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Improving the use of online resources to enhance efficiency of the Problem Based Learning in Engineering Education

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Abstract

Demand for trained engineers is high worldwide, and the situation can be characterized as critical for the Global South where challenges due to students' apprehension towards mathematics and physics further complicate the case. Engineering skills are essential and recent shifts in methods using problem or project-based learning (PBL) put engineering education in the right tracks. This paper is aimed at improving the PBL approach by introducing students to a better use of online resources, including those resulting from Artificial Intelligence (AI). With easy access to the Internet, some students might be tempted to search for ready-proposed solutions instead of investigating their own ideas with personal critical thinking. Engaging students, from day one, in PBL method exploiting efficiently AI, could result in enhancing motivation of engineering students, even those lacking scientific prerequisites. Practical experiments, like disassembling and reassembling technology, combined with PBL, are expected to reduce students' apprehension of engineering courses.

I. Introduction

The rapid technological innovations in all sectors such as sustainable infrastructures or automated machines require more engineers with versatile skills. This demand, though inequitably distributed around the world, is a global trend. In the US, the CHIPS and Science Act, the estimation is that in the semiconductor industry roughly 67,000 out 115,000 new jobs needed by 2030 might be unfilled. Of the unfilled jobs, 39% will be technicians, most of whom will have certificates or two-year degrees; 35% will be engineers with four-year degrees or computer scientists; and 26% will be engineers at the master's or PhD level (Chipping Away: Assessing and addressing the labor market gap facing the U.S. semiconductor industry, consulted on January 6, 2025). A blog of the World Bank states that an estimated 2.5 million more engineers are needed in sub-Saharan Africa to tackle its development challenges, yet as things stand, the region falls short of meeting the demand. (Amegah A. et al., 2023)

Globally, the need for civil engineers will continue growing as countries are willing to comply to net zero construction requirements; and for the Global South, basic infrastructures (roads, building for hospitals or schools for example) are urgently in need for skilled engineers.

The disparity in needs is also true in engineering education between developed counties and the Global South. Whereas students in the developed countries easily have access to computers, the Internet, and equipped labs, most engineering colleges in the Global South have limited access to the resources needed. Moreover, only a few engineers are ready to work in the education field.

The problem is more critical for remote areas where students, though willing to do engineering study, apprehend it for insufficient scientific prerequisites as most remote areas lack qualified scientific teachers even at the high-school level.

Historically, the term Problem Based Learning (PBL) was coined in 1974 by Howard Barrows retroactively describing an innovative approach to medical education, which had been developed at McMaster by John Evans and his team, starting in 1965 (Servant-Miklos V., 2020). It has since been adopted for several other disciplines, including engineering projects under the term Problem Oriented Project Work or Problem Oriented Project Learning in the beginning (Servant-Miklos V., 2020). In this paper, PBL will stand for both Problem Based Learning and Project Based Learning.

PBL is a promising method because it can easily be implemented in schools, even where there is limited access to resources. It promotes student-centered rather than teacher-centered learning, takes place in small groups, enables the students to apply knowledge to real-life situations and increases student motivation to learn, which could improve lifelong learning (Servant-Milkos V., 2020).

The general process of a PBL has at least three characteristics: presentation of the problem or the project taken from real-life, students' study and research on related subjects to the problem or project and interaction with experts who provide advice and explain difficult concepts. The expert can be one of the teachers in the school or an external stakeholder. The problem with the implementation of PBL in remote areas is with the third characteristics. Experts are less available for learners because they are busy in productive industrial activities. The interaction with experts is therefore limited. Here comes the need for integrating online resources, including the use of AI to enhance the PBL approach. This paper will focus on the professor's views on this integration from a prospective perspective. In future research, the students will be involved. This will cause an evolution in the concepts. The qualitative approach of the current paper will then be complemented with a more quantitative approach.

There are, however, minimum requirements and these can be met quite easily with ordinary computers that can be connected to the Internet from time to time and with digital labs.

II. Two examples of PBL implementation

Authors of this paper use the PBL approach for first year engineering students. They are reflecting on how to enhance their practice for implementation in the Global South. The first example presents the way PBL is done in the engineering college at the Loyola University of Congo (DRC, Global South) and the second is presented as an interview with a professor at the engineering college of University of Detroit Mercy (USA, North).

II.1. Steps of a PBL at the Loyola University of Congo

At the engineering school of the Loyola University of Congo, PBL approach is used in several courses, among which the introduction to industrial engineering science. In the beginning of the year, the students are given a year-long design project guided by the professor with expectations of increasing difficulties. The aim of the project is to help first year students to consolidate the basic prerequisites for successful engineering studies. They must integrate their scientific and technological subjects learned in high school and use them to design a mechatronic system.

The steps for this project are as follows:

Step 1 - presentation of the problem: The professor presents the problem chosen from real world and students brainstorm to divide the problem into different subjects. Each subject is given to a group in such a way that the load of work is similar for each group.

During the academic year 2021-2022 for example, the students were asked to design a semi-automatic system to make fired briquets. The problem is divided into small problems and each group explores on one of them: the first group researched on raw material, i.e. clay; the second group was destined to study different ways to sift clay, the third group had the design of the mechanical system, the fourth had to study the electrical circuits for semi-automatic functioning, the fifth was in-charge of the settings for security, the sixth had to suggest the maintenance of the system with a user manual and the seventh had to look at the ergonomics of the all system.

Step 2 - Study and Research: students are given time to study, individually and in a group, existing systems and raise out all the unsolved difficulties that they faced. This includes theoretical problems such as mathematic tools used in resources they consulted.

Step 3 - Expert time: conferences are organized around the key concepts and the difficulties encountered. The professor can encourage them to visit a manufacturing company or craftsmen. The mechanical group for example discussed with craftsmen who use manual brick making machine. Depending on the topic, this step can comprise of some workshop sessions such as how to solder or to program an Arduino, etc. This step also gives the opportunity to the professor or the expert to fill persistent gaps in scientific knowledge. A formal course can be taught using the most efficient pedagogy to reach expected outcomes.

Step 4 - Integration of sub-systems: the groups meet regularly to exchange information so that the various aspects can be easily assembled. Steps 2 to 4 are done in loop until the initial specifications are satisfied.

Step 5 - An oral presentation with a real or virtual prototype system closes the project and a final note is given to each group.

Benefits: students learn by themselves, they acquire research skills, they understand the requirements of working inside a small group but in coherence with the larger group, they face early in their study the obligation to design a system that works and they realize the necessity for engineers to efficiently communicate on what they are designing.

Limits: results depend much on the commitment of a few students. Some groups may reach the general expectations of the course and can even go beyond them according to the quality of the resources they used whereas some other groups can produce unsatisfactory results or be below expectations.

The success of this pedagogy also depends on accessibility of resources for theoretical research or practical workshops. Overall, PBL approach contributes to developing versatile skills and critical thinking in students.

II.2. Interview on PBL approach at the University of Detroit Mercy and use of AI

Q1: Could you describe a specific PBL activity or project you have used? What was the focus, and how was it structured?

Students in ENGR 1050 Freshmen Engineering Graphics and Design work with a non-profit client. Students design improvements to the client's building and grounds. Students visit the client's site several times as a whole class. In the beginning of the course, the students visit the client to learn about them and to become familiar with their building and grounds. The students are then motivated to learn about problems with buildings in areas such as energy use. They spend some time learning how to identify and measure building issues such as energy use. Then the class returns to collect data about the projects that they will be working on. Next, the students use that information to create a design proposal. Finally, they present their preliminary findings to the client and get their comments. By the end of the semester, they revise their designs based on the comments.

Q2: What changes have you noticed in students' problem-solving skills, creativity, or teamwork abilities since implementing PBL?

Students can seek out their own information. It varies from student to student. Students are more likely to independently seek information. They will show information that they have found to the instructor.

There are many types, levels, and definitions of creativity. With no PBL, creativity may be limited such as to just varying parameters within stated limits. With PBL, students are more likely to look for solutions from outside sources of information. I work with freshmen in this course, and they aren't likely to synthesize information from many sources for a new creative solution. However, the freshmen are creative in the sense that they look to outside information for one complete solution.

The students want to work in teams or to interact with the other students in their class. Many students may naturally hesitate to interact. However, providing students with a reason to interact encourages them to do so. The result is that the students develop closer bonds.

Q3: Have you observed any differences in how students approach engineering challenges when using PBL versus traditional methods?

The students are motivated to work on a project when it is a real project with a real client. Previously, the projects were academic, meaning that they were created for the purpose of learning but not for serving a client. Students viewed the assignments as obstacles to overcome. However, working on a real project that is often implemented makes the students feel an obligation to meet their responsibilities. They feel that their actions have consequences beyond just getting a grade.

PBL has more of a story and students say that story. Non-PBL has no story.

Q4: What logistical or resource-related barriers have you encountered when implementing PBL?

Since I have my students work with real non-profit organizations, this means that the students must go off-campus. I have had to sometimes arrange transportation for students. Taking appropriate measurements of energy use can sometimes require specific instrumentation. A logistical challenge for the instructor is finding an appropriate non-profit organization client and scoping for the right challenge for students in the course.

Q5: Could you share an example of a challenge you faced with PBL and how you resolved it?

Many students are simultaneously working on different types of projects simultaneously. It can be hectic trying to coordinate several different projects at the same time. One way that I have tried to manage this is to have an upperclassman be a teaching assistant in the course. For example, they could be assigned to a specific team with a project that is like one that they have done themselves in the recent past. This presents a new difficulty in finding the right student for this role. Another way that I deal with this challenge is to not set the expectation too high for weekly progress. Students may develop only one small incremental step from one week to the next.

Q6: What is your current understanding of Artificial Intelligence (AI), and how do you see its role in engineering education?

I regularly use generative AI. I am conflicted about its use.

Students can get quick answers to questions using AI. That is useful when they are trying to find information. However, it can enable the students cheat by having AI do their work. Data shows that students don't learn content effectively when they use AI.

Q7: What specific areas of engineering education (e.g., labs, assessments, personalized learning) do you think AI has the most potential to improve?

AI could be used by faculty members to prepare labs, assessments and personalized learning. This has tradeoffs for the faculty member. Relying on AI eases the burden of workload. However, by placing authority for creating materials elsewhere, the faculty member is less engaged. They will be less attuned to the expectations that they have of students.

From the student's point of view, AI provides too much ease to cheat on labs etc.

Q8: How do you think AI could help overcome barriers to education in resource-constrained settings?

In general, the web provides democratized access to information. Printed materials are only available to those who have them. AI uses information from the web. AI helps overcome barriers because it makes the web easier to use, so information is even more democratized.

Q9: What challenges or limitations do you foresee in integrating AI into engineering education (e.g., cost, ethical concerns, technical barriers)?

All learning should be from basic theory up to application. AI adds one more level of learning that is required. It is one more thing that must be taught. This adds to the burden of education.

There are many ethical concerns. For example, AI will dramatically increase the demand for electrical energy. (e.g. double it.)

Q10: Are there any potential risks you see in over-relying on AI in the classroom?

Data shows that students don't learn content as well when they rely on AI to provide answers to assignments.

Over-relying on any technology has a problem in that when the technology is unavailable, progress can't occur. For example, a long-term internet outage could stall work. If someone relied on AI and didn't understand how to solve the problem without it, then if AI became unavailable, they wouldn't have the skills to solve the problem on their own.

Q11: How would you address potential resistance from students or educators to adopting AI-based teaching tools?

I think that most students will not provide resistance to AI because they see it as making their lives easier. However, occasionally a student objects to requirements that are too easy, so they may not like using AI.

Most faculty members feel that using AI provides the answers and so is cheating. Even if the specific application of AI is approved, some faculty members may resist. To overcome resistance, discuss the course outcomes and how using AI improves attainment of those outcomes without sacrificing other outcomes.

III. Emerging themes from Educators' testimonies

III.1. Benefits of PBL in engaging students and building confidence.

In both experiences, PBL approach awakens creativity in students who are ready to search for solutions beyond given references. Students coming from high schools might be tempted to be satisfied if their grade is beyond the needed average. We noticed that the PBL approach reverses this grade-based assessment, and students' satisfaction comes from the adequacy of their solution to the given problem.

AI is expected to increase student engagement and bridge knowledge gaps. At Loyola University of Congo, incorporation of AI tools supplements limited instructor availability, allowing students to access on-demand tutoring. AI-assisted learning modules provide adaptive reinforcement.

Students struggling with complex engineering principles could receive step-by-step AI-generated explanations.

They also enjoy teamwork, and this is good preparation for real life way of working. Fair relationships between people engaged in the same project generally open to better results for the group. Students are divided into groups from this perspective, and we keep in mind the fact that the outcome should be seen as a group effort. AI has the potential to help teams organize tasks more efficiently. Tools such as AI-assisted project management platforms can enable students to track progress and distribute responsibilities, reducing logistical issues.

The idea of working on a real project brings more motivation to the students. Assignments are viewed not as burdens but as calls to enhance their primary thoughts. They feel that their actions have consequences beyond just getting a grade as stated in the above interview. At the University of Detroit Mercy, AI-driven simulations could allow students to test structural models before physical prototyping.

We can also see a reduction in apprehension toward engineering courses. The students see more clearly the importance of what they are learning as they connect it to solve a problem.

The students develop skills and adaptability to research. This aspect will be analyzed in future research. The students' perception of their progress will be considered.

III.2. Challenges of PBL approach

The PBL can add extra expenses for students as they are asked to visit sites or discuss with experts outside the campus.

Lack of appropriate equipment for some measurements or when trying to realize the prototype can create frustration.

In DRC, access to Internet resources is challenging and expensive for some students. The speed is also low in several places. A proposed solution is to integrate offline AI models that can function with intermittent Internet access.

On the professor's side, it asks to develop empathy towards many different solutions that students might bring and for which we do not spontaneously think of. It can be hectic trying to coordinate several different projects at the same time as stated in the interview.

Balancing AI assistance with manual calculations and traditional problem-solving approaches remains a priority.

In Global South, the use of AI is limited. The students cannot yet take advantage of it.

IV. Discussion

IV.1. PBL and AI

If PBL approach shows some strengths in the context of projects as shown in the testimonies, PBL methods still raise however challenges according to several studies. A 2020 paper by Chen et al. summarizes these challenges in PBL practice into three categories: individual, institutional, and cultural. The following paragraphs point out closely some key considerations from this paper on these three levels.

At the individual level, the study points out lack of facilitation training for teachers who face the challenge of transferring their roles from lecturers to facilitators in the PBL environment. They recommend that PBL pedagogical training be provided for engineering staff to learn PBL pedagogy knowledge and facilitation skills. There are also Challenges for choosing effective assessment methods, the need of continuous PBL skills training for students: In the PBL environment, not only teachers but also students need to transfer from traditional learning methods to PBL methods. They also warn about students who lacked learning motivation or self-reflection who can weaken the effectiveness of PBL and the teamwork. (Chen, J., Kolmos, A., & Du, X., 2020)

At the institutional level, the emphasis on developing students' capabilities to solve real-world problems brings new challenges for teachers and students as it demands more time and effort. For teachers, instead of just giving lectures and setting exams in traditional teaching courses, they face a heavier workload in PBL courses by providing professional guidance, practical experiences, and teamwork facilitation during the entire process of finishing projects. For students, working as real engineers and dealing with the messiness of problems required them to devote more efforts to overcoming expected and unexpected issues, and some of them even experienced anxiety or depression in this progress. Additionally, there can be lack of support from departments and institutions; difficulties in how to balance PBL projects with professional courses in curriculum design and limitations of external conditions: lack of infrastructure for teamwork, lack of technical support and limited financial support. (Chen, J., Kolmos, A., & Du, X., 2020)

At the cultural level, there can be cultural barriers, (including language barriers in international contexts) from different backgrounds as students might have different ways of thinking, working habits, and paradigms of their subjects, which shaped their beliefs and world views and led to gaps in their understanding of others' perspectives, especially at the beginning of the teamwork process (Chen, J., Kolmos, A., & Du, X., 2020)

On the other hand, there are also quite a few studies that consider that AI can ease implementation of PBL methods. The key role that teachers play as facilitators (experts) in PBL can significantly change as they can rely on AI tools such as intelligent tutoring system (ITS), chatbot, text mining or speech and image recognition. They propose the on-line PBL education system, which consists of the digital platform, the team database, the AI engine, the course materials, and know-how database. (Takao I et al., 2021, see also US Department of Education, 2023).

For Global South where there are infrastructure challenges, struggles with Internet access or shortage of electricity, the AI perspective can only be possible with the support of large tech companies. IBM, Microsoft, and Google offered such support by setting up research labs in Global South (Chinasa T. Okolo, 2021). A way to the integration of AI in learning and teaching in the Global South will also call Governments to train local researchers and developers, to forge partnerships with external entities and to integrate digital skills training into primary and secondary school curricula (Chinasa T. Okolo, 2021).

Menekse, despite raising some risks that students who rely too much on AI might lose interest and curiosity, also shows some confidence in AI. In the guest Editorial of the JEE (June 2023), he explains how AI-powered virtual laboratories, seen as able to simulate physical experiments and visualize fundamental engineering concepts, could be effective for teaching and learning purposes. Also, Large Language Models (LLMs) are presented as able to provide students with real-time feedback on their work (Menekse M, 2023).

IV.2. Responding to the challenges in the Global South.

Educational institutions in the Global South have deeper challenges in implementing PBL enhanced with AI. Some of the challenges are internet connectivity problems and less access to mentor experts. One of the difficulties in having expert mentors involved in student projects is that they would often have to do so remotely. In that case, the two problems are related because internet connectivity can be a problem while mentoring.

Archiving information locally solves the problems when the internet connection issue is between a southern country and elsewhere. For example, a mentor may be able to record a video of their advice. This could be saved on local computers. A disadvantage of having videos is that it is not interactive. An advantage is that if students and mentors speak different languages, having a video will provide more opportunities for the students to study the presentation.

Virtual collaboration on cloud sites may be less sensitive to internet disruption. Students can download files to work on and then upload them when they are done with a draft. If the internet is not working, then files might automatically update when the internet service returns. Students and mentors or teams of students in other countries may be working in different time zones. Sharing information on a cloud site rather than holding online meetings allows for time for systems to update.

IV.3. Digital labs

In previous sections, we stressed the design aspect in PBL methods, and we know that students can assess the feasibility of their project by simulation with numeric software. A more complete achievement of a PBL is to realize a tangible prototype if possible. This is possible with the development of digital labs. Global South countries can afford them as there are ways to do a lot of things with the essential equipment of every digital lab: 3D-printers, Laptops, Laser cutting, Electronic and Robotic kits, Digital milling machine, welding stations, drills, grinders, screwdriver, press and mechanical tools.

Different decommissioned machines can be recovered for operational analysis through exercises of disassembling and reassembling. This type of practical experiment should offer the opportunity to discuss safety matters with students so that they become aware that any design should consider the safety of the people and the good.

IV.4. Student Motivation and Bridging Foundational Knowledge gaps

How can apprehension of engineering study be overcome and how can more students be motivated? The introduction expressed that more engineers are needed worldwide. Attrition and poor success rates are not unique to any one country.

Many of the methods that are developed to improve student retention in one country are appropriate elsewhere. However, in some cases, curricular methods may not be culturally relevant. For example, a program to retain female engineers might not have any result in a country where there are no female engineering students. Instead, other changes should be considered first.

AI can be used in many ways, so it may be beneficial for student motivation. One reason that students become unmotivated is that they cannot understand a topic. AI has the capability of explaining information. For example, a student can write a prompt that says, "Explain integration of a cubic equation for someone with only a basic understanding of math."

In addition, manual experimentation and prototyping, by raising the feeling of becoming a maker, can amplify the love for technology while at the same time reducing apprehension towards theoretical aspects of engineering.

IV.5. Proposed AI – PBL Integration Framework

To systematically integrate AI into PBL, we propose the following structured framework:

Step 1: Presentation of the Problem or Project

Step 2: Personal or Group Study and Research (with or without use of AI tools)

Step 3: Expert time (with or without use of AI tools)

Step 4: Students' integrative solution to the given Problem or Project

Step 5: Comparison of their solution to potential solutions given by AI tools. For this step to be efficient, students are to be initiated in various aspects of AI such as AI-augmented research and information gathering in step 2, AI-assisted problem identification and definition in steps 2 and 3, AI-supported design and simulation in step 3 and AI for evaluation and feedback in steps 5 and 6. AI for personalized learning and tutoring can be used in step 2 and AI in project management and collaboration will help to enhance teamwork.

Step 6: Oral presentation

V. Conclusion

PBL in its double meaning of problem or project-based learning is an approach that shows some strengths in all teaching contexts. Online materials such as video recording lessons can be presented to students as an expert conference. Learners could review the videos as much as needed without preventing themselves from developing personal thinking.

AI can be a powerful tool that can be added to help learners in their use of multiple resources. It can either appropriately be integrated in the study-research and the expert steps and/or be added as a new comparative step.

Future research could cross the expertise of several professors and make the synthesis available in cheaper smartphones for consultation by students who cannot afford a computer

By developing video-resources that students can consult in the expertise step at their own convenience, they are likely less stressed to be judged if ever they are slow. Engineering education can therefore be accessible to many and countries in Global South, in particular, can reduce their deficit in engineers more rapidly than in the setup where there is only traditional teaching.

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