Engineering project-based learning using a virtual laboratory and mixed reality to enhance engineering and innovation skills

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ABSTRACT: The engineering project-based learning (EPBL) system outlined in this article, combines a virtual laboratory with mixed reality to enhance engineering and innovation skills. The system encourages students to practise and improve their creative thinking and problem-solving skills through engineering projects. Such skills are essential for the 21st Century. The system and its educational outcomes have been evaluated as follows: 1) the overall quality of the system was at the highest level; 2) the average student achievement scores before and after using the system showed a higher achievement score by students after using the system, with a statistical significance of 0.01; 3) the post-test of engineering skills showed that these skills were higher than the 80 percent requirement; and 4) the innovation skills score was at a high level.

INTRODUCTION

Research on education emphasises that learners should gain both theoretical knowledge and practical skills. Therefore, it is necessary to have an efficient and effective learning management system to improve learner capabilities considering individual differences. Skills improvement and creative thinking development goals must emphasise learning from experience and practice, so that the learners are able to think creatively, work productively, and identify and solve problems on their own initiative. In the 20th Century, technology has become critical part in the improvement of learners' academic achievement.

In this environment, learning management is likely to integrate mixed methods, even for theoretical teaching that focuses on experiment and practice using computer simulations is essential to efficiently and quickly teach complex principles or theories. Computer programs are considered a major tool to assists learners in telecommunications engineering and other fields to understand the relevant theories, test concepts, build new knowledge and perform in-depth research with competence.

Technological advances along with improvements in computer programming, enabled on-line simulations based on the Web technology, such as virtual laboratories [1]. A virtual laboratory can be created for on-line teaching, which allows learners to join the laboratory without limitations in time and location. It can decrease the cost of equipment procurement and maintenance, and it allows a larger number of learners to practise. The virtual laboratory seems to be an excellent solution to problems in distance education, as its availability can be effectively extended for distance learners. Hence, it is likely to become a key development trend for practical teaching in distance education [2].

An interesting and popular learning innovation is mixed reality [3], which can be combined with a virtual laboratory [4] to create a virtual laboratory with mixed reality.

The often-mentioned learning method, also in widespread use, is project-based learning [5], which allows learners to freely select what they want to learn, learn how to think, work and solve problems. This method is a teaching standard for learners' development in the 21st Century [6], which focuses on learners and self-learning, thus improving their creativity and innovative skills.

In this technology-driven era, teaching approaches need to change further, which requires an environment conducive to limitless learning. Considering this specific environment and the necessary skills for the 21st Century, the authors of this article became interested in developing an engineering project-based learning system using a virtual laboratory with mixed reality to enhance engineering and innovation skills.

RESEARCH OBJECTIVES AND HYPOTHESIS

The objectives of this research were to:

O1: Develop an engineering project-based learning (EPBL) system using a virtual laboratory with mixed reality to enhance engineering and innovation skills.
O2: Examine the academic achievement scores of students who learned within the EPBL system using a virtual laboratory with mixed reality.
O3: Examine and assess the engineering skills of students after participation in EPBL using a virtual laboratory with mixed reality.
O4: Examine and assess students' innovation skills after participation in EPBL using a virtual laboratory with mixed reality.

In this study, the following research hypotheses have been formulated:

H1: The engineering project-based learning (EPBL) system using a virtual laboratory with mixed reality to enhance engineering and innovation skills will have high quality.
H2: Students participating in EPBL using a virtual laboratory with mixed reality will have higher post-test achievement scores compared to the pre-test scores, with a statistical significance of 0.05.
H3: The assessment of students' engineering skills after participation in EPBL using a virtual laboratory with mixed reality (the post-test assessment) will show that the scores exceed the 80% requirement.
H4: The assessment of students' innovation skills after EPBL using a virtual laboratory with mixed reality (the post-test assessment) will show a high innovation score.

RESEARCH METHODOLOGY

This study has been particularly focused on the results of students after participation in the EPBL system using a virtual laboratory with mixed reality.

The system's evaluation included the following components: objectives; learning management planning; quality assessment - subject content and media; academic achievement assessment form; engineering skills assessment form; innovation skills assessment form; and the learning system assessment form.

Research methodology can be divided into two phases:

Phase 1: Development of the EPBL system using a virtual laboratory with mixed reality. The main objective of this phase was to develop such a system considering the latest trends in engineering education and technological advances applicable within an online-learning environment.

Phase 2: Examination of students' results after participation in the EPBL system using a virtual laboratory with mixed reality. The objectives of this phase were to:

- *Compare the achievement* of students before and after participation in EPBL using a virtual laboratory with mixed reality.
- *Evaluate the engineering skills* of students after participation in EPBL using a virtual laboratory with mixed reality (see Table 1 for scores and interpretation).
- *Evaluate the innovation skills* of students after participation in EPBL using a virtual laboratory with mixed reality (see Table 2 for scores and interpretation).

In data analysis average scores have been used for interpretation.

Table 1: Average score ranges and their interpretation in regard to the engineering skills assessment.

Average score range	Interpretation
49 - 64	Engineering skills are high
33 - 48	Engineering skills are average
17 - 32	Engineering skills are low
1 - 16	No engineering skills

Table 2: Average score ranges and their interpretation in regard to the innovation skills assessment.

Average score range	Result
19.00 - 24.00	Innovation level is high
13.00 - 18.00	Innovation level is average
7.00 - 12.00	Innovation level is low
1.00 - 6.00	No innovation

RESULTS

The sample group for this study, consisted of 30 undergraduate students from the Bachelor of Engineering programme (information and communications), in the Faculty of Engineering and Industrial Technology at Petchaburi Rajabhat University, Thailand, in the 2019 academic year.

The data concerning the development and testing of the EPBL system using a virtual laboratory with mixed reality have been analysed according to the main objectives, hypotheses and phases in the research, and the results are presented below.

The learning system has been developed as a smartphone application, and then the smartphone installed in digital goggles. The learner was asked to install the developed application on their Android smartphones. When the digital goggles were worn, the learner could see the virtual engineering laboratory, the digital media and the explanation of learning activities enabled by the EPBL system.

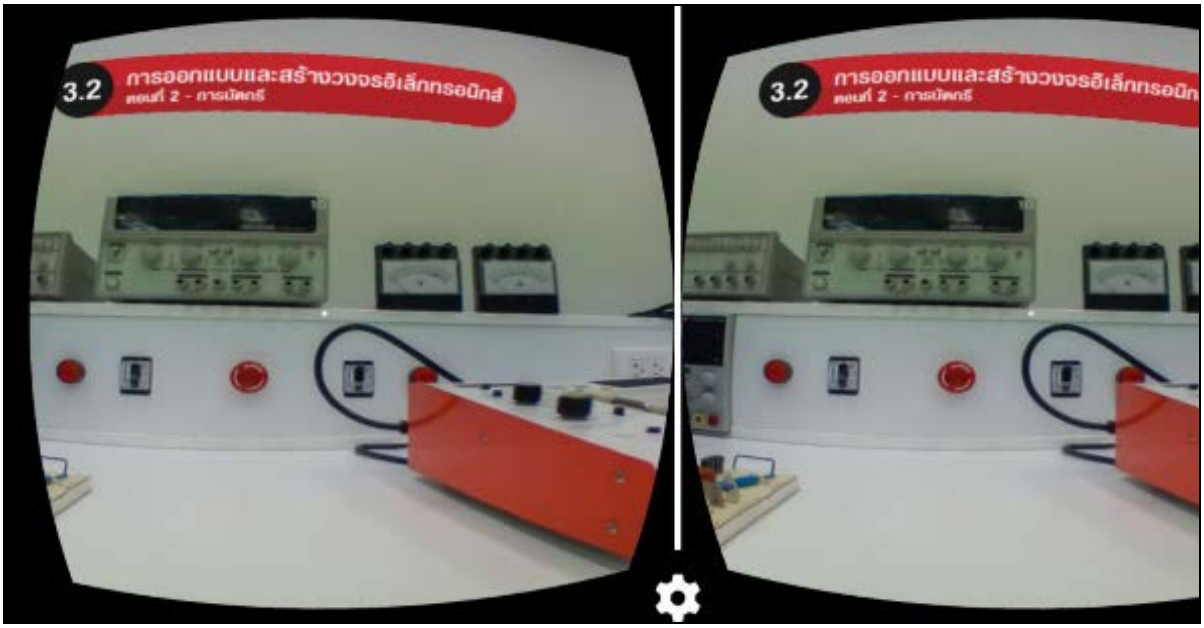

Figure 1: Virtual engineering laboratory.

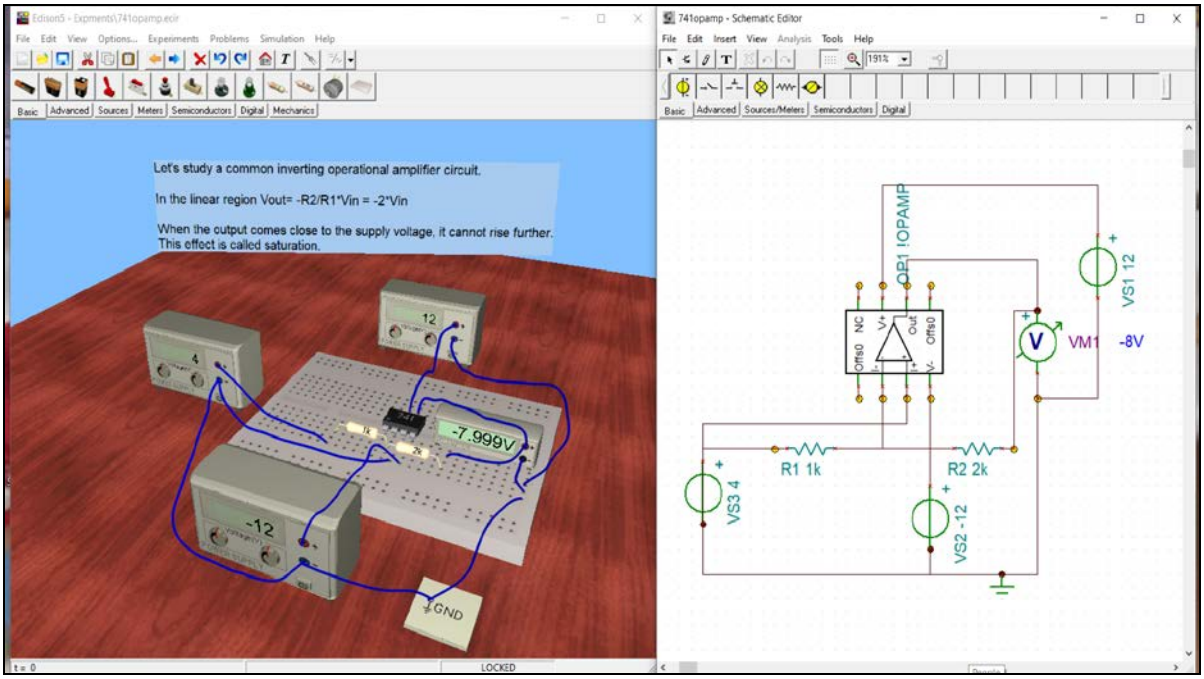

Figure 2: Electronics circuit simulator.

The quality assessment of the EPBL system using a virtual laboratory and mixed reality undertaken by experts has covered two aspects: content and media creation technique. The assessment results are shown in Table 3 and Table 4.

Table 3: Quality assessment of the EPBL system using a virtual laboratory and mixed reality - content.

Assessment items	Assessment results		Quality
	Mean	SD	
1. Content and presentation	4.53	0.50	Highest
2. Language and illustration	4.50	0.51	High
3. Character and colour	4.52	0.51	Highest
4. Content suitability with the teaching and learning activities of the EPBL system	4.58	0.50	Highest
Overall quality	4.53	0.48	Highest

Table 3 shows that in regard to the content, the quality of the EPBL system using a virtual laboratory with mixed reality has been rated at the highest level by the experts (mean = 4.53, SD = 0.48). Therefore, it can be concluded that the developed system has adequate content quality for the enhancement of engineering and innovation skills, and for self-learning.

Table 4: Quality assessment of the EPBL system using a virtual laboratory with mixed reality - media.

Assessment items	Assessment results		Quality
	Mean	SD	
1. Media format and presentation	4.60	0.50	Highest
2. Images for the media	4.60	0.50	Highest
3. Character of the media	4.53	0.52	Highest
4. Videos for the media	4.55	0.51	Highest
5. Design of teaching and learning activities	4.55	0.51	Highest
6. Design of the EPBL system	4.56	0.51	Highest
Overall quality	4.57	0.46	Highest

Table 4 shows that in regard to the media, the quality of the EPBL system with a virtual laboratory and mixed reality has also been rated at the highest level by the experts (mean = 4.57, SD = 0.46). Therefore, similarly to the content quality assessment, the media quality is adequate for the enhancement of engineering and innovation skills, and for self-learning.

A comparison of student achievement scores before and after participation in EPBL with a virtual laboratory with mixed reality has been undertaken and its results are included in Table 5.

Table 5: Compared pre-test and post-test learning achievements.

Test	Number of students	Full score	Mean	SD	*t*-value
Pre-test	30	50	24.30	0.62	24.55*
Post-test	30	50	42.07	0.24	

* Significant at the level of 0.05 (α = 0.05, df = 29)

According to Table 5, which shows the pre-test and post-test learning achievement scores, the learners had higher post-test learning achievement scores (mean = 42.07, SD = 0.24) compared to the pre-test achievement (mean = 24.30, SD = 0.62). This indicates that learners can benefit when using the system, with a statistical significance of 0.05. When tested at the statistical significance level of 0.01, the *p*-value or sig. equalled 0.00, so less than 0.01, which confirms the advantage of using the EPBL system with a virtual laboratory and mixed-reality over the previous learning approach.

The results of the engineering skills assessment after participation in the EPBL system with a virtual laboratory with mixed have been analysed and are included in Table 6.

Table 6: Results of the engineering skills assessment.

Number of students	Full score	Mean	SD	Percentage	*t*-value
30	48	41.08	2.11	85.58	0.48

Table 6 indicates that after participation in the EPBL system with a virtual laboratory with mixed reality, the 30 students surpassed the 80% engineering skills requirement, showing that the system can improve the learners' engineering skills.

As done in regard to the engineering skills, the results of the innovation skills assessment after participation in the EPBL system with a virtual laboratory with mixed reality have been analysed and are included in Table 7.

Table 7: Results of the innovation skills assessment.

Group number	Score (full score = 18)	Percentage
1	14.33	79.61
2	13.33	74.06
3	14.67	81.50
4	12.67	70.39
5	13.00	72.22
6	14.00	77.78
7	14.00	77.78
8	12.33	68.50
9	15.00	83.33
10	13.67	75.94
Average score	13.70	76.11

According to Table 7, the innovation skills results (group assessment) clearly demonstrate that after participating in the EPBL with a virtual laboratory with mixed reality, all 10 groups have an average innovative skills score of 76.11 (mean = 13.70), which is deemed high. This shows that the EPBL system with a virtual laboratory with mixed reality can improve the learners' innovation skills.

DISCUSSION AND CONCLUSIONS

The engineering project-based learning (EPBL) system enhances engineering and innovation skills by incorporating a virtual laboratory with mixed reality, resulting in two deliverables:

1) A virtual laboratory: this is an application installed on a smartphone, which can be paired with digital glasses. A student has to install the application developed by the researchers on an Android-based smartphone. When wearing the digital glasses, the student can see a virtual environment of an electronic engineering laboratory and can view digital media describing learning activities; and

2) Mixed reality media with a mixed electronic circuit simulation system. For the simulation of the circuits, students can use the developed application through digital devices including a tablet, smartphone or any other display devices with the program, which will instruct them on how to use instruments in the laboratory, such as a multimeter, oscilloscope and generator. This is done along with an on-line classroom to allow the learner to submit assignments and do tests without the need to use paper (paperless working). The results of the proposed system were evaluated by content and media production experts at the highest level.

The comparison of pre-test and post-test learning achievement of learners reveals that after participation in the EPBL system, the students had higher learning achievement scores with a statistical significance of 0.05. When tested at the statistical significance level of 0.01, the *p*-value or sig. Equalled 0.00, less than 0.01, which confirms the beneficial effect of the whole system.

This result concurs with the study by Boonkerd about the creation of multimedia-based computer lessons with mixed reality, which likewise found that after the post-test, the learners had higher learning achievement scores with statistical significance [7]. This can be attributed to the lessons' novelty and attractiveness that stimulated the learners into learning more, along with good design and clear explanation. Similar findings have also been reported by other researchers. The study by Shen and Qi discovered that the virtual simulation technology can improve students' learning and facilitate their coordination and communication; it can also improve students' characters and personality, thereby improving their ability to grasp and apply knowledge [8]. Further, Muali et al discovered that the augmented reality mobile application is an effective learning tool in improving students' concept understanding [9].

In this present study, the post-test results of engineering and innovation skills assessment revealed that the average engineering and innovation skills scores were higher than in the pre-test. This concurs with the study by Morales et al, which discovered that the developed system was capable of teaching learners about how to manage unforeseen problems during projects, and it enabled them to acquire the necessary skills for electrical engineering practice [10]. In addition, the present study's results concur with the research of Chatwattana and Phadungthin [11] and Stahre Wästberg et al [12].

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