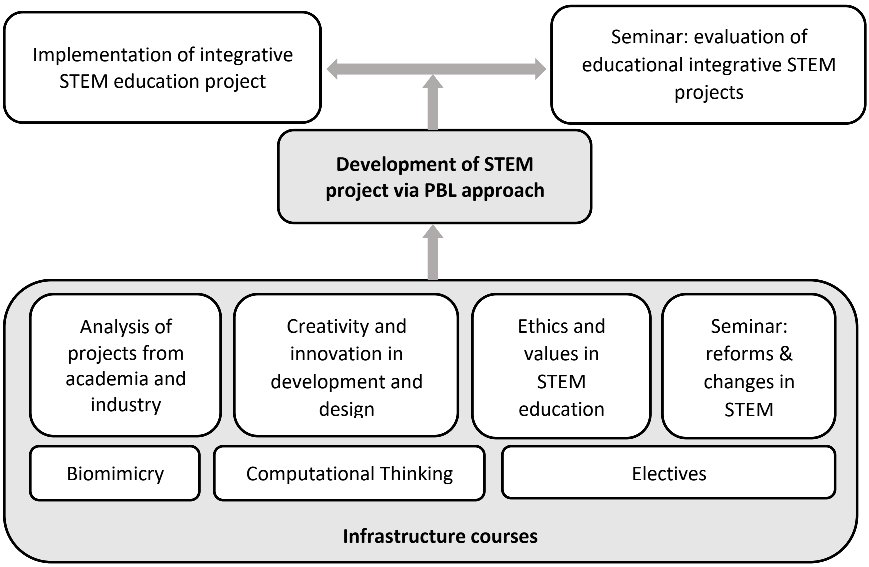
The paper explores the implementation of the problem-based learning (PBL) pedagogical approach in an academic course titled "Development of an Interdisciplinary STEM Project via PBL Approach" This course is one of the key courses in the master's in education (M.Ed.) degree on integrative Science, Technology, Engineering, and Mathematics (STEM) education developed at Beit Berl College, Israel. The M.Ed. program trains educators to design and implement interdisciplinary STEM curricula in schools and other educational settings. The course objective is to provide students with hands-on experience in the development of a STEM project. It is a 6 ECTS credits course extending two semesters. In this course, the students work in a multidisciplinary team and identify a problem relevant to society for which they develop a solution as a product. The teams plan their path to solving the problem, investigate and locate information to support the process, plan their timetable, and determine the criteria for assessing the product and their own PBL-based learning process. The project needs to include a response to Sustainable Development challenges. The course is co-taught by three lecturers from different disciplines: environmental sciences, computer science, and technology. Each lecturer contributes to the learning process from her specific field of knowledge, different educational backgrounds, and accumulated academic experience. This paper analyses, via the students, the course implementation through the lens of seven PBL essential attributes to evaluate the learning process, address challenges and proposes recommendation for similar courses.

Key Words: STEM education, Problem solving, PBL, Teacher professional development, Design thinking; student perspectives.

1. INTRODUCTION

This paper examines the implementation of the course titled 'Development of an Interdisciplinary STEM Project via PBL Approach' (from here on ‘the course’) conducted within the M.Ed. program 'Integrative STEM Education'. This unique program aims to (1) enhance students' knowledge and comprehension of STEM fields, and develop their pedagogical content knowledge (PCK), and technology PCK (TPACK) for teaching STEM, and (2) equip the students with the competencies to lead and manage interdisciplinary STEM learning approaches in educational institutions (Ragonis, Goldman & Dagan, 2023; Dagan, Ragonis, Goldman & Wagner, 2019). Additionally, the program encourages students to observe their teaching as a fruitful research field. Figure 1 presents the logical structure of the M.Ed. program, in which ‘the course’ ' holds a central role. The program is unique in that all the courses and interconnections among them are designed to scaffold the development of knowledge and skills from an interdisciplinary perspective. Emphasis is placed on two key aspects: the engineering design process and the PBL approach. Additionally, the program underscores ethical considerations in STEM education, the crucial role of Sustainable Development in the contemporary world, and the perspective of teacher-as-researcher (Guha, 2021). Building on these foundations, the program includes two core project-based courses: 'Development of STEM Projects via PBL Approach' and ‘Implementation of integrative STEM education project' complemented by the empirical seminar 'Evaluating Educational Integrative STEM Projects'. The program's pedagogical principles emphasise constructivism, constructionism, co-teaching, learning by need, and PBL.

Figure1.
The logical structure of the M.Ed. program



The study presented herein investigates the application of PBL in ‘the course’ as reflected in the students' experience. In particular, to investigate how students experience PBL as a process of learning and how does this reflect on the course goals?

2. LITERATURE REVIEW

2.1. Science Technology Engineering and Mathematics (STEM)

The term STEM is widely used in education to promote the integration of science, technology, engineering, and mathematics disciplines, reflecting their interconnectedness in the real world. While STEM is often understood as science- or mathematics-focused, the inclusion of technology and engineering is less prevalent. Dugger (2010) outlined three structures for STEM education: a) teaching each STEM discipline separately with limited integration, b) giving more emphasis to certain disciplines (typically science and math), and c) integrating one STEM discipline into the other three. It is increasingly recognized that current learning processes in schools and higher education do not adequately address the integration of STEM disciplines. In response, various curricula and initiatives have emerged (Bybee, 2013; Cagle, Caldwell, & Garcia, 2018; Sanders & Wells, 2006). The primary goal is to prepare students for a complex and unpredictable world, in which interdisciplinary professions and teamwork are essential for problem-solving, innovation, and entrepreneurship. Effective integrative STEM education enhances students' holistic understanding of the world and how things work, their technological literacy, and their capacity for innovation and problem-solving (Bybee, 2010; 2013). Addressing these challenges guides the curriculum of the M.Ed. program and provides the conceptual foundations of the course explored in this study.

2.2. Project Based Learning

PBL is a process that takes place over time, extending beyond the limits of regular lessons. It enables students to be active in learning by doing, to be creative and innovative, and to work independently or in teams while designing solutions to real-life, ill-defined problems. The PBL approach involves exploring, creating, and constructing (Dagan, 2023). This learning method necessitates the learners' use of critical, analytical, and synthetic thinking, evaluation, and reflection on their problem-solving processes (Capraro & Slough, 2013).

STEM literacy that is built on PBL is important for all students and is identified as a "Meta Discipline" (Zollman, 2012). Learning via the PBL method provides authentic content and context-related experiences that are crucial to the learner and are used to support meaningful and effective learning in STEM (Capraro, Capraro, & Morgan, 2013). Engineering design is a central pillar in STEM PBL; the learners use their knowledge of science, technology, and math to solve real-life, open-ended, and ill-defined problems (Capraro & Slough, 2013).

Six PBL characteristics were defined by Dagan (2023):

(i) *The problem*. Should be "wicked," ill-defined, open-ended, relevant to real-life situations including the learner's world, enable conceptual understanding, include various subjects, have different ways to be solved, and cultivate meaningful competence.

(ii) *The process*. The learners solve the problem in an iterative process using design tools (Mioduser, 1998) and design skills (Klappwijk, 2018), as shown in Figures 2 and 3.

Figure 2.
Design tools (Mioduser, 1998)

(iii)

Figure 3.
Design skills (Klapwijk, 2018)

(iv)

(v) *The product*. The process culminates with a tangible product that meets the defined problem's needs and constraints.

(vi) *The teachers' role.* Is to guide, assist, support, and mediate the students' learning processes by managing the learning environments and the process and setting the general timeline.

(vii) *The learners' roles*. Are to work collaboratively in teams, to be independent, and to construct their own knowledge and skills. Learners are responsible for the learning process, timetable, and assessment.

(viii) *Assessment.* The assessment criteria and their weight are planned and used by the learners.

These PBL characteristics provide the basis for the course's method and for the students' individual constructed reflections, which serve this study.

3. METHODOLOGY

3.1. Description of the course

The course aims to provide students with practical experience in developing a STEM project within the college environment. The course extends two semesters and models the integrative approach via team teaching of three lecturers from different disciplinary backgrounds: computer science, biology and environmental education, and technology education. The course's main aim is to enable actual experience in the long-term process of developing a valuable STEM project leading to product development. The project is carried out in multidisciplinary teams in which each team member has a different disciplinary background. The students are expected to contribute their knowledge and learn from their teammates to jointly achieve the development process via the design process. We consider it crucial that students experience such a significant process themselves towards their ability to apply such learning processes, that involve challenges, frustrations, and successes, in their respective educational frameworks.

Learning outcomes are that at the end of the course, the student will be able to: 1) Address problem-solving in a PBL approach, from defining the problem to presenting a solution and evaluating it; 2) Identify analogies and connections among the involved fields of knowledge; 3) Define criteria for evaluating suggested solutions and apply them; 4) Conduct thorough research to establish a foundational understanding for addressing the problem and its potential solutions and present this with clarity and focus; and 5) Document the PBL process systematically. Moreover, we addressed outcomes related to skills - the ability to: 1) Work in Teams; 2) Define group work practices; 3) Give and receive feedback; 4) Deal with constraints; 5) Manage a schedule; 6) Deal with disagreements; 7) Reflect individual and teamwork.

The main task of the course as defined for the students is: to define a problem whose solution is a product that requires a combination of STEM fields, takes into consideration sustainability issues, and responds to a societal necessity. The development process is based on the engineering design process and is conducted via the PBL process. To develop the students' understanding of sustainability, two introductory lectures are given. Students collaborate in teams, contributing their diverse disciplinary knowledge and expertise to the project. The Design process and the PBL principles and skills were taught and applied in previous courses and are revisited at the onset of the course. The course lecturers acted as supervisors and consultants, and additional experts (e.g., electrical engineer, industrial designer, chemist) provided advice according to the student's needs. The process commenced with the students selecting the problem and writing a design brief utilizing prior knowledge and skills. The iterative Design models they previously learned, such as Mioduser (1998) and Klapwijk (2018), were employed. Students had the autonomy to choose their design path, and to manage their timetable. Moreover, they were requested to determine their own assessment criteria, relating to the entire development process and the product, and to follow it. Together with the construction of the product, the course outcomes included a portfolio documenting the developing process. This included the research, constraints, inputs from intermediate presentations of experts and how they influence the process, a sketch model of their product and a tangible product to be presented for feedback and evaluation to peers and other guests, inspection of the compatibility of the product to its defined requirements, and assessment tools. The students also submit an individual constructed reflection.

The first cohort of students chose to address a human challenge arising from climate change - the need to lower the temperature of the immediate environment surrounding an individual's body when outdoors. For this purpose, they developed an "Umbrecoola", which is a portable umbrella with a cooling system.

3.2. Method

The research data are the individually constructed reflection documents that the first cohort of students (four) completed at the end of the course. The reflection protocol related to the seven

PBL characteristics: defining the problem, the design process of creating a solution to the problem, developing assessment criteria, establishing a timeline, and managing it, applying theory to practice beyond a discipline (here, the interdisciplinary approach), teamwork, the student's responsibility for the process while the lecturers serve mainly as facilitators. The students reflected on each of these criteria addressing three questions: 1) What were the challenges you confronted? 2) How did you act to meet these challenges? and 3) What did you learn from this? Additional questions mainly about what they take from the course experience to their future work as teachers are not addressed in this paper.

Content analysis was conducted on the students' responses.

4. FINDINGS

The findings offer a comprehensive overview of the students' perspectives. The organization is upon seven PBL aspects, in each answer to the three questions posed to the students are presented. The students' initials, indicating their mentioned aspects, are provided in parentheses at the end of the claims.

4.1. Aspect 1: Finding a topic and identifying the problem.

- *Students' Challenges*. The main challenge raised by students focused on finding an unsolved problem that aligns with the project requirements. "… a problem that motivates us, aligns with our research and technology capabilities, and considers sustainability…" (ES). The iterative process of continuous refinement of the accuracy of the problem throughout the entire process was also challenging for them (DS, YN).
- *Coping with the challenges throughout the process*. Students reported that they: (1) conducted brainstorming sessions (YN) and, (2) employed democratic decision-making through open dialogue (TS, DS). Moreover, in the process, they narrowed the scope of the problem and requested assistance from relevant faculty and other consultants (ES).
- What did you learn personally? The students testified that they learned to choose authentic problems and to apply them in their own teaching (YN, ES); that consensus in decision-making is vital (DS); and that their self-efficacy was strengthened despite the difficulties (TS).

4.2. Aspect 2: The problem-solving process

- *Students' Challenges.* Students faced several challenges: From their perspective, the research phase did not transpire at the appropriate time in the design process (TS, YN, DS, ES) the solution they selected for the problem was technologically ambitious and with high technical constraints (DS); time limits (ES); the need to choose a solution iteratively under these constraints caused frustration (DS).

- *Coping with the challenges throughout the process*. The students conducted counseling sessions with experts, which led to lowering excessive expectations (ES), focusing on the product, and using a categorization rubric to select the appropriate solution under the given constraints (TS, YN, DS).
- *What did you learn personally?* Students learned that: the non-linear, spiral, iterative approach is effective (TS, ES); the research should be conducted according to needs that arise during the process (YN); it is important to conduct feasibility testing before detailed planning (ES). Furthermore, they acknowledged the importance of constantly monitoring their own progress (DS).

4.3. Aspect 3: Formulating and developing assessment criteria

- *Students' Challenges.* Students found the need to develop their own assessment criteria challenging, particularly in relation to allocating points for each criterion while balancing awareness, professionalism, and fairness (DS, YN). They found it difficult to find the balance among the components when efforts are invested across all aspects of the process (TS, YN, DS, ES).
- *Coping with the challenges throughout the process.* They collaborated and shared ideas to overcome controversies, and revised the indicators based on the faculty's feedback.
- *What did you learn personally?* The students stated that the necessity of a clear formative assessment tool for self-management became clear to them, and that starting by defining metrics eases the process (DS). They also felt that involving students in the process boosts motivation and ownership (TS, ES, YN).

4.4. Aspect 4: Determining and managing a schedule.

- *Students' Challenges:* To create and follow a project schedule within the time limits despite deviations that occur in the process (ES, YN).
- *Coping with the challenges throughout the process*. They minimized deviations (TS), narrowed the problem to meet the deadlines (DS), and maintained full team cooperation - planning together and seeking full agreement (ES, TS).
- *What did you learn personally?* Students learned that time management is vital in PBL, that it is required to use accessible tools to acquire and practice this skill, and that changes are an inevitable part of project management (TS, DS, YN, ES).

4.5. Aspect 5: Expressing the integrative disciplines in STEM

- *Students' Challenges:* Lack of STEM disciplinary knowledge that was necessary towards the product development (DS). They also stated that the main challenge was aligning problems with sustainability (TS).

- *Coping with the challenges throughout the process*: The students stated that consulting with the lecturers and experts from various STEM subjects supported their inquiry into the different fields and helped in acquiring the necessary knowledge (ES).
- *What did you learn personally?* Students learned that the interactions with cross-disciplinary experts directed them to relevant STEM information (ES, YN), relevant indicators, and hence supported a better and more applicable process (DS, TS).

4.6. Aspect 6: Teamwork

- *Students' Challenges*: To utilize the strengths of each team member (YN); accommodate differences in working styles (DS); synchronize shared time (TS); divide tasks; and provide mutual support to "our enjoyable teamwork" (ES).
- *Coping with the challenges throughout the process*: "…Like a crane flock, everyone in the team took the lead when they could and stepped away from the arrowhead when they got tired." (TS). The students mentioned that they divided roles among themselves evenly and decided collaboratively on the subsequent steps, holding scheduled summary meetings (ES, DS, YN).
- *What did you learn personally?* Students stated that they learned to release control and trust others (YN), to appreciate diverse perspectives (DS, ES), and that all these components boost their motivation, mutual support, and growth (TS).

4.7. Aspect 7: Transferring the responsibility for learning to students.

- *Students' Challenges*: Releasing control; trusting others (YN); enabling diverse perspectives (DS, TS); and receiving seemingly conflicting messages from the faculty (ES).
- *Coping with the challenges throughout the process:* They distributed responsibilities based on each teammate's expertise (YN, TS); asked questions and consulted with the faculty (ES). They also stated: group work, maturity, and experience (TS, DS, YN, ES).
- *What did you learn personally?* Students learned that the space needed for embracing mistakes requires a non-judgmental teaching style (ES); transferring learning responsibility to learners involves the need to monitor it (TS); excessive freedom can create challenges and a defined framework is necessary (DS, YN).

5. DISCUSSION

The discussion centers on students' experiences with PBL as a learning process and its reflection on the course objectives. The content analysis of the students' responses reveals that through their active engagement in the process of PBL, they were able to identify the PBL characteristics and comprehend their significance to the learning process. They overcame challenges they encountered by building on the power of teamwork, self-regulation such as narrowing the range of the problem to be solved and seeking professional assistance from the faculty and additional experts. These strategies reflect 21-century skills central in contemporary [STEM] education that these teachers are expected to cultivate in their students.

The students experienced all six PBL principles (Dagan, 2023). A specific challenge they experienced was the difficulty in identifying a problem that motivates them but is also suited to their knowledge and capabilities. This led to their insight into the importance of focusing on a problem that can be solved within the allocated timeframe. They engaged in iterative problem-solving through design, utilizing two previously learned design tools (Mioduser, 1998; Klapwijk, 2018). Despite their prior experience in design, and their understanding of the iterative nature of the process, when conducted as a whole process, they found it challenging and frustrating. An important attribute of PBL is the learners' responsibility regarding assessment. The students comprehended the importance of taking on the role of developing the assessment criteria for their process and product, since it offers insights into the specific efforts and skills required for each component and helps determine their relative importance. Through planning the timetable of the project, they understood its importance for the learning process, but also that flexibility is needed, since changes are inherent to the PBL process. The students encountered gaps in their STEM knowledge related to the selected problem but viewed this as an opportunity for new learning. This corresponds with a central principle of PBL- active construction of knowledge through the learners' participation in a real-world problem (Blumenfeld, & Krijcik, 2005). They built on teamwork: they divided roles, put trust in their teammates and embraced the diversity of perspectives contributed by the different professional background of each member as well as their different approach to looking at the problem-at-hand. Importantly, these students acknowledged the need to be responsible for their project as the main PBL characteristic (Dagan, 2023), and viewed it as a crucial element.

The most difficult aspects of PBL encountered by these students were: 1) defining a problem such that it will be interesting to solve, embodies a feasible multi-disciplinary scope, and involves environmental considerations; 2) the iterative method which often creates frustration; 3) the positioning of the inquiry component in the process that was determined by the lecturers and did not fit into their design rhythm; 4) the need to listen to others' opinions; and 5) the need to decide on their own assessment criteria. All the students expressed how they were able to connect various aspects of the overall process and acknowledged that it provided valuable insights into teaching and learning within a STEM PBL environment. They expressed a desire to apply this newfound knowledge in their respective educational fields.

Analysis of the students' responses supports that in the process of developing the STEM project, the course met all its goals. Their responses reflect the development of a deep understanding of the principles of PBL. Importantly, their experience of the different challenges associated with the different aspects of the PBL learning process developed their awareness of how to work, as teachers, with their students. The following quotes nicely reflect this:

> "It opened a new way for me as a teacher to transfer learning responsibility to the students and be a facilitator who directs and monitors the process of making." (YN);

> “It allows me as a teacher to know where the points of failure are, to know what should be more or less structured, how to assist learners in the process, and above all, how to really implement a PBL project in the best way for all partners in the process." (ES);

> “It mainly opens the mind and allows me to think and dream. I don't really know if it can be applied at this point.” (DS);

> "To understand that the main goal of the PBL process is to develop personal abilities along with empathy, which will increase the chances that he/she will grow up to be a person engaged in improving the world.” (TS).

The course effectively implements Dugger’s (2010) type C approach, integrating disciplines within the engineering design process for STEM content. Furthermore, the course effectively incorporates PBL as a learning approach, as demonstrated by the students' comprehension and application of the seven components of PBL (Dagan, 2023; Bybee, 2013). However, some components posed challenges, while others were easier to implement. A major goal of this M.Ed. program is to equip experienced teachers with the competencies to lead and manage interdisciplinary STEM learning in their respective educational institutions. The students' responses provide evidence that their experience in the PBL process, and specifically the challenges they encountered, developed their awareness of the changes they need to incorporate in their role as teachers. Sterling (2009), in his discourse on 'Sustainable education - Education in and for change' emphasizes the necessity of transformative, constructive, and participatory education and pinpoints differences between conservative, mainstream transmissive education and transformative education. The students' reflections indicate that the course presented herein succeeds in making this move from transmissive to transformative education. For example, the focus was not on faculty's teaching but rather on students' bottom-up learning. The students had local ownership of learning as opposed to the faculty's control. Learning was process-oriented. The students learned in a constructive as opposed to instructive manner. Together, these indicate that the presented course made the shift from a teacher-oriented to a learner-oriented approach, overcoming one of the rhetoric-reality gaps in contemporary education.

6. CONCLUSIONS AND IMPLICATIONS

Based on the findings of this case study adaptations to the course were made to deepen the methodological tools required for students. First semester: developing the foundations of PBL skills, capabilities, and knowledge such as: teamwork, assessment and how to assess PBL projects, planning a flexible schedule, and incorporating what they learned in previous courses. Second semester: conducting the engineering design process in teams to solve the defined problem, during which they implement the skills cultivated in earlier stages.

From a holistic point of view, we can conclude that the course successfully implemented a learner-oriented approach, emphasizing student-centered learning, local ownership of learning, and a constructive learning process. This shift aligns with the need for transformative, constructive, and participatory education in the realm of sustainability and STEM education. Moreover, the students expressed a desire to apply this newfound knowledge in their respective educational fields. The implementation of PBL in interdisciplinary STEM education aligns with the need to prepare students for a complex and unpredictable world, where interdisciplinary professions and teamwork are crucial for problem-solving and innovation. The shift from teacher-oriented transmissive education to learner-oriented transformative education reflects the importance of providing students with ownership of their learning process and the opportunity to engage in constructive and participatory education.

Further research is needed to explore and refine these aspects in greater depth. Suggested directions for ongoing research around this and other PBL-based courses in this M.Ed. program include exploring: (a) How the PBL approach influences students' critical thinking skills and problem-solving abilities in the context of interdisciplinary STEM education? (b) The long-term effects of PBL on students' motivation and engagement in STEM education? (c) How the iterative nature of PBL impact students' perseverance and resilience when faced with complex and open-ended problems? (d) What are the best practices for facilitating collaboration and teamwork among students in PBL projects, particularly in an interdisciplinary context? (e) How does the PBL approach promote interdisciplinary thinking? Such research questions can direct further studies into the effectiveness of PBL in interdisciplinary STEM education, leading to continuous improvement and refinement of the pedagogical approach.

The study of this course provides valuable insights for the professional STEM education community in terms of curriculum development, pedagogical strategies, and the integration of interdisciplinary approaches.

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