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Exploring PBL as a New Learning Context in Engineering Education

Elena GOGOI, ORCID: 0000-0002-4159-34771[1]
[1] Technical University of Moldova, Republic of Moldova, Chisinau, email: elena.gogoi@faf.utm.md

***Abstract* - This paper explores the experience of engineering students in an innovative context, namely, Problem-Based Learning (PBL). It first describes some particular details of PBL framework implementation at the BSc Degree in Software Engineering, an English-taught Honours Programme at the Faculty of Computers, Informatics, and Microelectronics (FCIM), Technical University of Moldova (TUM). The research also addresses some specific aspects of its implementation, preparation for collaboration, milestones, working processes, guiding sessions, etc. A comparative study between the 2022 and 2021 editions of BSc graduates in Software Engineering was conducted to identify the efficiency of several dimensions of PBL as one of the most recently adopted learning environments at TUM.**

Keywords – Problem-based Learning; mentoring; learning environment; educational context; engineering education; collaborative learning; teamwork; challenges.

I. INTRODUCTION

In the context of rapid technological progress, our society urges a vital interest in skilled employees who can easily update their knowledge, learn and relearn things and processes, to quickly adapt and be ready to recreate old technologies into new ones.

One of the principles of the Higher Education Learning Framework (HELP) states that: "A university education provides a learning experience that broadens students' knowing and being for life beyond the classroom" [1, p. 1], which serves as a foundation for academic staff to focus on offering engaging learning experiences to prepare students for the world of work.

To keep up with these dynamic changes and to align with the needs of this digital society the Technical University of Moldova (TUM) strives to prepare future engineers fully equipped to analyze problems, find possible improvements and implement them in close collaboration with the industry.

Our university has been investing effort, support, and resources to enhance active participation and to create regular contacts and bonds that promote fruitful exchanges and efficient learning. It has also been making considerable efforts to provide innovative learning environments to transform learners' educational experiences into more efficient, meaningful, and impactful ones.

Adapting the curriculum is among our priority objectives, which is why the academic staff from our University constantly works on expanding and redefining opportunities to improve it by adding new dimensions oriented to innovative learning contexts meant to enhance teamwork, collaboration, and hands-on activities aiming at better preparing engineering students to face this paradigm-shifting age.

II. PROBLEM-BASED LEARNING AT TUM: CONTEXT, BACKGROUND, FRAMEWORK

"Learning occurs in a context, and it can be used to enhance the learning experience", another HELF principle aims to make the learning experience more relevant, meaningful, and engaging, so that students develop skills to apply learning to different contexts after graduation [1, p. 3]. It is a well-known fact that engineers do not work in isolation and TUM, in this regard, is in permanent search of favourable learning contexts. Also, many researchers claim that: "It is inconceivable to think that great engineering projects of high complexity can be conceived and created by an engineer in solitude. Consequently, collaborative learning is most suited and a natural must in preparing engineering students for the challenges that lie ahead" [2, p.175].

In this context, PBL, as a small group learning, was adopted at TUM as the driving key that can ensure collaboration and teamwork for future engineers. In 2017, the previously English-taught Honours Programme in Computer Science (FAF), was redesigned into English-taught Honours Programme in Software Engineering. Being complimented by Problem-Based Learning (PBL), a modern pedagogical framework, it has immediately become popular. This innovative collaborative approach was introduced in the curriculum of the Bachelor's Degree

in Software Engineering with the purpose of "enhancing students' competitiveness and employability" [3].

An interesting fact to mention is that the *collaborative learning strategy* is considered one of the oldest forms of group learning. The first attempt to address it began thousands of years ago when studying the Talmud, the Jews insisted on boys working in partnership with others to decode and facilitate the interpretation of sophisticated texts [4].

Quite often the concept associated with group learning varies from *cooperative learning*, *collaborative learning*, and *problem/project-based learning*, to *small-group learning*, *team-based learning*, *peer instruction/ mentoring*, etc., and it becomes difficult to distinguish among them. As it has been appreciated, these approaches share so much in common, that the terms are considered similar forms, often combined or used interchangeably or alternatively. Even researchers, argue about the term, accepting them as synonyms, as professor M. E. Weimer, in one of her public communications was insistently asking whether it matters what we call it [in 5].

Whatever the term of reference, it is extremely important to understand that all these philosophies or forms of small group learning promote active learning, active involvement in the learning process, a lot of interaction, and personal accountability leading to increased motivation and achievements, and development of critical and creative thinking skills.

The early 1960s are distinguished by an increased interest in small-group learning approaches both at the pre-university and university levels. The origin of PBL, as a form of cooperative learning, can be found in the medical program at McMaster University, gradually evolving into an educational methodology implemented by many other institutions around the world, being identified as "a learning method based on the principle of using problems as a starting point for the acquisition and integration of new knowledge" [6].

In our case, this pedagogical framework is always collaborative, encouraging students to engage actively in the learning process and skill acquisition. The PBL context model alludes to joining efforts in learning to achieve common educational goals. In this framework, disciples have the opportunity to identify and explore real-life problems, analyze them from different perspectives, apply knowledge to practice, collect relevant data, and discover and provide various viable solutions together with their fellows.

The PBL within the Faculty of Computers, Informatics, and Microelectronics, widely explores teamwork by addressing and developing multidisciplinary semester-wide projects as can be seen in Table 1 according to the *Study Plan for the Bachelor of Science in Software Engineering* approved in 2021 [7].

TABLE I. SEMESTER PROJECTS

Semester / Name of the Project	
1.	Conceptual Design of an IT Application
2.	Equivalent Models
3.	Basics of Application Development
4.	Development of Domain-Specific Languages
5.	Secure Application Development
6.	Internet of Things
7.	Information System Design
8.	Bachelor's Thesis

Teamwork, in a PBL environment at FCIM, TUM, means that students collaborate to enhance individual learning. This small-group learning can be translated into how group members actively support each other's learning processes. Teams shaped at the project start have to work out viable solutions for a proposed or identified challenge, problem, or real-life issue. Each team is expected to develop the vision of the challenge and propose an original IT solution to it. The students have to organize themselves to plan a roadmap, make decisions and find solutions decide, anticipate, adapt, and adopt different perspectives, and all actions needed to solve a problem which is turned into a project.

The PBL projects are always carried out in teams that are built at the beginning of a new semester. Usually, students are put together during the PBL take-off session in the first week of each semester. If in the first semester there are 5-6 students in a team, we move to smaller teams of 3 or even 2 students in the last semester (for the graduation project). The number of individuals assigned to a team depends on some factors rooted in hour distribution per academic staff. Moreover, in the first 2 years, the number of people is bigger (usually 90 students enrolled for the Software Engineering study programme), while in the 3rd and 4th years, the number decreases drastically because of dropouts (sometimes decreasing to 60-70 students for the same programme).

Of course, the most challenging, in terms of group formation, is the first semester because students hardly know each other and the rationale beyond the criteria used to set up the teams focuses on heterogeneity (male/female, ethnicity, knowledge, skill backgrounds, and many others). The MBTI personality type indicator has been recently adopted as one of the tools suggested by psychologists for teamwork and one that helped us build balanced teams in terms of personality and character, commitment, leadership, etc.

In the context of PBL, team-building activities are carried out to engage students in discussions, interaction, and knowledge sharing. Also, some hours usually focus on teamwork issues: teamwork objectives, team formation and team development stages (forming, storming, norming, performing, and adjourning) according to Bruce

Tuckman's model, Meredith Belbin's team roles, the importance and the need of synchronizing hard and soft skills, assertive communication, conflict management, time management, project management, etc.

Each team is randomly assigned a teacher-supervisor. During both PBL editions a group of teachers, mainly from the Department of Software Engineering and Automation, has been steadily guiding the teams.

It is important to emphasize that in PBL, a crucial transformation in both teachers' and students' roles should be considered. The teachers move from the traditional knowledge imparting and sharing, to facilitating, guiding, and supervising students' learning. The student, in this paradigm, is no more passively absorbing the information but moves to self-directed learning, focusing on a learning-by-doing approach.

Broadly speaking, the teacher in a collaborative PBL setting will guide, notice, observe and intervene only when s/he considers it necessary, so that, students do not deviate from the right path to knowledge acquisition and learning objectives attainment. Furthermore, s/he becomes *a mentor*, *a supervisor*, and *a facilitator* of the educational process. In our academic community, colleagues, working in the PBL context, are known as *mentors*.

Another important point to make is that PBL mentors are occasionally recruited from IT companies on a voluntary scheme. This form of collaboration has only forged the partnership between industry and university, aiming to get constant feedback from the labour market, a helpful tool meant to guarantee permanent optimization of study programmes and future-oriented technologies.

The PBL mentoring/supervising process normally involves a mandatory weekly one-hour-and-half-session between the mentor and his/her team. These meetings are held in the team-assigned project room or online, at a pre-scheduled date and time. During this meeting, the mentor discusses the progress and project management issues with his students. The other meetings without the mentor, are not included in the faculty schedule because they are held in extra-curricular time.

Of course, implementing Problem-Based Learning as a collaborative context for engineers doesn't mean a new curriculum adoption and content change only, but also adequate infrastructure aimed to simulate the world of work. The meeting point, called the *PBL area*, was designed to offer more interaction, and it was configured to pursue ideas and creative solutions to real-world problems, providing opportunities to explore new technologies and to engage with peers giving a meaningful impact on their studies.

Several classrooms, large lobbies, recreation spaces, mobile furniture, and collaborative open spaces have been designed to support small group learning and also engage the active minds of students and mentors. To fulfil course and programme requirements, this environment is meant to immerse students in deep learning.

III. METHODOLOGY

In this article, we tried to explore teamwork challenges faced by the 2022 and 2021 graduates of BSc in Software Engineering at the end of their degree. The responses were collected by an individual survey and also in small and academic group open discussions within several PBL follow-up sessions. The discussions were meant to highlight several aspects related to the PBL framework and environment to improve the level of satisfaction and the learning outcomes in the next editions, and also to reinforce the positive dimensions pointed out by our graduates. The results are shared among the faculty staff, students, and PBL mentors, of course.

The survey was applied at the end of BSc, which means 8 semesters of teamwork in PBL. The overview of the survey consists of several sections: PBL dimensions, mentor's roles in PBL, collaborative principles, etc. For this specific paper, we have focused on the dimensions of PBL as a new learning context, the optimal number of team members, the level of satisfaction with the PBL experience, challenges faced and, of course, suggestions to improve this new learning context to increase the learning efficiency.

Small group discussions with students were organized after the survey was completed. The discussions were facilitated by the faculty staff and aimed at collecting students' opinions more openly. Some of the topics discussed included the project themes, the assessment methods, and the PBL as a learning methodology.

As previously mentioned, the study is focused on exploring the elements of a new learning environment based on teamwork and problem-solving. Also, the methodology uses a quantitative and a qualitative instrument to collect the opinions and perceptions of students about PBL elements, giving them the opportunity to both write and discuss in an open and informal environment, and to express themselves freely and honestly.

IV. RESULTS AND ANALYSIS

We explored the effectiveness of several elements of PBL as a new learning context, applied to undergraduates from the English-taught Honours Programme in Software Engineering, Faculty of Computers, Informatics, and Microelectronics, Technical University of Moldova.

After 8 semesters in a collaborative environment, we have chosen to compare the results of the first 2 editions of graduates with an equal number of respondents: the 2022 edition (41 respondents out of 46 graduates) and the 2021 edition (41 respondents out of 43 graduates).

The following tools have been analyzed: the size of the most efficient group work, level of satisfaction, elements, challenges faced, things to be improved, etc in the PBL context.

From the figure below, it is clear that there is no significant difference between the number of females and males entering the Software Engineering (SE) field. This representation leads us to the idea that women get more and more interested in domains, previously chosen, mainly, by males.

Figure 1. The number of male vs female students in SE: a) 2022 edition, b) 2021 edition. (figure caption)

In the table below, we present the collected data for each question of the survey.

Q 1. Teamwork will help me be more marketable in the workforce.

TABLE II. IMPORTANCE OF TEAMWORK SKILLS

	2022 graduates	2021 graduates
Yes	30	36
No	1	1
Maybe	10	4

When asked about *the importance of teamwork skills* after graduation, the vast majority of graduates from both editions have positively appreciated it; the figures reveal that the young people entering the IT world are already familiar with the requirements of the labour market. Interestingly that one person from each edition denies the importance of teamwork as being an unimportant skill on the job. We have also identified 10% of indecisive individuals from the 2021 edition, while the number doubles in the 2022 edition.

Another important element of a collaborative environment is the optimal number of teammates for a more efficient working process.

Q 2. What is the optimal team size?

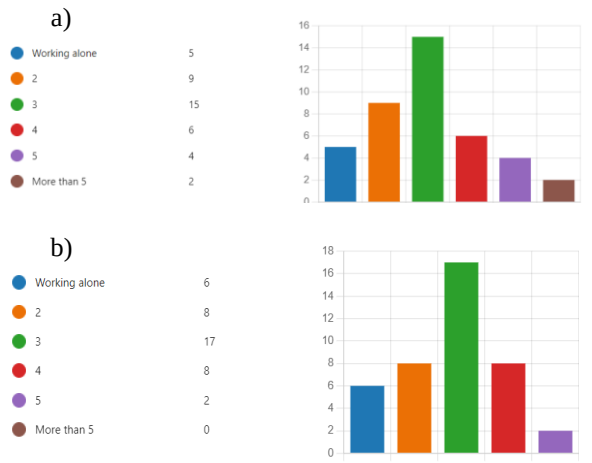

Figure 2. The number of team members in an efficient team: a) 2022 edition, b) 2021 edition. (figure caption)

During their degree, Software Engineering students worked on their PBL projects being assigned to 8 different teams, having the possibility to interact with new teammates every semester (from 6 members to 2). The data would seem to suggest that the optimal number for the most efficient teamwork is 3. As they have explained further, the fewer people, the easier the working process, and task delegation and the more individual responsibility assumed. We cannot ignore the fact that more than 10% of respondents dislike working in teams preferring to work alone. It might happen that an eight-semester period is not enough to adapt to a collaborative working environment or to develop teamwork skills. Or, this happens because they are introverts, finding it difficult to collaborate with others. On the opposite end, just a couple of students feel comfortable working in a bigger team.

Q 3. Which PBL element(s) did you enjoy most?

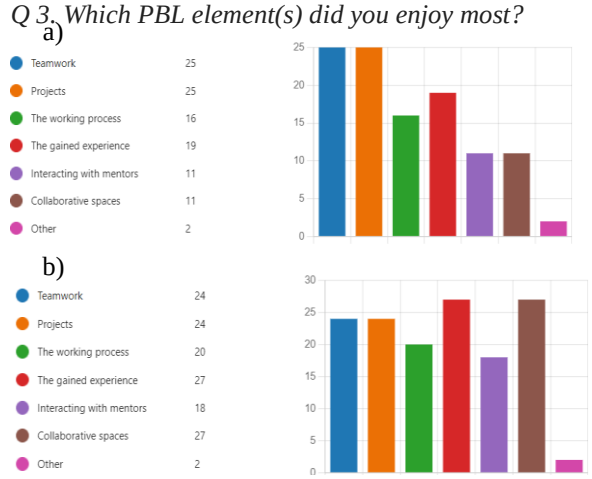

Figure 3. PBL elements students enjoyed most: a) 2022 edition, b) 2021 edition. (figure caption)

Working in a new context like PBL means dealing with several elements meant to enhance the learning process, knowledge acquisition, and efficiency. Since respondents have suggested several elements like teamwork, projects, collaboration, collaborative spaces, interacting with mentors, and gaining experience, we can't say that they have highlighted their preferences more for some elements, and less for others. One distinct difference between the two editions is that the 2022 graduates enjoyed less the collaborative spaces and interaction with mentors than their 2021 peers. The explanation is quite simple in this dimension: the 2019 pandemic and the transition to online education led to less human interaction and of course the lack of possibilities to learn and work in a physical collaborative space for students enrolled in 2018.

Q 4. On a scale from 1 to 5, how would you appreciate your level of satisfaction with your 4-year PBL experience?

TABLE III. AVERAGE RATING NUMBER WHEN APPRECIATING THE LEVEL OF SATISFACTION IN A NEW ENVIRONMENT, PBL

2022 edition	*2021 edition*
3.63	**3.68**

When asked to appreciate the level of satisfaction with a four-year PBL experience, on a scale from 1 to 5, the average rate represents 3.63 points for the current year, 2022 graduates, and 3.68 points for the previous year, 2021 graduates. These data seem to suggest that our graduates faced a similar number of challenges. On the one hand, these results are encouraging for our institution since we have managed to get above the average with the first 2 editions of graduates who experienced learning and knowledge acquisition in a new setting like PBL. On the other hand, these data must be considered as a signal that we have to continually work on improving the elements constituting the new learning context to get to a higher level of satisfaction.

Q 5. Would you advise other students to join a study programme based on the PBL framework?

TABLE IV. ADVISING SCHOOL GRADUATES TO JOIN PBL

	2022 edition	2021 edition
Yes	21	23
No	1	2
Maybe	19	16

To see how enthusiastic about encouraging other school graduates to join a study programme that aims at a collaborative paradigm oriented to PBL 51% of 2022 graduates and pretty the same number, 56% of 2021 edition reported their desire and openness to advise others to join this degree.

Q 6. Would you like to become a part of our PBL Mentoring Team?

A big discrepancy between the two editions of graduates concerning their desire to join our team of mentors was discovered. While more than two-thirds of the 2021 graduates, right after graduation accepted to become part of our PBL mentoring team, actually only one graduate has joined our team. In the 2022 edition, the number of those enthusiastic about supervising a PBL project decreases drastically to less than one-third, thus, 3 of them have joined our team. Further research needs to be conducted to identify the reasons for refusing to work in an academic environment.

Of course, students working in a collaborative context oriented to PBL have faced a lot of challenges common for both editions: free riding and difficulties to convince every member to contribute, task delegation, tight deadlines, conflicts among peers, difficult milestones, etc. They have also complained about the tough bureaucratic process, including writing meeting notes and meeting agendas with the current status of the project for every single team meeting.

The graduates' insights below serve as a window to an understanding of the challenges they faced while working under the PBL framework.

"Teamworking process ... so complicated to work in a team when everyone has his point of view", anonymous 2022 graduate.

"Some team members know that other team members will work on the project and don't contribute until the last week before the deadline", an anonymous 2022 graduate.

"Not all the teammates are interested in working on the project. Feedback is not understood properly", anonymous 2021 graduate.

"Learning a new programming language in 3 weeks, and writing meeting notes, that I didn't do before", anonymous 2021 graduate.

While some of our graduates faced a lot of challenges, some others felt positive about their 4-year of PBL experience and fully enjoyed learning in this new context.

Learning in a collaborative environment helped our graduates grow and develop soft skills and improve their hard ones as can be seen from their insights:

"I didn't face many specific challenges; every new project was a challenge but it was interesting to work on them", anonymous 2022 graduate.

"It was a challenge for me to get out of my comfort zone and to speak in front of a public, this was a problem for me and PBL context helped me to overcome it", an anonymous 2022 graduate.

"The biggest challenge was to socialize. PBL requires teamwork and social interaction. Throughout the school period, all the students are taught to face all their issues alone, and PBL is the exact opposite of that. It was

difficult to adjust, but the more I studied in the PBL environment, the easier it became, and I didn't even notice how much more enjoyable the teamwork and social interactions became …", an anonymous 2021 graduate.

"I wouldn't say there were exactly challenges, I would rather call them opportunities; when you do not know a specific programming language, our mentors' timely answers and resources provided the exact help I needed. Besides that, our professor XY's homework, at the beginning was so terrible that everyone wanted to finish his course, but later you understand how important the assignments were and what happiness was to have him as a teacher.", an anonymous 2021 graduate.

In the end, they were invited to suggest aspects to be improved in the teaching-learning process. The most common suggestions were oriented toward the organizational process of project development, clear assessment criteria, clear deadlines for the checkpoints, and less bureaucratic stuff, like writing weekly meeting notes, and others.

"To work in smaller teams, 2-3 people for each project", anonymous 2021 graduate.

"To have more interactions with the mentor", anonymous 2021 graduate.

"Let students choose their mentors, teammates, projects … ", anonymous, 2022 graduate.

"PBL framework should be applied for all students at the Technical University of Moldova", anonymous 2022 graduate.

CONCLUSIONS

This paper explored the elements of a new learning context, Project-Based Learning in the Bachelor of Science degree in Software Engineering within the Faculty of Computers, Informatics, and Microelectronics, Technical University of Moldova. The study was grounded on the first 2 editions of graduates (2022 and 2021). The answers were collected at the end of their 4-year degree using questionnaires, small group open discussions, and individual feedback. The results show that in both editions students have a more than average level of satisfaction with their experience with teamwork. Students also acknowledge that PBL, as a collaborative tool, will help them be more marketable in the workforce market. The results of the present study demonstrate that 3-4 individuals in a team are the optimal number for a more efficient working process Additionally, students consider teamwork as a valuable asset to their personal and professional development.

The respondents also point out that they prefer to learn by working in teams. While a lot of them have acknowledged their desire to become part of our mentoring team, only a few have joined us.

The small group and individual discussions reinforced the idea that working with free riders is time-consuming and should be immediately addressed requiring an official reaction.

It is now clear that future work should also focus on promoting a culture of reflections in PBL, requirements for formal meetings, and strategies for wider adoption within teams. Moreover, research should be conducted on the assessment process analysis: peer evaluation, group project, and individual interviews and the weighing of each for the final grade. system of teamwork and group project along with the reflection processes.

Of course, future work will be aimed at improving the whole process which will include more guidance from mentors, addressing the free-riding phenomenon, giving penalty points for those who do not contribute to the project work or, in the worst scenario, to be eliminated from the initial team and be assigned an individual project of lower complexity.

All of this points to the fact that the most important dimension requiring improvements is the planning process, especially for the teachers joining the PBL mentoring team for the first time. This can be achieved through continuing teacher training where new teachers will be initiated on how to act in a new educational context, the one oriented to small group learning and identifying real-life issues like PBL.

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