Achievements, efficiency and performance of mechanical engineering students in project work using the 5E inquiry-based learning process in a pneumatics and hydraulics course

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ABSTRACT: This research focused on learning management in mechanical engineering education, emphasising analytical thinking, design and practical application for problem-solving and new knowledge creation, impacting student quality. The study aimed to assess the project achievements, efficiency and performance of mechanical engineering students in a pneumatics and hydraulics course, in Pathum Thani, Thailand, utilising the 5E inquiry-based learning process. The target group comprised 24 mechanical engineering students. A mixed-method research approach was adopted, employing tools such as focus group recording forms, observation evaluation forms, group interview forms and project report evaluation forms. The achievement results demonstrated that the students achieved satisfactory project outcomes. The efficiency evaluation results, based on the 5E inquiry-based learning process, exceeded 80% overall. Performance evaluation across the four dimensions yielded an average score of 4.00, surpassing the established criteria. The implementation of the 5E inquiry-based learning process, in conjunction with project work in mechanical engineering, effectively developed students' design thinking, practical skills, teamwork and collaboration abilities. These skills are crucial for systematically addressing project challenges and play a significant role in the ongoing enhancement of engineering education quality.

Keywords: 5E inquiry learning, students project work, mechanical engineering, achievement, efficiency

INTRODUCTION

Teaching and learning management in the 21st Century prioritises and fosters the learner's development in innovation skills, information and communication technology (ICT) proficiency, and life and career competencies. This entails a holistic integration of subject-specific knowledge, expertise and awareness in diverse fields to equip individuals for success in both their professional and personal lives. The outcomes of learning are of critical importance [1]. Educational institutions must prioritise learners, shifting their focus beyond mere knowledge acquisition to encompass critical thinking and skill development. The emphasis should move from teacher-centred instruction to learner-centred education. Effective learning environments encourage active student engagement in the thinking process, utilising scientific inquiry skills to seek answers and construct their own knowledge bases. Educators play a crucial role in this process by stimulating curiosity, provoking thought and facilitating knowledge exploration, empowering learners to independently synthesise answers and draw conclusions [2]. Learning management directly impacts the development of learners' academic achievements.

Enhancing student capabilities is achieved through self-directed knowledge construction processes. Effective teaching strategies incorporate inquiry-based learning, where questions are central to the learning journey. Educators should move beyond the sole focus of obtaining correct answers and recognise that the learning process itself (learning skill) is of paramount importance, regardless of the specific answers obtained [3]. Learning through an active process, where learners generate new ideas and concepts from their existing knowledge and experiences is essential. Inquiry-based teaching and learning serves as a powerful tool in this regard, empowering learners to discover various truths independently. This approach fosters a culture of curiosity, exploration and critical thinking, enabling individuals to become autonomous learners and lifelong knowledge seekers.

Project development in pneumatics and hydraulics courses plays a vital role in training students' thinking skills through collaborative work and self-directed tasks aligned with their interests. This encompasses the entire cycle of planning, designing, developing and presenting project outcomes. The emphasis lies on the learning outcomes derived from project work, which are essential for students to achieve by the end of their mechanical engineering programme [4]. Education focused on learning-driven outcomes prioritises the development of teaching activities that directly support learning results and inform the design of effective course assessments [5]. This approach encourages instructors to adopt a blended learning approach, strategically integrating diverse teaching strategies within a comprehensive instructional management system. Pneumatics and hydraulics systems are fundamental components of nearly every industrial sector, playing a crucial role in automated production processes. These systems contribute significantly to increased manufacturing speed and reduced

errors, while also enabling extended operational hours and reduced labour costs [6]. Their widespread adoption across industries, from small-scale workshops to large-scale factories, underscores their importance in facilitating efficient work practices and precision machinery control.

Given the importance of the 5E (engagement, exploration, explanation, elaboration, evaluation) inquiry-based learning approach [7][8] in pneumatics and hydraulics for the development of mechanical engineering student projects, the research objective was to evaluate the effectiveness of these projects. Utilising the 5E inquiry-based learning process in pneumatics and hydraulics courses enables students to understand and perform team-based tasks, and to manage learning through an inquiry-based approach. This process resembles a collaborative search method, using collective thinking within a team and promoting systematic work following scientific methods. This significantly enhances the efficiency of project outcomes for mechanical engineering students.

METHODOLOGY

This study was pre-experimental research employing a one-shot case study design. The target population of the study were 24 mechanical engineering students majoring in mechanical education at Rajamangala University of Technology Thanyaburi, Pathum Thani, Thailand, who were taking the pneumatics and hydraulics course. The conceptual framework of the research is shown in Figure 1:

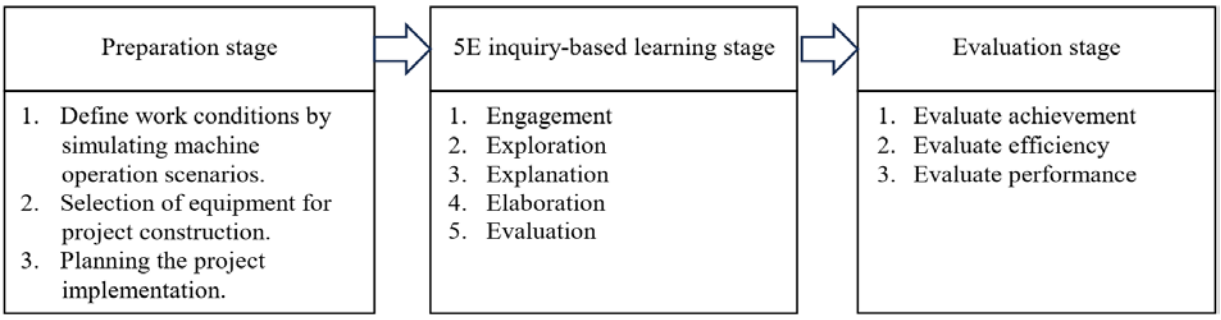


Figure 1: Conceptual framework of the research.

Steps in conducting a student project in mechanical engineering using the 5E inquiry-based learning process in the pneumatics and hydraulics are as follows:

Preparation Stage

1 The instructor divides the students into 5 groups, establishes working conditions by simulating machine operation scenarios, and defines the selection of equipment for project construction, choosing from materials available in the pneumatics laboratory.

2 Plan the project. Students are tasked with thinking, analysing and planning the project design. This requires advanced planning to ensure a rigorous, meticulous and coherent process. Students then present their plans to the instructor for approval before proceeding. The project outline is generally written to demonstrate the concept, plan and procedural steps of the project.

Learning Phase

The 5E inquiry-based learning process includes engagement, exploration, explanation, elaboration and evaluation [7][8], as shown in Table 1. The tools used in the learning process include design worksheets, planning worksheets, project development worksheets, and materials and equipment related to pneumatics.

Table 1: 5E inquiry learning process in the pneumatics and hydraulics course model.

Phase	Pedagogical function
Engagement	The instructor must stimulate students' interest and enthusiasm in the subject matter by setting work conditions through simulating machine operation scenarios. This is done to encourage students to collaboratively think, analyse and design the project according to the specified requirements.
Exploration	The instructor allows students to seek knowledge and ideas through experiential learning, collaboratively planning their project work in alignment with the 5E process. The students must work together to plan the tasks, timeline and budget.
Explanation	The instructor provides opportunities for students to present their project design concepts and project plans. Students are expected to present and explain the characteristics of the project in relation to the industrial sector, engaging in discussions and exchanging opinions between themselves and the instructor in a group dialogue format.
Elaboration	Students in each group collaborate on the project, adhering to the specified work conditions and predetermined plans. The instructor provides close guidance and consultancy on the project to facilitate learning that is applicable to real-life scenarios.

Evaluation	The instructor evaluates the students' projects by assessing the project's outcomes, evaluating the efficiency of the project and assessing the students' performance in implementation. This is done to ensure that students develop practical skills and efficient team-working capabilities.

Evaluation Phase

1 Evaluate achievement: this involves assessing the outputs and outcomes using data collection tools such as group discussion records and observation assessment sheets. The data is collected according to the specified requirements and analysed for the completeness of the project, with a focus on qualitative data analysis based on the students' projects [9].
2 Evaluate efficiency: this is assessed through the 5E inquiry-based learning process [10]. Learning efficacy is verified by reviewing achievements in several aspects, including readiness for project work, application of the learning process, and efficiency evaluated by the duration of project completion and the cost-effective use of available resources to achieve the objectives. Efficiency is assessed using the CIPP (content, input, process, product) model [11], which includes 1) environmental factors; 2) the learning process; 3) project efficiency; and 4) project outcomes. Data collection tools include group student interviews, observational assessments, and project report assessments, with a quantitative data analysis focusing on the students' work and project reports.
3 Evaluate performance: this is assessed based on the project work following the 5E inquiry-based learning process, considering four dimensions aligned with 21st Century skills: design thinking, problem solving, teamwork and collaboration (DPTC). The data collection tool is the project report assessment using a 5-level Likert scale rating [12]. The scale ranges from level 1 (low-level performance) to level 5 (high-level performance), with a quantitative analysis based on the students' work and project reports, aiming for an average score of no less than 3.00 [13].

There are two methods of data analysis: quantitative, involving the calculation of statistical values such as percentage and mean; and qualitative using content analysis.

RESULTS

The outcomes of the mechanical engineering students' project work in pneumatics and hydraulics, using the 5E inquiry-based learning process are presented in Figure 2 and discussed below.

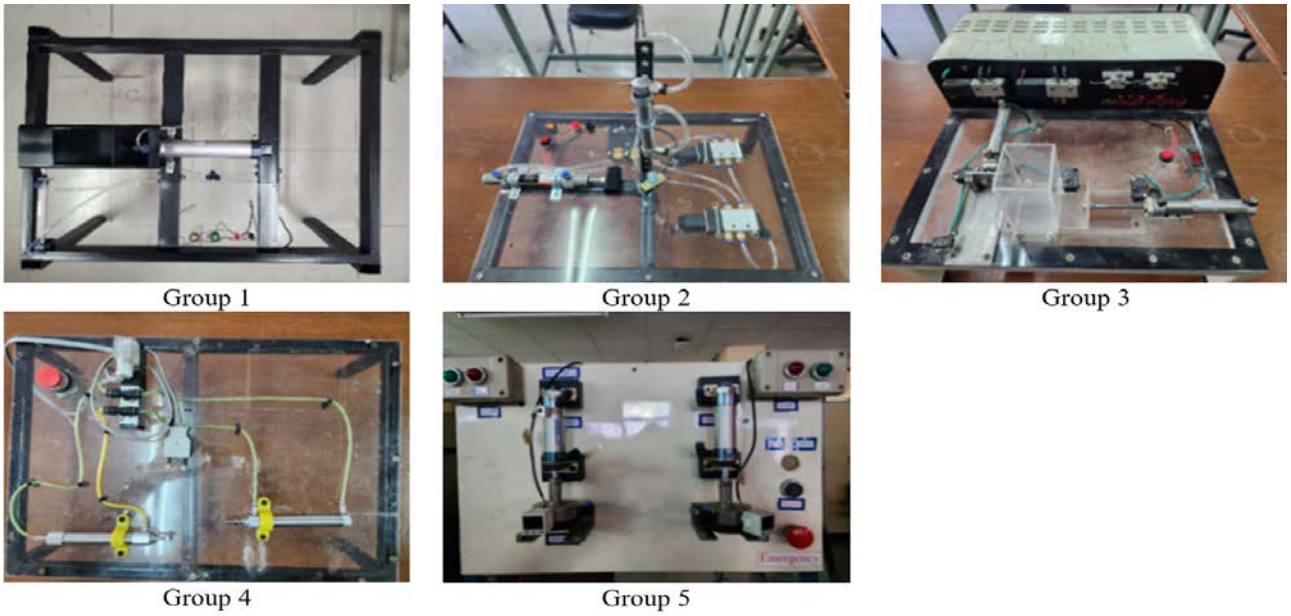


Figure 2: Projects of five mechanical engineering student groups.

Evaluation of achievement results: the evaluation of outputs and outcomes indicates that the project achievements of mechanical engineering students are appropriate. This assessment was made by analysing content from group discussions and observing performance, based on a 5-dimensional assessment: 1) creativity in project design; 2) accuracy according to requirements; 3) appropriateness of project characteristics; 4) practical application; and 5) adequate work quantity for the educational level, as shown in Table 2, below.

Evaluation of efficiency results: the project efficiency was assessed using the CIPP model, which includes: 1) environmental factors; 2) learning process; 3) efficiency in project implementation; and 4) project outcomes. The average overall efficiency assessment for all five groups reached a maximum of 90%, followed by an efficiency assessment of 88%, with the lowest being 78%. In summary, the efficiency of mechanical engineering students' project work using the 5E inquiry-based learning process overall exceeded 80%, as shown in Table 3, below.

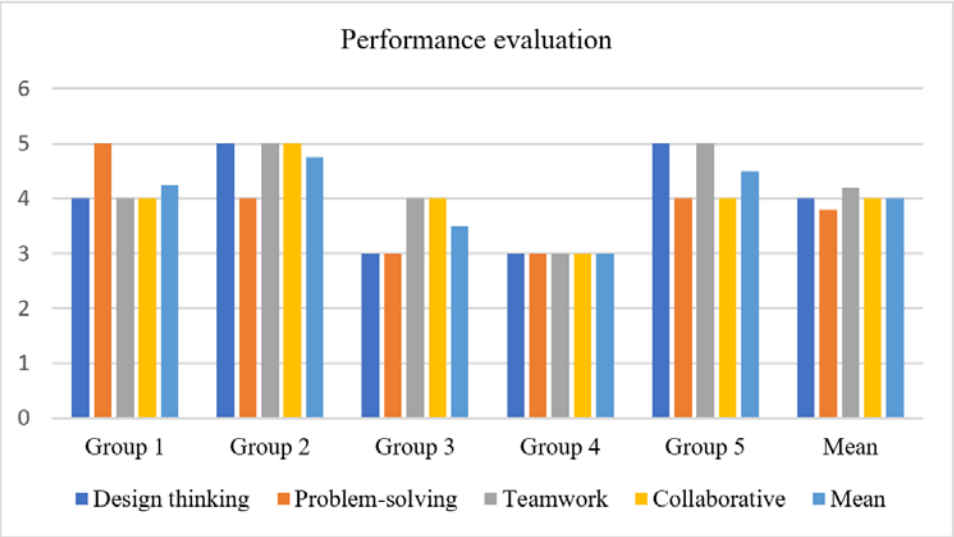
Table 2: Assessment of project achievement by mechanical engineering students in pneumatics and hydraulics using the 5E inquiry-based learning process.

Assessment item	Indicator	Tool	Data analysis	Evaluation results (outputs)	Achieved results (outcomes)
1. Creativity in project design	Considering the alignment with the specified work conditions and requirements.	Design worksheet	Content analysis	Each group demonstrated ideas that were consistent with the specified work conditions and requirements.	Each group had unique design concepts for the project and presented these ideas as per the design worksheet.
2. Accuracy according to requirements	Planning of work following the 5E inquiry-based learning process.	Planning worksheet	Content analysis	Each group planned their work according to the 5E inquiry-based learning process; three groups fully incorporated all 5E elements, while two groups did not present all 5E aspects completely.	Each group planned the 5E inquiry-based learning process as per the planning worksheet.
3. Appropriateness of project characteristics	Explanation of the simulation of machine operation scenarios.	Project development worksheet	Content analysis	Each group designed the project according to the operational characteristics of machinery.	Each group explained the functioning of their project in the context of machine operation scenarios.
4. Practical application	Explanation of the project's functioning in alignment with real-world applications.	Project development worksheet	Content analysis	Each group was able to explain the practical applications of their project.	Each group described how the project's functioning correlates with real-world tasks.
5. Adequate work quantity for educational level	1. Duration; 2. Budget for operation.	Project development worksheet	Content analysis	Two groups submitted their work within the set timeframe, and each student group adhered to the predefined budget criteria.	Each group's project had components that were overall appropriate in terms of work quantity for their educational level.

Table 3: Efficiency evaluation of mechanical engineering students' projects in pneumatics and hydraulics using the 5E inquiry-based learning process.

Assessment item	Maximum score	Score achieved				
		Group 1	Group 2	Group 3	Group 4	Group 5
1. Environmental factors						
1.1. Preparedness for project implementation	10	8	10	8	7	9
1.2. Concept of project design	10	8	9	7	7	9
2. Learning process						
2.1. Understanding of the 5E inquiry-based learning process	10	9	9	7	7	9
2.2. Application of the 5E inquiry-based learning process in project development	10	10	9	8	8	9
2.3. Connecting learning with project implementation	10	8	8	8	8	8
3. Efficiency in project implementation						
3.1. Duration of project development	10	9	10	9	8	10
3.2. Reporting and presenting the project	10	8	9	7	7	8
3.3. Value of the project	10	9	9	9	9	9
4. Project outcomes						
4.1. Application of knowledge in project development	10	9	9	9	9	9
4.2. Utilisation of the project for real-world extension work	10	8	8	8	8	8
Mean	100	86	90	80	78	88

Evaluation of performance results: the evaluation was based on four dimensions: design thinking, problem solving, teamwork and collaboration (DPTC). The overall average score for these four dimensions was 4.00. Breaking it down by each aspect, the scores were as follows: design thinking at 4.00, problem solving at 3.80, teamwork at 4.20 and collaboration at 4.00. The highest average score was in teamwork, and the lowest was in problem solving, as shown in Figure 3.



*Mean ≥ 3.00

Figure 3: Performance evaluation of mechanical engineering students' projects using the 5E inquiry-based learning process.

DISCUSSION

Based on the research question regarding the achievements and efficiency of mechanical engineering students in their project work, the following was observed: the evaluation of the project achievements of mechanical engineering students yielded appropriate results [14]. The process fostered creativity, innovation and healthy competition among groups in the classroom.

The overall efficiency evaluation was higher than 80%, and performance evaluation, assessed across four dimensions - design thinking, problem solving, teamwork and collaboration - averaged 4.00, exceeding the set criteria [15].

The applied learning management facilitated the development of collaborative skills among students, arising from group co-operation in thinking, problem-solving and successful task execution [16]. Active participation, creativity, diversity of thought, reflection, personal relevance and collaboration are the best forms of learning, resulting from students' preparedness for project work [17].

The practical approach helped students learn through project work, adhering to specified work conditions and requirements, and utilising the 5E inquiry-based learning process, leading to increased student engagement in activities, analytical thinking and problem-solving [18]. This built confidence in enthusiastic students, making complex concepts more understandable and applicable, and promoting effective teamwork [19].

The 5E experiments enhanced students' research capabilities, critical thinking and reasoning skills, resulting in efficient project work in all groups. The project outcomes allowed students to present their work and explain the principles of their projects realistically, stemming from co-operative efforts, promoting teamwork in the classroom, including design and problem-solving in project work [20].

The best teaching practices that encourage co-operative learning improved students' work practices and problem-solving abilities, developing skills and competencies through learning and teamwork, leading to the production of quality work applicable in future opportunities.

CONCLUSIONS

The project achievements of mechanical engineering students, utilising the 5E inquiry-based learning process, were satisfactory and produced acceptable outcomes. This process enhanced students' design thinking, supported by learning theories, and developed their academic achievements, higher-level capabilities, practical skills and creativity. Particularly notable was the development of teamwork, while systematic problem-solving skills in project work scored at the lowest level.

The research revealed that the highest assessment scores were in teamwork, suggesting that this area should be strengthened to further enhance students' analytical and quality design thinking. This could significantly improve problem-solving in project work. Therefore, the integration of the 5E inquiry-based learning approach with mechanical engineering projects is crucial for the ongoing development of quality in engineering education.

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BIOGRAPHY

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