DESIGN THINKING AND PROJECT-BASED LEARNING IMPLEMENTATION THROUGH COMPETENCY-BASED MODEL AND CRITERION-REFERENCED ASSESSMENT

Soumaya Argoubi, Rihab Chaari, Yosra Fraiji, Salma Hajjem

ESPRIT School of Engineering, Tunis, Tunisia.

ABSTRACT

Engineering education is a challenging subject due to the particularity of skills acquisition issues in nowadays context. Students need to acquire diverse talents that are essential for career prospects beyond technical skills. Project-based learning (PBL) is a submerging pedagogical approach that applies active training by targeting the different learning outcomes needed for engineers through authentic, real-world educational scenarios. Even though it offers many advantages helping students to enhance their soft skills as well as the hard ones, it also faces some challenges such as assessment mechanisms, learners engagement and motivation, teamwork and conflict management, and harmonious integration in the curriculum. In line with our commitment to excellence in engineering education, we have integrated the PBL method, harmonized it with CDIO (Conceive, Design, Implement, and Operate) standards, and combined it with a design thinking (DT) methodology. This initiative was experimented with the second-year common core computer science engineering students at ESPRIT School of Engineering. The evaluation of students in this project is based on a detailed criterion-referenced assessment (CRA) derived from the learning outcomes of the module. This competency-based evaluation includes various metrics to measure skills acquisition based on the contribution of each student, his commitment, and collaboration with the other team members, and his creative engineering skills. In this paper, we will show how effective this DT-PBL experience was thanks to the use of CRA providing detailed insight into the performance of each learner. As a consequence, we were able to collect valuable feedback to highlight the areas of improvement. Besides, this evaluation method boosted transparency by clarifying the expectations and the evaluation criteria to the learner. Based on the experiments, we will show that this valuable and meaningful competency-based educational model ensured better individual achievement in the learning process.

KEYWORDS

Project-based learning, Design thinking, DT-PBL, criterion-referenced assessment, Engineering Education, Standards: 2, 5, 7, 8, 11

INTRODUCTION

Various educational experts have suggested numerous adaptations of the CDIO standards (Edström & Kolmos, 2014), to improve the quality of training provided to engineering students. These adaptations aim to reinforce the relevance and applicability of the acquired skills, through exposure to educational experiences that reflect the challenges and demands of the professional world. This paper presents a module inspired by the CDIO (Conceive, Design, Implement, and Operate) educational approach. It adopts an active learning method, Project Based Learning (PBL) (Edström & Kolmos, 2014), which encourages training through the realization of a project in line with precise specifications.

This method helps engineering skills acquisition such as problem-solving, professional ethics, and critical thinking. So this contribution implements a DT-PBL (Design Thinking - Project Based Learning) pedagogical strategy. Through discussions and brainstorming among team members, we motivate students' design thinking (DT), innovation, and creativity to generate possible solutions based on prior knowledge and collected information. Within the scope of this project, the students are challenged to create ERM (Enterprise Resource Management) applications relying on a chosen topic. The technical backdrop involves the use of the C++ programming language within the QT framework, Oracle DBMS, Git, and Github. Besides, the developed solutions generally integrate an electronic part using sensors and Arduino uno microcontrollers to get started on embedded programming. Furthermore, we opted for the GitHub classroom workflow as a project and version management tool to enable progress tracking through project boards, effective collaboration, and proactive problem-solving which contributed to ensuring smoother development processes and high-quality delivered output.

The organization of the paper unfolds as follows: In Section 2, an exhaustive review of relevant literature about the PBL approach is presented. Section 3 delineates the methodology adopted to implement DT-PBL in our context, offering intricate details about the assessment method while comparing an old approach with a new one. The details about CDIO standards implementation are encapsulated in Section 4, succeeded by the presentation of findings and results. Then a comprehensive discussion to explore the impact of the applied changes is discussed in Section 5. Lastly, Section 6 concludes the paper by summarizing key insights.

EXPLORATION OF BACKGROUND LITERATURE

Project-Based Learning (PBL) is an instructional approach in which students actively assume a central role in structuring their learning around well-defined projects, guided by educators (Haatainen & Aksela, 2021; Han, Yalvac, Capraro, & Capraro, 2015; Kokotsaki, Menzies, & Wiggins, 2016). According to Barab (2014); Savery (2019), PBL places a strong emphasis on context-specific learning, encouraging students to actively engage with real-world issues. Through interactive social exchanges and knowledge sharing, students not only address these issues but also achieve educational goals, fostering a deeper and more practical understanding of the subject. Robust research supports the efficacy of PBL in enhancing 21st-century skills and immersing students in authentic tasks (Bell, 2010; Haatainen & Aksela, 2021; Han et al., 2015; Kingston, 2018). These skills encompass critical thinking, problem-solving, collaboration, communication, and self-management skills (Viro & Joutsenlahti, 2020). In Krajcik and Shin (2014), the authors identified six key features of PBL. These include the introduction of a central question, a focus on learning objectives, active engagement in educational activities, collaboration among students, the use of scaffolding technologies, and the creation of tangible artifacts. The unique aspect of PBL lies in the development of artifacts that address authentic problems, distinguishing it from other student-centered pedagogies such as problem-based learning (Amini, Setiawan, Fitria, & Ningsih, 2019; Anazifa & Djukri, 2017; Savery, 2019).

In Poonpon (2017), the author explored students' views on the integration of PBL into the language classroom, specifically through interdisciplinary projects (Warr & West, 2020). This work aims to motivate students to apply both their language skills and subject-specific knowledge in completing tasks. Students expressed their appreciation for the opportunity to apply their understanding of information science and English in these projects. They confirmed that engaging in these projects helped them recognize and enhance their English language skills in real-life scenarios. Ralph examined fourteen studies on PBL in STEM education, revealing favorable impacts on learners' knowledge and skills (Ralph, 2016). Students noted that PBL promoted collaboration and negotiation within groups, although some faced difficulties in maintaining motivation for teamwork.

The seamless integration of PBL into educational settings aligns harmoniously with the development of these crucial competencies, empowering students to navigate the intricate challenges of the 21st century with a scientifically informed perspective. This creative process requires learners to collaboratively find solutions to real-world problems, facilitating the implementation, application, and construction of knowledge. Facilitators, often in the roles of instructors and community members, play a crucial role in providing feedback and support to guide learners through their educational process.

OLD VS NEW: ASSESSMENT MECHANISMS & PROCESS

The presented module uses the Project-Based Learning and design thinking approaches (DTPBL) following the CDIO process to help students practice the knowledge acquired in several modules, including Object-Oriented Programming in C++, Databases, Electronics, and Communication. In addition to consolidating existing knowledge, this module introduces new learning objectives focusing on design thinking and problem-solving. As such, it offers students a holistic learning experience, preparing them to apply their knowledge in real-life contexts and develop essential skills for tackling complex challenges. During the first session (phase Conceive), tutors assign students to 6 groups, each comprising 5 to 6 members, and engage in discussions regarding projects' themes.

To facilitate communication with students and the sharing of resources, the tutor establishes a Google Classroom and extends invitations to all students. To achieve the defined objectives, we have implemented two main methods to ensure continuous improvement. In the following subsections, we will detail these two experiences (the old and new assessment), emphasizing their notable differences. This comparative approach aims to provide an in-depth understanding of the advantages and disadvantages of each method, while highlighting the lessons learned from feedback. This in-depth evaluation process helps to guide our approach toward more effective and adapted pedagogical practices.

The old approach

The first method was implemented following the four phases proposed by the CDIO initiative, with a detailed schedule as follows. The "Conceive" phase lasts for 4 weeks, dedicated to assigning modules to team members and drafting the specifications (including functional and non-functional requirements). The "Design" phase spans 3 weeks and focuses on creating graphic interfaces and designing the database. The ”Implement” phase extends over 5 weeks, covering the development of basic (CRUD) and advanced features, embedded aspects, and concluding with the integration of various modules developed by team members to produce the final deliverable. Finally, the ”Operate” phase, scheduled for 2 weeks, includes the technical and commercial evaluation of the delivered product.

The assessment of different learning outcomes was organized as follows: initial team validation to assess the quality of established specifications, communication skills, and the overall presentation. A second individual validation to evaluate graphic interfaces, the database, basic CRUD operations, advanced functional aspects, and the use of project management tools. A third individual validation to assess the integration of different modules by team members to achieve the final product, including the use of embedded hardware (Arduino Uno board, sensors, etc.). A fourth team validation was conducted to assess the student's ability to market their product and persuade the client. The final grade comprises two essential components: the individual grade and the team grade. The individual grade evaluates the skills acquired by each team member, while the team grade assesses collective work, assigning the same grade to the entire team. The calculation of the final grade is based on a weighting of 60% for the individual grade and 40% for the team grade. It is important to note that if the individual grade is below 10, the team grade is not considered in the final grade calculation. This grading system is designed to recognize both individual skills and the collaborative contribution of the team to the overall assessment.

The new approach: criterion-referenced assessment

Despite the growing interest in DT-PBL, it is challenging for educators to properly and legally evaluate the competency of each student. As we have seen in the old approach, the workload associated with the 4 validations was considerable, with a significant duration for each of them. In addition, major challenges arose in distinguishing the individual competencies acquired by each student, due to an overlap in the added value provided by different students. So, starting with the 2021-2022 academic year, we embarked on a new experiment, making significant changes to both the assessment process and process, to address the challenges encountered. This work led to a stabilized version adopted from the academic year 2022-2023. Details about the implementation of this new approach are presented in this section. The CDIO approach is built on the core premise that engineers should acquire practical skills via hands-on projects from the beginning of their education. The CDIO approach relies heavily on criteria-based evaluation to objectively and openly measure student achievement. This technique is based on pre-defined criteria that are connected with the core concepts of the CDIO standards and provide a comprehensive evaluation of learners' competencies. Unfortunately, developing a suitable assessment strategy remains an arduous task in the context of DT-PBL. This difficulty stems in particular from the complex nature of DT-PBL, which emphasizes active learning, concrete problem-solving, and collaboration between learners. Effective assessment must take these specific characteristics into account to accurately measure students' understanding and ability to apply the knowledge they have acquired. Given this reality, it is essential to promote the research and development of innovative assessment methods that better correspond to the principles of DT-PBL. This could involve collaboration between academics, educational researchers, and practitioners to design assessment tools aligned with DT-PBL's pedagogical objectives. Ultimately, while the challenge of finding an appropriate assessment strategy in the DT-PBL context is present, it also offers an opportunity to rethink and create approaches more suited to this innovative learning methodology.

Accordingly, a new detailed criterion-referenced assessment was proposed to evaluate the students' competencies. This assessment entails the evaluation of students based on 16 distinct criteria (learning outcome), outlined in Table 1. The assessment of competencies through a criterion-based evaluation mechanism, where several learning outcomes are defined, constitutes a rigorous and precise approach for measuring mastery of skills within a given domain.

The new evaluation consists of 7 principles Learning Outcomes (LO) distributed over the semester. Some assessment criteria are divided into more specific sub-criteria. This division makes the assessment more precise; and facilitates the identification of strengths and areas for improvement. It also allows evaluators to focus on specific aspects, making the assessment more controllable and promoting a more balanced evaluation. Besides, students will understand what is expected from them, thus facilitating their preparation and understanding of the assessment areas. Moreover, this approach will give students a better understanding of their skills and areas for improvement, helping them to make informed choices about their future specializations.

The first Learning Outcome (LO) and LO.7.1, LO.7.2, and LO.7.3 are evaluated in week 5, where students should present the application specifications including the main entities, the application's users, functional and non-functional requirements, and the suggested embedded features. Before starting the implementation, each tutor discusses the entities of the project's database, the attributes, and the relation between entities, based on various tutorials shared with the students in the Google Classroom. The criteria related to the project database (LO.2) are evaluated at the end of the ”Design” phase. The assessment of the application development criteria, including the basic operations (CRUD), the advanced features, and the embedded aspect is distributed over five weeks during the ”Implement” phase. During this phase, tutors guide students through pre-prepared workshops. For each stage of the development, a workshop containing foundational information is provided to the students. Most workshops are held asynchronously outside class hours. Subsequently, the students are expected to demonstrate proficiency in leveraging this information effectively and, incorporating design thinking principles to enhance and contribute their unique perspectives. During the ”Operate” phase, the tutors evaluate the final application from different perspectives, including the proper functioning of all features, the GUI design, and the use of project versioning tools for integration. This evaluation is followed by a presentation of the application, where students have to prepare a marketing campaign.

Table 1. The criterion-referenced assessment

Learning Outcome (LO)		CDIO phase	Assessment date	Assessment tool
LO.1: Define the application specification		Conceive	Week 5	Specification report
LO.2: Build a relational database to guarantee data consistency	LO.2.1: Elaborate the entity association model	Design	Week 7	Document
	LO.2.2: Elaborate the relational model			Document
	LO.2.3: Elaborate the physical model			Oracle Database
LO.3: Project management	LO.3.1: Use a project management tool	All CDIO phases	Every week	Github todo list updated
	LO.3.2: Use a project versioning tool	Implement	Week 7 to week 13	Github repository updated
LO.4: Develop a management application	LO.4.1: Develop basic operations (CRUD)	Implement	Week 8	Desktop application
	LO.4.2: Develop advanced functionalities		Week 10	
	LO.4.3: Design the GUI	Operate	Week 13	
	LO.4.4: Integrate a module to get a final deliverable		Week 13	
LO.5: Develop and integrate the embedded aspect in a management application		Implement	Week 12	Arduino scenario
LO.6: The cooperative working skills		ALL CDIO phases	Every week	Team cooperation
LO.7: Idea presentation and critical thinking	LO.7.1: Argumentation	Conceive + Operate	Week 5 + week 14	Presentation
	LO.7.2: Prepare a presentation			
	LO.7.3: Oral presentation			
	LO.7.4: prepare a marketing campaign	Operate	Week 14	

To foster collaboration while maintaining the importance of individual contributions, a learning outcome related to cooperative working skills is defined and evaluated every week starting from week 2. Since we are aligned with the CDIO standards, we gave great importance to project management skills. Accordingly, two learning outcomes were defined. The first one (LO.3.1), is a weekly assessment, that consists of evaluating a key skill that can considerably improve the students' efficiency. The second one (LO.3.2), is evaluated during the "Implement" phase, presenting the collaboration of all students in the preparation of the final deliverable.

The ultimate grade of each student is determined by aggregating the scores assigned to individual assessment criteria. Within criteria containing sub-criteria, the assigned score is the sum of the scores allocated to the sub-criteria. The score assigned to each assessment is communicated to students as an appreciation. This evaluation, referenced by criteria, adheres to a grading rubric where the appreciation attributed to evaluating the acquisition of different learning outcomes ranges from A (Excellent) to E (Not acquired), reflecting a comprehensive assessment of students' performance.

Table 2. Descriptions of both implemented methods

	Old approach	New approach
Process	Conceive: 4 Weeks Design: 3 Weeks Implement: 5 Weeks Operate: 2 Weeks	Conceive: 4 Weeks Design: 2 Weeks Implement: 6 Weeks Operate: 2 Weeks
Assessment	Numeric 2 individual assessment 2 team assessment Outcome-based	Appreciation-based 5 individual assessment 2 team assessment Competency-based

Table 2 summarizes the main distinctions between the two approaches, examining both the project process and the assessment methods.

ALIGNEMENT WITH CDIO STANDARDS

CDIO Standard 2: The DT-PBL pedagogical approach aims to develop essential learning outcomes such as the ability to analyze and synthesize information, develop effective solutions and communicate clearly and persuasively.

CDIO Standard 5: This module enables students to apply their knowledge and skills in real-life engineering situations, working on specifications; that meet concrete, potentially useful customer needs.

CDIO Standard 7: The exposed approach fosters close collaboration within a group of students, encouraging them to jointly solve complex engineering problems. It emphasizes the sharing of skills and ideas, creating an environment where each team member contributes collectively to overcoming the challenges encountered. The aim is to strengthen communication skills, encourage creativity, and develop the ability to work effectively in a team - all essential aspects in the engineering field. This approach offers learners an immersive learning experience integrating technical and interpersonal skills.

CDIO Standard 8: This project promotes innovative teaching and learning methods through the use of DT-PBL combined with blended learning and competency-based assessment. It therefore aims to create a dynamic educational experience. These methods promote competencybased assessment, enabling students to develop and demonstrate practical skills while adapting to a diverse learning environment.

CDIO Standard 11: The assessment approach introduced in the new method enables students to illustrate their learning outcomes and receive feedback on their performance, promoting continuous improvement and personal development. In addition, students have the opportunity to self-assess through a criterion-referenced assessment approach, evaluating each learning outcome independently. This approach reinforces learners' responsibility and encourages in-depth reflection on their acquired skills and knowledge.

IMPACT AND COMPARATIVE STUDY

In this section, we present an in-depth analysis regarding the impact of the changes made, observed between 2020-2021 and 2022-2023 academic year. We conducted this study using three samples, each comprising around 1,000 students, to provide a comprehensive perspective on the impact of these changes.

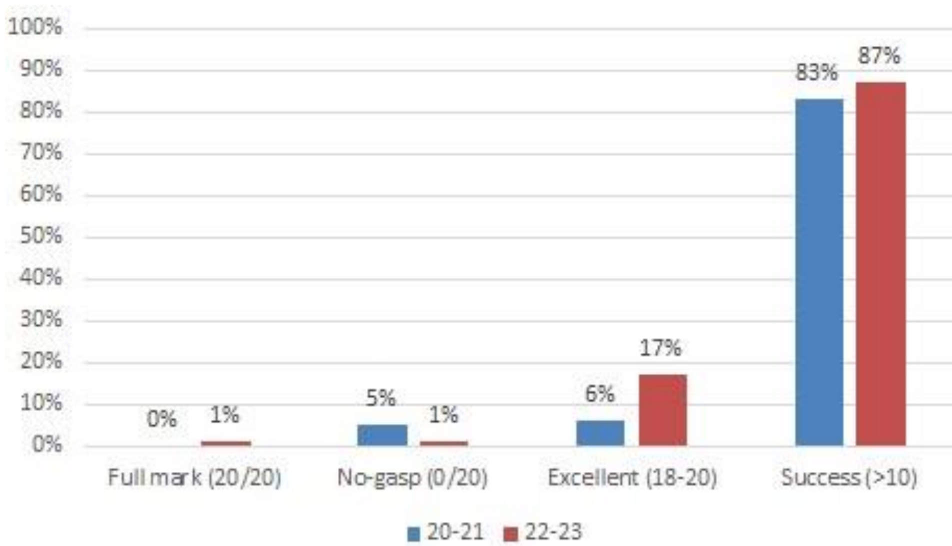

Figure 1. Impact of changes on student performance

Analysis of the results shown in Figure 1 presents a significant improvement in student performance. The no-gasp rate (0/20) decreased from 5% to 1% equates to a 5-fold reduction in the frequency of failures, suggesting a better understanding of concepts and a reduction in fundamental errors. Furthermore, the increase from 0% to 1% for full marks (20/20) can be interpreted as a significant improvement in the performance of a specific category of students. Indeed, given the size of the sample (around 1000 students), it is important to note that even a small percentage increase can represent a significant number of students having achieved this maximum mark. This implies a favorable trend, though attaining the highest score remains infrequent and poses a considerable challenge. Adopting the old approach, this mark was out of reach. Besides, the rise in the proportion of grades between 18/20 and 20/20, from 6% to 17%, suggests a marked improvement in student performance at the highest levels. This indicates a significant increase in the number of students achieving outstanding results in this grade range. This improvement can be interpreted as a positive sign that the new assessment method and changes are working, indicating more students have achieved high levels of mastery in their learning. In addition, the success rate (grade > 10) increased from 83% to 87%, indicating an overall positive impact on student performance. These results suggest that the new method helped to provide increased pedagogical support, and stimulate student engagement, thus promoting an overall improvement in academic results.

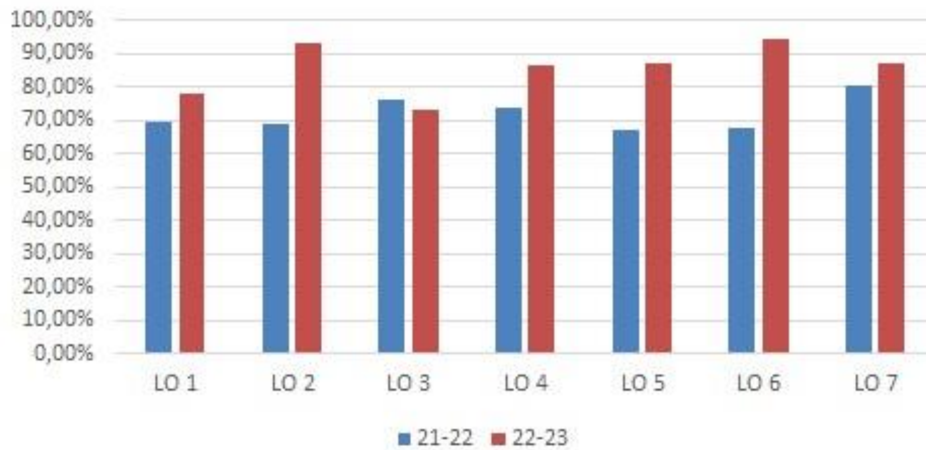

Figure 2. Learning outcomes acquisition rate

Due to criterion-referenced assessment, we were able to track the acquisition of skills by evaluating assessments. Figure 2 shows a comparison between the validation rates of our 7 learning outcomes between the academic years 2021-2022 and 2022-2023. We can see that improvement rates range from around 7% to 27% for all learning outcomes, except one (LO.3). In fact, we noted a 3% decrease in the learning outcome related to the use of version and project management tools via Git/GitHub and project boards. This variation suggests the need to explore the underlying reasons for this decrease, by examining student feedback and considering possible pedagogical adjustments to reinforce understanding of these specific concepts.

CONCLUSION

This paper proposed a new approach to improve the assessment process of the intended learning outcomes in DT-PBL courses offered at the ESPRIT School of Engineering. The first approach is a result-based assessment, comprising three individual validations, which collectively contribute to 60% of the overall grade, while a team validation constitutes the remaining 40% of the final grade. In the new assessment approach, students are evaluated around 16 individual and/or group assessment criteria distributed throughout the semester. Accordingly, the new assessment provides better continuous feedback for the students and helps them to improve their learning process. The comparative study between both approaches has proved the effectiveness of the second one in enhancing the understanding and skills of the students. Given the increasing prevalence of Artificial Intelligence (AI), it became crucial to leverage this technology in the context of DT-PBL to foster students' creativity, encourage exploration of emerging fields, and equip them with relevant skills for a technology-driven professional landscape. Additionally, it is imperative to contextualize these projects within discussions on the ethical implications of AI and promote responsible use of this technology.

FINANCIAL SUPPORT ACKNOWLEDGEMENTS

The author(s) received no financial support for this work.

REFERENCES

Amini, R., Setiawan, B., Fitria, Y., & Ningsih, Y. (2019). The difference of students learning outcomes using the project-based learning and problem-based learning model in terms of selfefficacy. In *Journal of physics: Conference series* (Vol. 1387, p. 012082).

Anazifa, R. D., & Djukri, D. (2017). Project-based learning and problem-based learning: Are they effective to improve student's thinking skills? *Jurnal Pendidikan IPA Indonesia*, *6*(2), 346– 355.

Barab, S. (2014). Design-based research: A methodological toolkit for engineering change. *The Cambridge handbook of the learning sciences*, *2*, 151–170.

Bell, S. (2010). Project-based learning for the 21st century: Skills for the future. *The clearing house*, *83*(2), 39–43.

Edström, K., & Kolmos, A. (2014). Pbl and cdio: complementary models for engineering education development. *European Journal of Engineering Education*, *39*(5), 539–555.

Haatainen, O., & Aksela, M. (2021). Project-based learning in integrated science education: Active teachers' perceptions and practices. *LUMAT: International Journal on Math, Science and Technology Education*, *9*(1), 149–173.

Han, S., Yalvac, B., Capraro, M. M., & Capraro, R. M. (2015). In-service teachers' implementation and understanding of stem project based learning. *Eurasia Journal of Mathematics, Science and Technology Education*, *11*(1), 63–76.

Kingston, S. (2018). Project based learning & student achievement: What does the research tell us? pbl evidence matters, volume 1, no. 1. *Buck institute for education*.

Kokotsaki, D., Menzies, V., & Wiggins, A. (2016). Project-based learning: A review of the literature. *Improving schools*, *19*(3), 267–277.

Krajcik, & Shin. (2014). and shin, n.(2014). project-based learning. *The Cambridge handbook of the learning sciences*, 275–297.

Poonpon, K. (2017). Enhancing english skills through project-based learning. *The English Teacher*, 10.

Ralph, R. A. (2016). Post secondary project-based learning in science, technology, engineering and mathematics. *Journal of Technology and Science Education*, *6*(1), 26–35.

Savery, J. R. (2019). Comparative pedagogical models of problem-based learning. *The Wiley Handbook of problem-based learning*, 81–104.

Viro, E., & Joutsenlahti, J. (2020, Jun.). Learning mathematics by project work in secondary school. *LUMAT: International Journal on Math, Science and Technology Education*, *8*(1), 107– 132.

Warr, M., & West, R. E. (2020). Bridging academic disciplines with interdisciplinary projectbased learning: Challenges and opportunities. *Interdisciplinary Journal of Problem-Based Learning*, *14*(1).

BIOGRAPHICAL INFORMATION

Soumaya Argoubi is a Faculty member and head of the algorithms and programming pedagogical unit at ESPRIT School of Engineering, Tunisia. She holds a PhD, a Research Master's in Protocol, Networks, Images, and Multimedia Systems, and a National Engineer's Diploma in computer sciences. The research areas in which she is involved revolve around wireless networks, the incorporation of Sustainability in engineering education, and innovation in educational strategies. She teaches courses related to algorithms and C/C++ programming as well as networking. She has published 4 scientific papers in international conference proceedings.

RihabChaâri is an associated lecturer at ESPRIT School of Engineering, Tunisia. She is teaching C++ programming courses and projects. She holds a Ph.D. degree, a master's degree, and an engineering degree in computer science. She has published 2 scientific conference papers and 2 research journal papers.

YosraFraiji received a Ph.D. degree in computer science from the National School of Computer Science (ENSI), Tunisia, and the University of Normandie, France in 2021. Since 2021, she joined the ESPRIT School of Engineering, Tunis, Tunisia. Her research interests are in the areas of wireless sensor networks, vehicular networks, context-aware security, and privacy, with an emphasis on mathematical modeling and performance analysis.

Salma Hajjem is a professor of computer science at ESPRIT. He holds a research master's degree from the National School of Computer Science. His research focuses on project-based learning and artificial intelligence.

Corresponding author

Soumaya Argoubi
ESPRIT School of Engineering
1, 2 rue André Ampère - 2083 Technological
Pole - El Ghazala soumaya.argoubi@esprit.tn