Effect of Inquiry-based Learning on Engineering Students as Collaborative Approach in Problem-Solving and Research for Formal Language Automata Course

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***Abstract*—Inquiry-based learning is an approach to teaching and learning that focuses on problem-solving and requires students to identify and use the knowledge they have acquired in their studies. Through an exploration of the literature, the paper examines the effectiveness of collaborative learning environments such as inquiry-based learning, the benefits it can bring to engineering students, and the challenges associated with its implementation in the classroom. The survey questions were created, and online responses (n=171) were gathered. The questions were divided into 4 input attributes such as 'Student – Professor Interaction', 'Student – Team Interaction', 'Learning Tool', and 'Assessment Methodology', and each of these inputs was further divided into sub-attributes. For this research, regression analysis and correlation between the inputs and the Student Learning Experience, the output, were built. Results showed that in the Formal Language and Automata course, Inquiry-Based Learning promoted a positive correlation with ($R2 = 0.47$) on student learning experience for the inputs like "Student - Team Interaction" and ($R2 = 0.63$) for "Assessment" respectively. The students performed better and were motivated by their ability to solve problems and conduct research. Additionally, the paper examines how inquiry-based learning can be used to facilitate peer engagement, creative thinking, and collaboration in engineering courses. A qualitative approach is utilized to describe the implementation of inquiry-based learning tools in an engineering classroom, and the impact it can have on student motivation and achievement. The conclusions of this research provide implications and recommendations for educators and administrators interested in incorporating collaborative learning paradigms into engineering education.**

***Keywords*—Inquiry-based learning, Inquiry Process, Engineering Students, Problem-solving, Research Work, Formal Language and Automata, Collaborative Learning, Correlation Coefficient, Innovative Pedagogy, Quality Education.**

I. INTRODUCTION

In inquiry-based learning, students actively investigate issues and challenges from the real world and gain greater understanding by posing questions, cooperating with others, and solving problems. It is a student-centered approach to education, where the students are actively engaged in their learning and are encouraged to think outside the box and ask questions to deepen their understanding (Orosz et al., 2023). This approach focuses on developing the student's skills such as critical thinking, communication, and collaboration, rather than memorizing pre-existing knowledge. It encourages students to take control of their learning and develop autonomy as learners. Inquiry-based learning promotes inquiry, collaboration, and exploration, and is highly applicable to real-world situations (Loyens et al., 2022).

1.1 Types of Inquiry-Based Learning

Active learning techniques like inquiry-based learning begin by posing questions, problems, or scenarios. It contrasts conventional education, which typically relies on the teacher presenting information and their subject-matter expertise. The following are the various types of Inquiry-Based Learning used in Academics (Song et al., 2022).

1.1.1 Project-Based Learning: Here students come up with their ideas, develop a plan, research it, and present their findings to their peers or teachers (van der Graaf et al., 2023).

1.1.2. Problem-Based Learning: Here students work collaboratively to solve real-world problems.

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1.1.3. Guided Inquiry: In guided inquiry, students are guided spiritually or academically through a series of carefully designed questions or tasks (Chau et al., 2023).

1.1.4. Inquiry-Based Instruction: The instruction focuses on student-led discovery of the material.

1.1.5. Collaborative Inquiry: Collaborative inquiry is a form of inquiry-based learning in which students work together to explore and understand a concept or challenge (Kor et al., 2022).

1.1.6. Design-Based Learning: It is an inquiry-based approach to education that encourages students to design solutions to the real-world challenges they are presented with industry tie-ups (Anand et al., 2023).

1.1.7 Open-ended Inquiry: Open-ended inquiry is a type of inquiry-based learning that is student-centered and allows students to construct their understanding of concepts. Students can develop their thoughts and perspectives while also being encouraged to explore, think critically, and solve problems.

1.1.8. Exploratory Inquiry: Exploratory inquiry is a type of inquiry-based learning that encourages students to explore a certain topic. It includes collecting background information, posing questions, and seeking answers through research (Nzomo et al., 2023).

1.1.9. Discovery Inquiry: Discovery inquiry is a type of inquiry-based learning that encourages students to find answers to questions on their own, through their efforts. It typically involves exploration, experimentation, and analysis (Costes-Onishi & Kwek, 2023).

1.1.10. Discussions and Debates: This type of inquiry-based learning encourages students to engage in conversations and debates to explore a concept or inquiry topic from multiple perspectives.

1.1.11. Inquiry Stations: The purpose of this approach is to provide students with a variety of sources and activities focusing on a single topic, allowing them to explore the concept in a hands-on way.

1.2 Activities Based on Inquiry-Based Learning

Inquiry-based learning maintains students' interest regarding what they are learning through investigation and thought-provoking questions. It's a teaching strategy that encourages learners to engage in problem-solving and experiential learning (Wen et al., 2023).

1.3 Foundational Tenets of Inquiry-Based Learning

To help students develop their capacity for questioning, designing investigations, interpreting evidence, creating explanations and arguments, and communicating findings, inquiry-based learning prioritizes issues that call for critical and creative thinking (Verma et al., 2023).

1.4 Importance of Inquiry-Based Learning

Students who engage in inquiry-based learning become independent, lifelong learners. Using an inquiry-based learning approach, students can ask thoughtful questions, make sense of information, and gain new insights into a subject and their surroundings (Siantuba et al., 2023). Among engineering students, as well as in promoting active learning and the development of critical thinking skills among them. The paper concludes by providing valuable input for the future implementation of technological tools in engineering education.

The assessment of inquiry-based learning should be formative, meaning it helps students improve their learning and informs instructional decisions. It should also align with the learning objectives and outcomes of the inquiry-based activities (Khasawneh et al., 2023). Additionally, providing constructive feedback to students is crucial in supporting their growth and development as independent learners (Donnelly et al., 2023). The Inquiry-based Based Learning assessment methodology is described in Fig. 1.

The Various elements that influence students' performance in the Formal Language and Automata course are looked at in the research framework shown in Fig. 2. The interactions between students and professors, students and team members, learning materials, and Inquiry-Based Learning assessment methods were the characteristics that were taken into consideration to analyze the students' learning experiences.

1.5 Constitutes of inquiry-based learning

When people attempt to turn information and data into useful knowledge, a complicated process is involved. A context for questions, a framework for questions, a focus for questions, and different levels of questions are all necessary components of an effective application of inquiry learning (Caudo et al., 2023; Karimi, 2023).

This paper explores the effectiveness of an inquiry-based learning tool as a collaborative learning methodology in engineering education. The main objective of this research is to understand the impact of an inquiry-based learning tool on engineering students’ learning experience and the development of critical thinking skills. The research is conducted according to the experimental research design using a quasi-experimental model. The primary data was collected from second-year and third-year engineering students who were enrolled in a third-level domain course (at Kalasalingam Academy of Research and Education). The findings of the paper suggest that the use of the inquiry-based learning tool was effective in facilitating collaborative learning.

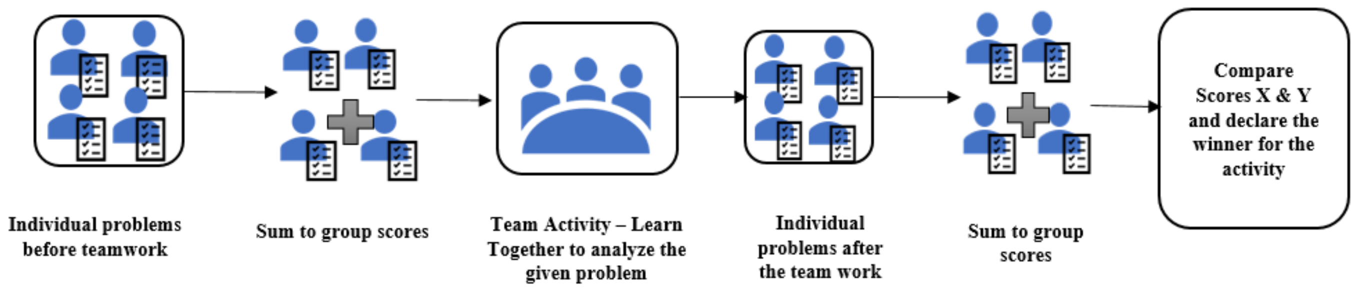

Fig. 1 Inquiry-Based Learning Assessment Methodology

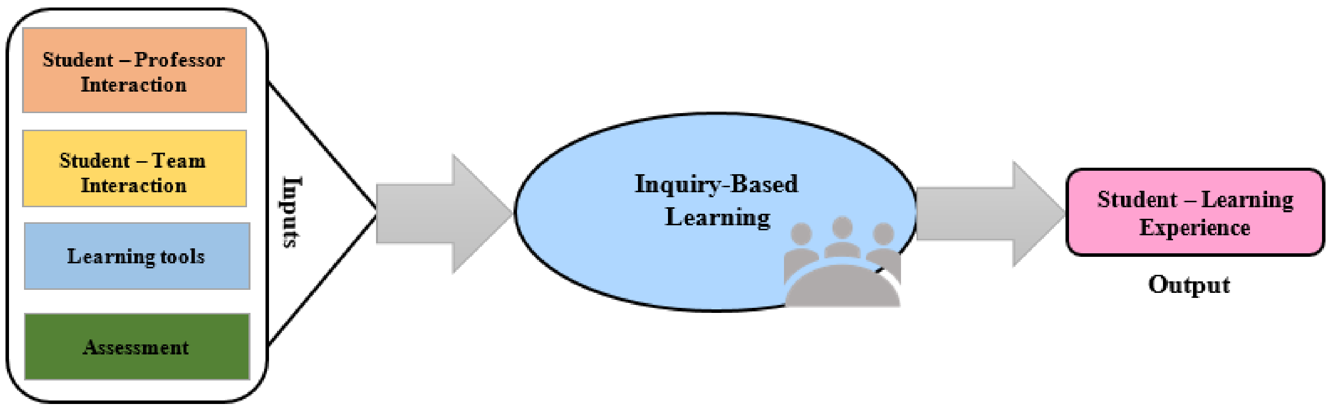

Fig. 2. Research Framework

II. METHODOLOGY

2.1 Recruiters and Participants

All engineering students enrolled in the Formal Language and Automata course at the School of Computing, Department of Computer Science and Engineering, Kalasalingam Academy of Research and Education (Deemed to be University) who were in the third year of a four-year Bachelor of Technology program) were invited to participate in the study's quantitative component. In the Bachelor of Technology program, Formal Language and Automata are regarded as problem and critical-thinking-oriented subjects that students take in their second to third year. Purposive sampling was modified for the qualitative arm to include a variety of students enrolled in the course at various levels of participation. During the focus group participation, 98 students with varying levels of access to our online platform (low access (50 min/week), moderate access (40-50 min/week), and high access (>50 min) - with 15-26 students in each group) participated.

2.2 Design Methods

A total of (n=171) engineering students participated in the Inquiry-based collaborative teamwork activities inside the classroom, with (n=137) male students accounting for 80.12 % and (n=34) female students accounting for 19.8 %. They were randomly assigned to teams of one female and the remaining male students. Additionally, it was ensured that the team had at least one advanced learner. The students took individual quizzes before and after the group activity, and the results were compared to gauge how well they performed in problem design and exploration. Through guided inquiry, students identified states, transitions, and acceptance conditions. They collaborated to explore and refine their designs iteratively. This approach allowed students to construct knowledge actively, thereby deepening their understanding of abstract concepts like deterministic and nondeterministic finite automata. Student-Professor Interaction (SPI), Student-Team Interaction (STI), Learning Tools (LT), and Assessment (AT) were the attributes used for the survey. Each of these attributes was further subdivided into sub-attributes, which were then represented in the questionnaires via surveys. Google Forms was used to deliver the surveys online. The survey links were distributed to student groups. The students were expected to respond with a total of 171 responses. Each question was presented to the students on a 5-point Likert scale, with 5 representing Strongly Agree, 4 representing Agree, 3 representing Neutral, 2 representing Slightly Disagree, and 1 representing Strongly Disagree. There was a total of 17 sub-attributes in the survey (Nagaraj & Raja, 2024). Table I lists the sub-attributes that students were asked about in the survey.

TABLE I
ATTRIBUTE AND SUB-ATTRIBUTE DETAILS OF THE SURVEY.

I / O	Attribute No.	Attributes	No.	Sub Attributes (Likert Scale 5) 5 = Strongly Agree, 4 = Agree, 3 = Neutral, 2 = Slightly disagree, 1 = Strongly Disagree
Inputs	SPI	Student – Professor Interaction	SPI-1	The professor guided me to develop teamwork skills that enabled me to work in a team effectively.
			SPI-2	The professor allowed individual team members to express his / her opinions.
			SPI-3	The professor guided team members to form collaborative groups.
	STI	Student – Team Interaction	STI-1	There was effective team management and organization within the team
			STI-2	The interaction among the team members favored the development of teamwork skills.
			STI-3	I can learn new abilities and information from my group members.
			STI-4	I can develop problem-solving skills through peer collaboration.
			STI-5	I actively exchange ideas with my group members regarding my research articles.
	LT	Learning tools	LT-1	The learning materials provided by the professor helped me apply the skills during the team activity.
			LT-2	The hands-on laboratory session allotted for this course helped me to apply problem-solving skills during the team activity.
			LT-3	The professor provided relevant links and resources to the books for learning this concept.
	AT	Assessment	AT-1	The quiz questions correctly assessed my problem-solving knowledge learned during the collaborative activity.
			AT-2	I can apply the knowledge gained through the group activity in answering the quiz questions.
Output	SLE	Student – Learning Experience	SLE-1	Collaborative learning is fun
			SLE-2	I enjoyed working out the problem with my team members.
			SLE-3	I am satisfied with this style of group collaboration learning for analytic problem-solving.
			SLE-4	Writing research articles helped me to develop good relationships with my professors and peers.
			SLE-5	Student performance in the final evaluation

The mean and standard deviation of the various input responses collected for the individual factors are shown in Table II. The first sub-attribute (SPI-1) of the student – Professor Interaction received the highest rating with a mean of 4.60, indicating that students were satisfied with the professor's involvement in team building during inquiry-based learning.

TABLE II
STATISTICS FOR INPUT ATTRIBUTES USED IN THE SURVEY.

Attribute No. (inputs)	Sub No.	No. of responses	Mean	SD
SPI	SPI-1	171	4.605	0.589
	SPI-2	171	4.559	0.559
	SPI-3	171	4.57	0.587
STI	STI-1	171	4.441	0.681
	STI-2	171	4.373	0.678
	STI-3	171	4.479	0.588
	STI-4	171	4.396	0.652
	STI-5	171	4.389	0.67
LT	LT-1	171	4.485	0.662
	LT-2	171	4.382	0.705
	LT-3	171	4.52	0.613
AT	AT-1	171	4.487	0.577
	AT-2	171	4.411	0.706

Likewise, the mean and standard deviation of the output response of the student experiences were statistically examined. Table III displays the statistics for the sub-attributes used to assess students' learning experiences. Students showed high satisfaction in accepting this type of group collaboration for problem–solving (SLE-2) as indicated by the mean value of 4.48.

TABLE III
STATISTICS FOR OUTPUT ATTRIBUTES USED IN THE SURVEY.

Attribute No. (Output)	Sub No.	No. of responses	Mean	SD
SLE	SLE-1	171	4.411	0.706
	SLE-2	171	4.483	0.616
	SLE-3	171	4.45	0.636
	SLE-4	171	4.459	0.627
	SLE-5	171	4.821	0.612

Table IV shows the Cronbach coefficient, which was calculated to test the survey's reliability. The correlation and consistency between survey results were found to be adequate, as all values were greater than 0.9.

TABLE IV
RELIABILITY TEST OF THE RESPONSES

Attributes	α value
SPI	0.96
STI	0.95
LT	0.97
AT	0.96
SLE	0.95

III. RESULTS AND DISCUSSION

Overall analysis was done between the output attribute, the Student Learning Experience, and their correlation with the input attributes such as Student Professor Interaction, Student – Team Interaction, Learning Tools provided, and the Assessment methods. The data points in the X-axis and Y-axis of the graphs shown from Fig. 3 to Fig. 6, represent the Sub Attributes (Likert Scale 5) and the plot values in all the graphs represent only the highly correlated values between one instance (input attribute such as SPI, STI, LT, AT) and another instant (output attribute SLE). Fig. 3 shows the correlation between the SPI and the SLE using a scatter plot. The best fit shows (R2 = 0.47) where the correlation coefficient equation is given as in equation (1).

$$SLE = 0.7955SPI + 0.9751 \qquad (1)$$

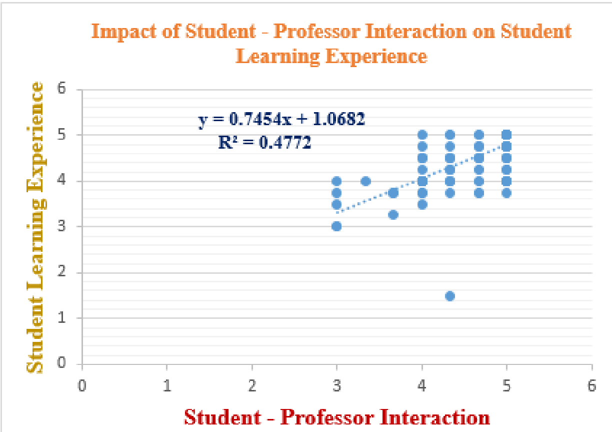

Fig 3. The correlation coefficient between Student Professor Interaction and Student Learning Experience

Fig. 4 shows the correlation between the STI and the SLE using a scatter plot. The best fit shows (R2 = 0.63) where the correlation coefficient equation is given as in equation (2).

$$SLE = 0.8531STI + 0.7211 \qquad (2)$$

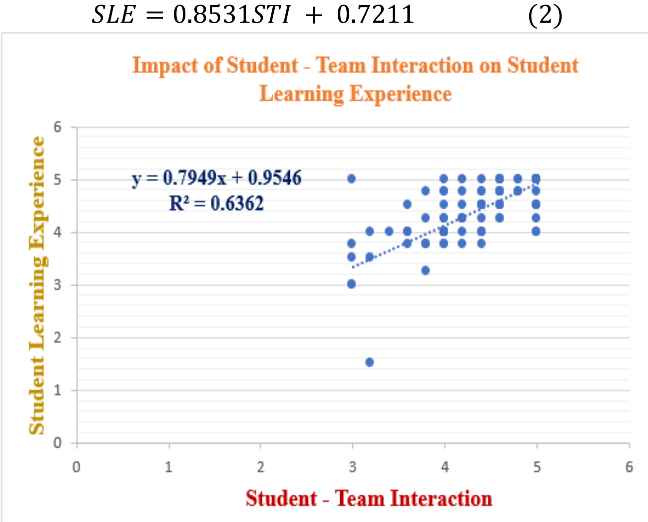

Fig 4. The correlation coefficient between Student Team Interaction and Student Learning Experience

Fig. 5 shows the correlation between the LT and the SLE using a scatter plot. The best fit shows (R2 = 0.58) where the correlation coefficient equation is given as in equation (3).

$$SLE = 0.7939LT + 0.9556 \qquad (3)$$

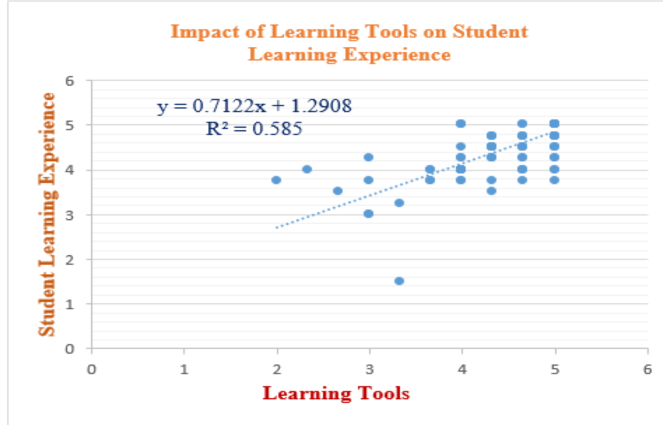

Fig 5. The correlation coefficient between Learning Tools and Student Learning Experience

Fig. 6 shows the correlation between the AT and the SLE using a scatter plot. The best fit shows (R2 = 0.69) where the correlation coefficient equation is given as in equation (4).

$$SLE = 0.917AT + 0.3878 \qquad (4)$$

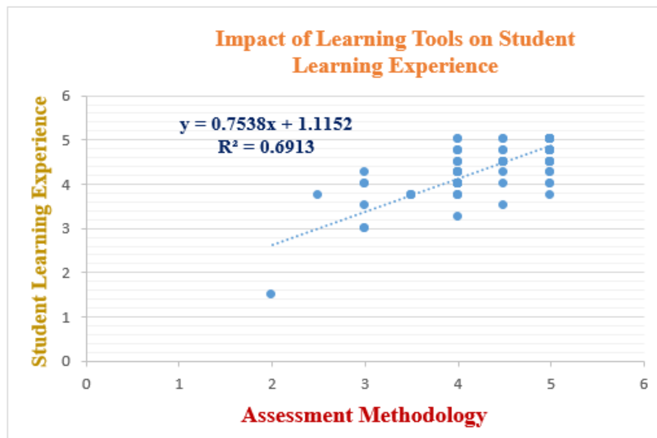

Fig 6. The correlation coefficient between Assessment methodology and Student Learning Experience

The coefficient correlation between each attribute and its effect on students' learning experiences was validated using the R2 values. The input attributes for Student-Team Interaction and Assessment Methodology in the aforementioned regression models demonstrate positive correlations. Due to the high levels of satisfaction with these two survey responses, it is believed that they have a positive impact on students' learning experiences.

TABLE V
STATISTICS OF STUDENT–TEAM INTERACTION ATTRIBUTE

Attributes No.(inputs)	STI_1	STI_2	STI_3	STI_4	STI_5
Valid	171	171	171	171	171
Missing	0	0	0	0	0
Mean	4.50	4.43	4.52	4.45	4.45
Std. Dev	0.68	0.67	0.58	0.65	0.670
Variance	0.46	0.45	0.34	0.425	0.45

A stepwise regression analysis of the STI is carried out to ascertain the connection between the STI sub-attributes and the

SLE. Here, analysis of variance is used to further examine the relationship between STI and SLE. The results are shown in Table V using the SPSS software. The table demonstrates that students' efficient time management and organizational skills (STI_3, mean=4.52) are the elements that have the biggest influence on satisfaction, enabling them to participate in the discussion and produce successful outcomes in the group activity. Equation (5) produced by stepwise regression displays the overall Student Learning Experience equation as a representation of the sub-attributes of Student-Team Interaction.

$$Overall\ student\ learning\ experience = 0.63 + 0.53STI\_1 + 0.53STI\_2 + 0.68STI\_3 + 0.62STI\_4 + 0.53STI\_5 \quad (5)$$

Similarly, assessments are crucial to students' learning experiences and were taken into account in the analysis. A quiz was given in the classroom before the group activity, and each student's grade was recorded. A second quiz-based assessment was given after the group activity, and the outcomes were compared. In comparison to the previous quiz-based evaluation, the grades were higher. The students understood the value of group discussions as a result, and the activities were successfully applied during the Inquiry-Based Learning. Here, the impact of assessment on SLE is further examined using analysis of variance, and the outcomes are displayed using the SPSS tool in Table VI. The table shows that students were highly satisfied and provided responses with a high mean value (AT, mean = 4.51).

Equation (6), which was created using stepwise regression, represents the overall Student Learning Experience equation as a representation of the sub-attributes of assessment.

$$Overall\ student\ learning\ experience = 1.11 + 1.012AT_1 + 0.837AT_2 \quad (6)$$

This demonstrates that both their competency level before and following the group activity, as well as the problem-solving skills they acquired during the collaborative activity, were accurately assessed by the quiz questions. They were able to use the assessment to apply what they had learned from the group activity to the quiz questions.

TABLE VI
STATISTICS OF ASSESSMENT METHODOLOGY ATTRIBUTE

Attributes No. (Inputs)	AT_1	AT_2
Valid	171	171
Missing	0	0
Mean	4.52	4.48
Std. Deviation	0.57	0.70
Variance	0.33	0.49

CONCLUSION

This study discovers the potential benefits of integrating inquiry-based learning methodologies into engineering education. The findings suggest that utilizing inquiry-based learning tools can have a positive impact on engineering students' learning experiences and outcomes. By engaging students in active exploration, problem-solving, and collaborative activities, inquiry-based learning promotes deeper understanding, critical thinking, and knowledge retention. Through the implementation of these learning tools, engineering students may develop a heightened sense of ownership over their education, as students take on a more proactive role in constructing their knowledge and skills. The collaborative nature of inquiry-based learning encourages students to work together, fostering teamwork and communication skills that are essential in real-world engineering settings. Furthermore, the paper highlights the importance of adaptability and continuous improvement in education. As the landscape of engineering and technology evolves, educators must continually assess and refine their teaching methods to ensure that students are adequately prepared for the challenges of their future careers.

ACKNOWLEDGMENTS

The administration of the Kalasalingam Academy of Research and Education, Krishnankoil, is acknowledged by the authors for providing all of the supplies needed and computing resources for the study. The researchers thanked the students who participated in the study with enthusiasm and provided feedback on the survey questions.

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