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Improving Learning Outcomes (LO) in Engineering Design with ADAMFATIH: A Gui-Based Simulation Tool

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ABSTRACT

This study introduces ADAMFATIH, a graphical user interface (GUI) developed to support learning in pipeline integrity and fatigue design within the MEC531 Design 1 course. Grounded in industry standards like ASME B31G and DNV-RP-F101, the tool allows students to simulate calculations, visualise outcomes, and grasp multi-step design concepts through an interactive, cause-and-effect feedback loop. Methodologically, the study employed a within-subject quasi-experimental design involving 23 third-year engineering students. The intervention utilised a mixed-methods approach, assessing effectiveness through pre- and post-tests, perception surveys, and semi-structured interviews analysed via thematic analysis. Results demonstrated significant improvements in student performance following the intervention ($t(22) = 3.42$, $p < 0.01$; Wilcoxon $Z = -3.15$, $p < 0.01$; $d = 0.71$). These findings confirm that the ADAMFATIH GUI had a statistically significant and meaningful impact on learning outcomes. Qualitatively, perception surveys confirmed high usability and pedagogical value (α=0.83). Furthermore, thematic analysis of student interviews revealed that the tool effectively provided instant error visualisation, reduced design anxiety by lowering cognitive load, and fostered a preference for active peer instruction over traditional lecture formats. These findings suggest the potential for integrating GUI-based simulation tools in technical engineering modules to enhance learning outcomes in specific, technically intensive domains.

1. INTRODUCTION

Engineering education has undergone a major transformation in recent decades, driven by the growing integration of educational technologies designed to bridge the gap between theoretical knowledge and practical application. In disciplines such as mechanical and materials engineering, where conceptual understanding must be paired with precise computational execution, interactive tools have been increasingly adopted to improve learning outcomes. One such pedagogical innovation is the use of Graphical User Interfaces (GUIs), which allow learners to manipulate inputs, visualise real-time outcomes,

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and internalise complex technical relationships in an intuitive and student-centred environment (Almeida et al., 2014; Gopabala Krishnan et al., 2023).

In the context of pipeline engineering and fatigue design, students are required to master industrial standards such as the ASME B31G and DNV-RP-F101 codes (Alang et al., 2013). These frameworks govern the calculation of burst pressure and fatigue life in corroded pipelines, where precision and procedural compliance are critical (Ismail & Mahmud, 2023). However, students often encounter significant difficulties in performing these calculations manually (Kim & Hannafin, 2008). The learning process is prone to human error due to the intricate formulas, variable inputs, and reliance on trial-and-error methods—especially when estimating parameters such as corrosion depth (t_{corr}). Missteps in these calculations not only compromise accuracy but also erode confidence and slow down the instructional process (Fahed et al., 2020). Moreover, the challenge is pedagogical as well as technical. Traditional teaching methods in design-heavy courses like MEC531 ("Design 1") frequently emphasise procedural repetition over conceptual engagement. As a result, students may become disengaged, particularly when their results do not align with expected values (Nasir et al., 2022; Pope et al., 2016). Contemporary literature in engineering pedagogy emphasises the importance of interactive, learner-centred environments that promote not only accuracy but also motivation and conceptual clarity (Sweller et al., 2019). GUIs can offer a solution by transforming abstract engineering principles into dynamic simulations, aligning with cognitive load theory and experiential learning frameworks that support deeper knowledge construction (Ma et al., 2024; Nurullaeli & Astuti, 2019; Smith et al., 2022).

While general-purpose tools like MATLAB-GUI and immersive VR platforms have proven effective in enhancing engagement (Coker et al., 2022; Kayisli et al., 2024; Obregon Quinones et al., 2017; Torres-Freyermuth et al., 2022), ADAMFATIH provides a specialised, subject-specific application grounded in real-world pipeline integrity codes (ASME B31G and DNV-RP-F101). Unlike many existing tools that focus primarily on visualisation, ADAMFATIH acts as a cognitive scaffold for high-stakes industrial calculations, specifically targeting the reduction of design-related anxiety and cognitive load in third-year engineering students. While the adoption of GUIs in engineering education has been reported in previous studies (Banerjee et al., 2023), there remains limited empirical evidence evaluating their specific impact on student outcomes in pipeline design courses. Moreover, few studies offer paired pre/post-test data or measure both usability and academic performance simultaneously in a live classroom setting (Krishnanand et al., 2021; Peter et al., 2025).

Despite the documented benefits of GUIs in general engineering education, a significant gap remains in the literature concerning specialised tools for pipeline integrity and fatigue design. Most existing studies focus on generalised software like MATLAB or broad subjects like circuit analysis. There is a lack of empirical research that evaluates the combined impact of subject-specific GUI automation—grounded in industrial standards like ASME B31G—on both academic performance and the reduction of cognitive load in design-intensive mechanical engineering courses. This study addresses this gap by providing paired pre- and post-test data alongside qualitative insights into student anxiety and conceptual mastery.

In response to these challenges, we developed the Assessment & Diagnostics for Aging Materials Fatigue Assessment Tool for Integrity and Health (ADAMFATIH) — a Python-based GUI designed to automate and visualise key calculations in pipeline integrity assessment. Unlike static digital learning content, ADAMFATIH enables students to directly interact with variables related to corrosion, pressure, and material strength, thereby facilitating active learning. It functions as a supplement to formal engineering education, enabling real-time feedback and reducing cognitive overload associated with manual computation.

This study contributes to the field by evaluating ADAMFATIH as both a pedagogical tool and a learning outcome enhancer. Specifically, this pilot study was conducted to assess: (1) the usability and student perception of the ADAMFATIH GUI; and (2) its impact on student performance through pre- and post-intervention test scores. Although the sample size was limited to 23 third-year engineering students, the within-subjects design and statistically significant results provide meaningful insights into how digital simulations can improve teaching effectiveness in technical design education. In addition to primary data collection, this study also undertakes a comparative analysis with findings from existing GUI-based instructional tools reported in the literature. This benchmarking component allows for contextualisation of ADAMFATIH's effectiveness relative to comparable educational technologies, thereby offering a more comprehensive understanding of its pedagogical value. The findings not only validate ADAMFATIH's potential but also lay the groundwork for future scalability and cross-disciplinary applications of GUI-based tools in engineering education.

2. LITERATURE REVIEW

The integration of interactive technologies in engineering education addresses the critical need to bridge the gap between abstract theoretical knowledge and practical, precise computational execution. In the domain of mechanical and materials engineering, Graphical User Interfaces (GUIs) have emerged as essential pedagogical innovations that foster intuitive, student-centred learning environments.

2.1 Theoretical Frameworks: Cognitive Load and Constructivism

The pedagogical effectiveness of ADAMFATIH is grounded in several well-established learning theories. According to Cognitive Load Theory (CLT), traditional manual calculations in pipeline integrity can overwhelm a student's working memory due to their multi-step, error-prone nature (Obichere et al., 2023). By automating these complex procedures, GUI tools reduce extraneous cognitive load, allowing learners to focus their mental resources on "germane load"—the underlying conceptual principles of design and modelling (Chen et al., 2021; Habibi et al., 2025; Jiang & Pang, 2023).

Furthermore, the tool aligns with Constructivist Learning Theory by enabling students to actively construct knowledge through exploration and the manipulation of input parameters. This is enhanced by Multimedia Learning Theory, which suggests that integrating text, visual input fields, and graphical outputs facilitates dual-channel processing for deeper information retention (Knöpfel et al., 2024).

2.2 GUI-Based Tools in Engineering Education

Existing literature highlights the success of various GUI applications in technical disciplines. For instance, MATLAB-GUI applications have been shown to significantly improve student motivation and performance in circuit analysis. Similarly, the use of visual simulation tools in mechanics and strength of materials has resulted in test scores 15–25% higher than those achieved through traditional textbook instruction (Boom-Cárcamo et al., 2024).

While general-purpose tools and immersive VR platforms have proven effective in enhancing engagement, many focus primarily on visualisation (Abdullah et al., 2019; Tahmina et al., 2025). A significant gap remains regarding specialised tools for pipeline integrity that are grounded in real-world industrial standards. ADAMFATIH addresses this by specifically automating calculations governed by the ASME B31G and DNV-RP-F101 codes, serving as a cognitive scaffold for high-stakes industrial applications.

2.3 Interactivity and Student Engagement

Contemporary research emphasises that interactive, learner-centred environments promote both accuracy and conceptual clarity. Studies on virtual and GUI-based platforms consistently report high levels of student satisfaction due to features like live user control and layered visuals, which allow learners to grasp relationships between variables more effectively than static lectures (Alias et al., 2020; Chan et al., 2023). The inclusion of instant visual feedback—such as integrity indicators that change color when design constraints are violated—acts as a powerful diagnostic tool that reduces design-related anxiety (Abd Latiff et al., 2025; Bunian Mokhtar et al., 2023).

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3. MATERIAL AND METHODS

This study employed a within-subject, quasi-experimental design to evaluate the effectiveness of the ADAMFATIH graphical user interface (GUI) as a pedagogical tool for enhancing learning outcomes in the MEC531 Design 1 course, a subject focused on pipeline integrity analysis and fatigue life assessment. The research design was selected to allow for direct comparison of individual student performance before and after exposure to the GUI, thereby reducing inter-participant variability and increasing statistical power - a common and validated approach in small-sample educational technology studies.

3.1 Participants

A total of 23 third-year undergraduate engineering students enrolled in the CEEM 222 (Bachelor of Engineering (Hons) Mechanical) program at Universiti Teknologi MARA (UiTM) participated in this pilot study. All participants were currently undertaking the MEC531 Design 1 course during the semester of implementation and were recruited through classroom participation.

At this stage of their academic career, these students possessed a foundational knowledge level in mechanical and materials engineering, having completed the necessary prerequisites to engage with complex industrial standards such as ASME B31G and DNV-RP-F101. While specific demographic breakdowns for age and gender were not the primary variables of interest for this pilot, the cohort was confirmed to be representative of the third-year engineering population at the institution, sharing a similar academic background in technical design and computational execution.

Informed consent was obtained, and participation in the study did not affect course grades. The demographic profile of the students was collected as part of the survey and included age, gender, and prior experience with simulation tools. While the study did not utilise a separate control group, a within-subject quasi-experimental design was employed where each participant served as their own control. This approach was selected to maximise statistical power and minimise the impact of inter-participant variability within the small cohort (N = 23).

3.2 Research Procedure

The study followed a sequential within-subject quasi-experimental procedure conducted over two primary instructional sessions. The process is detailed below:

Step 1:
Pre-Test Assessment – During the first session, students completed a standardised pre-test consisting of engineering problems related to burst pressure and fatigue life. This established a baseline for their existing understanding of pipeline integrity.

Step 2:
Tool Introduction – Following the pre-test, a domain expert introduced the ADAMFATIH GUI, detailing its features and its alignment with industrial codes such as ASME B31G and DNV-RP-F101.

Step 3:
Interactive Simulation – Students were given guided time to access the web-based platform (*https://adamfatih.streamlit.app*). They performed multiple simulations by manipulating input parameters and observing real-time feedback.

Step 4:
Post-Test Assessment – Immediately following the simulation, a post-test with similar problem types was administered to measure performance gains.

Step 5:
Perception Survey – After the post-test, students completed a 5-point Likert scale questionnaire to evaluate the tool's usability, clarity, and perceived effectiveness.Step 6: Qualitative Interviews – To capture deeper insights, a purposive sub-sample of five students (N = 5) participated in semi-structured

interviews. These sessions explored the cognitive experience of using the GUI and its impact on their design anxiety.

3.2.1 ADAMFATIH Tool Architecture, Logic and Interface Design

The ADAMFATIH tool is structured to function as a cognitive scaffold, automating the multi-step procedures required by industrial codes. The architecture and computational logic are defined as follows:

System Architecture:
The tool is developed using Python and deployed as a web-based application via the Streamlit framework.

Core Modules:

- Input Module: Captures user-defined pipeline parameters.
- Computational Engine: Executes calculations based on ASME B31G and DNV-RP-F101 standards.
- Visualisation Module: Provides real-time feedback, including an integrity indicator that changes colour (e.g., turning red when design rules are violated).

Input Parameters:
Students manipulate variables critical to pipeline safety, including:

- Pipe Geometry: Wall thickness and diameter.
- Material Properties: Material strength and grade.
- Corrosion Data: Corrosion depth (t_{corr}) and length.
- Operational Conditions: Internal pressure.

Computational Process & Outputs:

- Burst Pressure Calculation: The engine estimates the pressure at which a corroded pipe will fail.
- Fatigue Life Assessment: Predicts the remaining operational life under cyclic loading.
- Visual Output: Renders calculated numerical results alongside dynamic visual indicators to facilitate immediate error detection.

The ADAMFATIH GUI was designed to transform abstract engineering principles into dynamic simulations. Figure 1 illustrates the user interface, which integrates text, visual input fields, and graphical outputs to facilitate dual-channel processing.

- **Input Panel:**
  Located on the sidebar, allowing students to manipulate variables such as pipe geometry, material grade, and corrosion depth (t_{corr}).
- **Computational Display:**
  The central dashboard displays real-time results for burst pressure and fatigue life based on ASME B31G and DNV-RP-F101 codes.
- **Visual Feedback Mechanism:**
  Features an integrity indicator that provides instant error visualisation (e.g., turning red when design constraints are violated), which acts as a powerful diagnostic tool for students.

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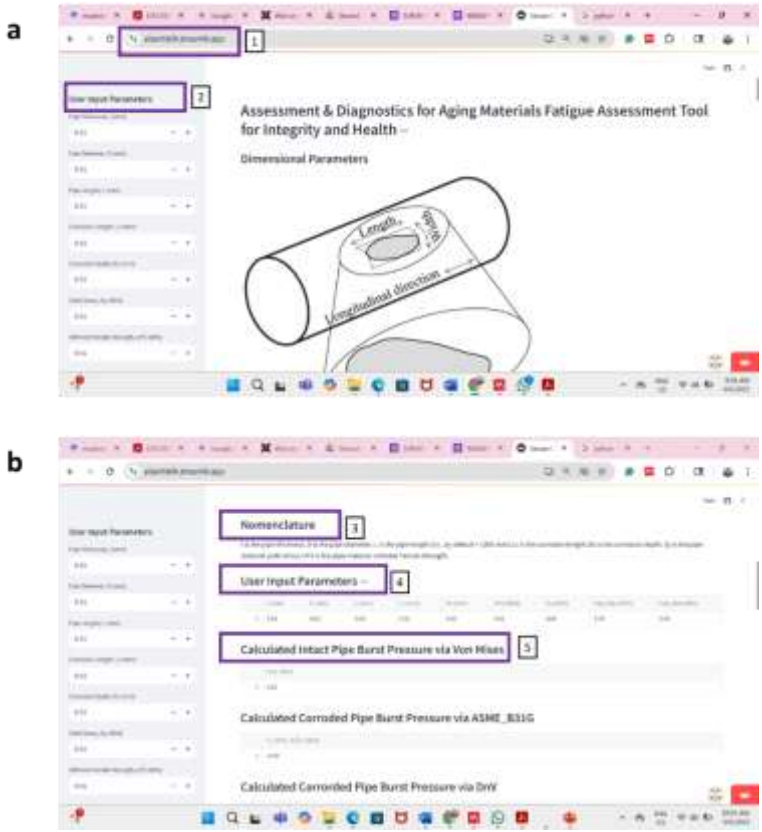

Fig 1. The ADAMFATIH GUI environment. (a) The user interface featuring a sidebar for parameter manipulation and a 3D conceptual diagram of corrosion defects; (b) The computational dashboard displaying calculated burst pressures based on theoretical and industrial codes.

3.3 Instruments

The study utilised a combination of quantitative and qualitative instruments:

a. Pre- and Post-Test Instrument

The knowledge assessment consisted of structured calculation problems designed to measure student understanding of pipeline fatigue and pressure concepts. The same scoring rubric was applied across both tests to ensure consistency. Content validity was confirmed by two subject matter experts, and items were based on actual course objectives aligned with the MEC531 syllabus.

b. Perception Survey

A post-intervention questionnaire was designed to capture students' perceived ease of use, satisfaction, and relevance of the ADAMFATIH tool. The survey used a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree), adapted from validated usability studies. Five core dimensions were measured: usefulness, clarity, confidence, interest, and recommendation intent. Internal consistency reliability (Cronbach's alpha) was computed and exceeded 0.80 for the scale items.

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3.3.1 Data Analysis

Descriptive statistics (means, standard deviations, frequency distributions) were used to summarise the test results and Likert-scale responses. To examine differences between pre- and post-test performance, both parametric and non-parametric analyses were conducted:

- A paired sample t-test was used to detect significant changes in mean scores.
- A Wilcoxon signed-rank test served as a robustness check in the case of non-normal distribution.

All statistical analyses were conducted using IBM SPSS Statistics. A significance threshold of $p < 0.05$ was adopted for all inferential tests. The dual use of t-test and Wilcoxon analysis reflects methodological rigor for small-sample, educational interventions.

2.4 Qualitative Data Collection (Student Interviews)

To complement the quantitative assessment of learning gains and tool usability, a qualitative approach was employed to capture rich, contextual student perceptions. A purposive sub-sample of five third-year engineering students (N = 5) who completed the MEC531 Design 1 course intervention was selected for individual, semi-structured interviews. The interviews were designed to elicit detailed feedback on two primary areas: 1) the cognitive and affective experience of using the ADAMFATIH GUI for complex design tasks, and 2) the perceived effectiveness and motivational impact of the different classroom discussion sequences (i.e., Peer Instruction versus Class-wide Discussion). All interviews were recorded and transcribed verbatim, with an average duration of 25 minutes.

3.4.1 Data Analysis

Interview transcripts were subjected to a thematic analysis following the six-step process outlined. This process involved familiarisation with the data, generation of initial codes, searching for overarching themes, reviewing and refining themes, defining and naming themes, and producing the final report. This allowed for the systematic identification of recurring patterns and core concepts related to student engagement, clarity of instruction, and self-efficacy in complex engineering design.

3.5 Ethical Considerations

Ethical approval was obtained from the faculty's academic research committee. Participants were informed of the study's goals and gave consent for their anonymised data to be used. The ADAMFATIH tool was used purely as a teaching aid, and no assessment scores from the study influenced students' final academic grades.

4. RESULTS AND DISCUSSION

4.1 Internal Consistency Reliability

To examine differences between pre- and post-test performance, both parametric and non-parametric analyses were conducted. The paired sample t-test detected a significant change in mean scores ($t(22) = 3.42$, $p < 0.01$). As a robustness check for the small sample size, the Wilcoxon signed-rank test also confirmed a significant upward shift in performance ($Z = -3.15$, $p < 0.01$). These results, paired with a medium-to-large effect size of $d = 0.71$, validate the tool's effectiveness in enhancing computational accuracy.

In addition to the observed shift in categorical score distributions, an effect size analysis was conducted to quantify the magnitude of learning gains. Based on approximated group scores, the Cohen's d was calculated at 0.71, representing a medium-to-large effect. This suggests that the use of the ADAMFATIH GUI tool not only yielded statistically significant improvements but also had a meaningful impact on student learning outcomes. Such effect sizes are consistent with educational interventions that produce real-

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world improvements in performance and are particularly noteworthy given the short duration and pilot nature of the study.

These findings suggest that students not only accepted but also valued the integration of ADAMFATIH into the course. The preference for interactive media over traditional text-based learning reflects a broader shift toward active, technology-enhanced education in engineering programs.

4.2 Student Perception Analysis

To evaluate students' perceptions of the ADAMFATIH GUI tool, a post-intervention survey was conducted using a 5-point Likert scale, where 1 indicated strong disagreement and 5 indicated strong agreement. The survey consisted of four items related to multimedia learning, interactivity, and comprehension support.

The analysis of student perceptions revealed strong support for interactive and media-enhanced learning tools. Respondents reported high agreement with the statement that audio-visual media helped them understand the lesson content, with a mean score of 4.30 (SD = 0.70). Similarly, interactive teaching materials were viewed positively, receiving a mean score of 4.17 (SD = 0.78), further reinforcing the preference for dynamic, engaging instructional formats. In contrast, the item "I don't need interactive learning media" was rated considerably lower, with a mean score of 2.35 (SD = 1.15), indicating that students largely rejected passive or traditional modes of instruction in favor of technology-supported approaches. Interestingly, while students acknowledged the usefulness of textual materials, this modality was rated more moderately (Mean = 3.74, SD = 1.18), suggesting that while still valuable, text-based content was seen as a complementary aid rather than a preferred primary method. These findings collectively emphasise the value of integrating interactive technologies such as ADAMFATIH into engineering education to meet learner expectations and improve comprehension.

Figure 2 presents the distribution of student scores across three achievement bands: 51–60, 61–79, and above 80, comparing pre- and post-intervention results. The data show a clear upward shift in student performance following exposure to the ADAMFATIH GUI tool.

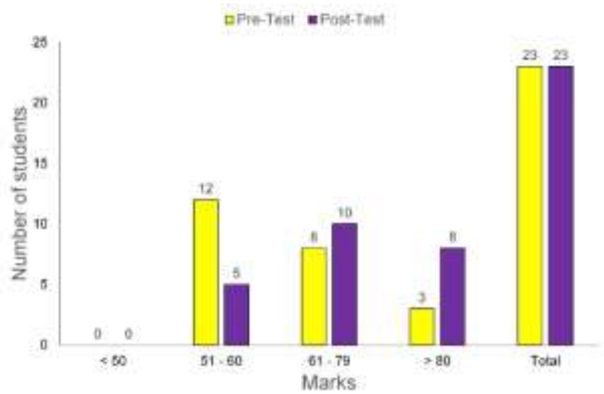

Fig. 2. Distribution of student marks before and after exposure to the ADAMFATIH GUI tool in MEC531 Design 1 course (N = 23).

In the pre-test, a majority of students (52%) fell within the 51–60 range (n = 12), while only 3 students (13%) achieved scores above 80. After the intervention, this pattern changed significantly: only 5 students (22%) remained in the lowest band, and the number of high performers (>80 marks) nearly tripled to 8 students (35%). The middle range (61–79) also saw modest improvement, increasing from 8 to 10 students. While raw mean scores are not shown here, the categorical shift reflects a meaningful gain in student performance. This is particularly relevant given the small sample size (N = 23) and supports the hypothesis

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that interactive, GUI-based learning tools can enhance both conceptual understanding and computational accuracy in complex engineering domains.

These findings are consistent with prior research showing that visual, simulation-based learning tools increase academic performance by reducing cognitive load and promoting deeper engagement with the material. Moreover, the improvement across all score bands - especially the increase in high-performing students - demonstrates the tool's ability to support differentiated learning outcomes within a diverse cohort.

The results of this study are in line with prior research in engineering and STEM education that demonstrated the efficacy of interactive digital tools in enhancing student performance. For example, (Naim et al., 2016) reported statistically significant learning gains among engineering students who used MATLAB-GUI applications for circuit analysis. Their findings indicated not only higher post-test scores but also improved student motivation, aligning closely with the outcomes of the current study. Similarly, a quasi-experimental study by (TANER, 2017) found that students exposed to visual simulation tools for mechanics and strength of materials achieved 15–25% higher test scores compared to peers using only textbook-based instruction. These findings reinforce the value of interactivity and visual feedback in technical domains where abstract concepts often present learning barriers (Kacetl & Klímová, 2019). More broadly, a meta-analysis by (Sung et al., 2016), covering over 60 studies on mobile and digital learning systems, concluded that students using interactive platforms consistently outperformed control groups across a range of subjects — particularly when the platforms allowed for self-paced exploration and real-time visualisation. Benchmarking the current findings against these prior studies affirms the pedagogical viability of ADAMFATIH as an effective GUI-based learning intervention. The tool not only facilitates accurate calculations but also supports students across different achievement levels, contributing to more equitable educational outcomes in design-intensive engineering courses.

Figure 3 presents the average responses to four Likert-scale items evaluating student perceptions of the ADAMFATIH GUI tool following its use in the MEC531 Design 1 course. The results reveal a clear preference for interactive, media-rich instructional strategies. The highest-rated items were *"I use audio visual learning media"* (Mean = 4.30) and *"I can easily understand the lesson with interactive teaching material"* (Mean = 4.17), both indicating strong student agreement with the educational value of GUI-based learning environments.

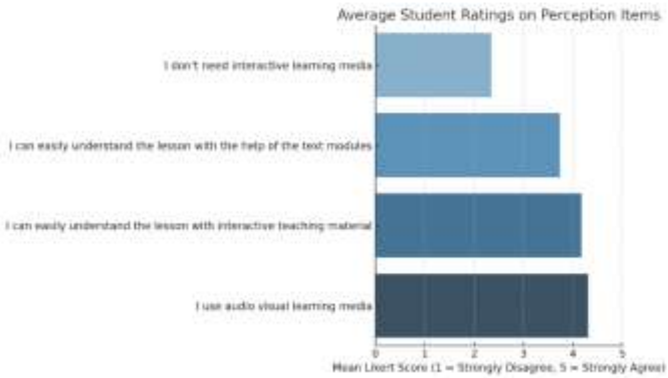

Fig. 3. Average student responses on post-intervention survey measuring perceptions of ADAMFATIH's effectiveness (N = 23).

Conversely, the item *"I don't need interactive learning media"* received a notably lower mean rating (2.35), suggesting that students actively reject traditional passive modes of instruction in favour of interactive alternatives. This contrast underscores the alignment between learner expectations and the affordances provided by the ADAMFATIH tool — namely real-time feedback, dynamic simulations, and autonomy in learning. Interestingly, the moderately high rating for *"I can easily understand the lesson with* *the help of the text modules"* (Mean = 3.74) indicates that while textual materials are still appreciated, they are seen as complementary rather than primary learning tools. This finding supports a blended approach where traditional and digital resources coexist, reinforcing the role of the GUI as an enhancement, not a replacement, of instructional content.

From a pedagogical perspective, these results echo trends in constructivist learning theory and cognitive multimedia learning, which advocate for the use of visual, interactive formats to reduce cognitive load and foster deeper conceptual understanding. The positive reception of ADAMFATIH indicates that GUI-based tools can serve as effective vehicles for delivering complex engineering content — especially when designed to support both comprehension and computation. These findings are consistent with research by (Osifo, 2019), who showed that student-centred digital tools integrating tangible or visual interaction significantly enhanced learners' understanding of abstract concepts — particularly in early cognitive development and design-related domains. Their study demonstrated that when students interact directly with visuals and feedback mechanisms, their perceived understanding and confidence increase markedly.

Similarly, (Ling et al., 2023) found that university students using virtual and GUI-based learning platforms rated the experience highly in terms of clarity, engagement, and usefulness. Their study noted that GUI elements, such as layered visuals and live user control, enabled learners to grasp relationships among variables more effectively than through static lectures or notes alone. A broader benchmarking study by (Gopabala Krishnan et al., 2023), focusing on the use of a renewable energy GUI simulator in engineering education, echoed these outcomes. They reported increased learner satisfaction, engagement, and preference for GUI-based content delivery, citing its contribution to both affective and cognitive learning dimensions. These parallels validate the results seen with ADAMFATIH, reinforcing its role as a cognitively aligned and pedagogically effective tool in enhancing learner satisfaction and comprehension in a technical engineering context.

As shown in Table 1, ADAMFATIH demonstrates comparable or stronger results in terms of student engagement, learning gains, and usability, particularly when measured alongside more mature and institutionally scaled tools. While tools such as MATLAB-GUI and the VR-based 3D modelling platforms focused primarily on enhancing spatial reasoning or learner motivation, ADAMFATIH provided measurable academic gains through pre- and post-assessment, with a medium-to-large effect size (Cohen's d = 0.71). Unlike meta-analytic studies, which aggregate across diverse learning contexts, this study presents a focused evaluation of a subject-specific tool grounded in real-world engineering codes, offering both theoretical alignment and curricular relevance. Moreover, some studies confirm that interactivity, visual feedback, and autonomy are central to student satisfaction—qualities echoed in the high Likert-scale ratings observed in this study. Thus, while smaller in scale, the ADAMFATIH intervention aligns strongly with pedagogical best practices and shows promise for broader application.

Table 1. Overview of GUI-Based Learning Tools and Their Reported Educational Outcomes

Study	Tool/Technology	Methodology	Sample	Key Findings
This Study	ADAMFATIH (Python GUI)	Pre/Post Test, Usability Survey	N = 23 (Engineering undergraduates)	↑ Student scores, ↑ preference for GUI-based learning (Cohen's d = 0.71), high usability
(Naim et al., 2016)	MATLAB-GUI	Survey-based perception analysis	N = 30	↑ Student motivation and understanding in electrical engineering
(Banerjee et al., 2023)	VR GUI for 3D modelling	Usability study, focus group	N = 20	↑ Spatial reasoning, ↑ satisfaction with GUI design interface
(Sung et al., 2016)	Multiple mobile platforms	Meta-analysis of 60+ studies	>6,000 learners	Interactive digital tools consistently ↑ academic performance
(Cheng & Lee, 2023)	Tangible visual interface	Experimental + perception study	N = 35 (Children)	↑ Engagement and learning with interactive, visual simulations

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(Gopabala Krishnan et al., 2023)	Renewable Energy GUI	Quantitative survey + open feedback	N = 41	↑ Satisfaction, engagement, and learning through hands-on simulation

The observed improvements in student performance and positive perceptions of the ADAMFATIH tool can be interpreted through several well-established cognitive learning frameworks.

First, in line with Constructivist Learning Theory, ADAMFATIH allowed students to actively construct knowledge through exploration, manipulation of input parameters, and visual feedback—supporting the idea that learners internalise concepts more effectively when they are engaged in authentic problem-solving tasks. Second, the tool aligns with Cognitive Load Theory (CLT) by reducing extraneous cognitive load. Traditional manual calculations in pipeline integrity often overwhelm working memory due to their multi-step and error-prone nature. ADAMFATIH mitigated this by automating complex procedures, allowing learners to focus their cognitive resources on germane load—i.e., the underlying principles of corrosion modelling and fatigue design. Lastly, the tool reflects principles from Multimedia Learning Theory, particularly those articulated by Mayer, by integrating text, visual input fields, and graphical outputs. This multimodal interface facilitates dual-channel processing and fosters deeper learning, as reflected in both the score improvements and favourable Likert-scale feedback. Together, these theoretical perspectives provide a robust explanation for the educational effectiveness of the ADAMFATIH intervention.

The integration of technology into engineering education has evolved from the use of static digital resources to the deployment of interactive, simulation-based tools aimed at improving students' engagement and comprehension. Central to this evolution is the development of graphical user interfaces (GUIs), which provide learners with visual and interactive mechanisms to understand complex calculations and theoretical constructs. Several studies have demonstrated the pedagogical potential of GUI-based tools in technical disciplines, particularly in contexts where computational precision and procedural fluency are critical.

4.3 Qualitative result and analysis

The thematic analysis of student interviews yielded three central themes that provide critical insight into the quantitative performance data: 1) The Power of Instant Feedback and Error Visualisation, 2) Reduction of Design Anxiety and Cognitive Load, and 3) Preference for Active Peer Interaction over Instructor-Led Discussion.

4.3.1 The power of instant feedback and error visualisation

Students consistently highlighted the interactive, visual feedback loop of the ADAMFATIH GUI as the most critical feature for promoting immediate understanding of design constraints. The ability to see immediate consequences of input changes acted as a powerful diagnostic tool. One student remarked:

> *"In the past, I would spend hours on calculations only to find the answer was totally wrong at the end. With ADAMFATIH, when I changed the pipe wall thickness and the integrity indicator immediately turned red, I knew I had broken the rules right then. The instant visual check saved me so much time and made the rules stick better." (Student 3)*

4.3.2 Reduction of design anxiety and cognitive load

Interview participants often described their prior experience with the pipeline design calculations as "overwhelming" and "error-prone." The GUI was perceived as an effective tool for managing the complexity of the task, thereby lowering affective barriers to learning.

> *"It basically handles the calculation noise for you. Before, I was worried about whether I added a plus or a minus sign wrong in step seven. Now, I focus on why the pressure needs to be this value, or why the material property matters. It shifted my brain to the design part." (Student 5)*

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4.3.3 Preference for active peer interaction over instructor-led discussion

When reflecting on the two different classroom discussion models utilised, students expressed a strong preference for active, Peer Instruction sessions. They found that debating a question with a classmate helped solidify their understanding more than passive listening to an instructor's final summary.

> *"When you discuss the concept quiz with your partner, you have to explain your reasoning out loud. That's when I realised if I actually understood it. It's a lower-stakes environment than talking to the whole class, and often my peer could explain the error better than the textbook." (Student 1)*

4.4 Some commentary

This study reveals that optimal learning outcomes in technical engineering design stem from a deliberate blended pedagogical approach that systematically integrates supportive technology with structured student interaction. The significant improvements in academic performance observed post-intervention are supported and richly contextualised by the qualitative interview data.

The success of the ADAMFATIH GUI aligns with Cognitive Load Theory, as students explicitly recognised the tool's ability to offload the mechanical burden of complex calculations. This freed them to engage with the higher-order germane load related to design principles, as evidenced by their quotes detailing a shift in focus from "calculation noise" to "why" a design choice was made. Furthermore, the qualitative finding emphasising the value of instant visual feedback directly supports the dual-channel processing principles of Multimedia Learning Theory, confirming that the dynamic, visual interface promoted more efficient information processing and retention.

Crucially, the study also supports the necessity of tailoring the sequence of classroom instruction. The strong student preference for Peer Instruction suggests that for maximum engagement and conceptual clarity, the technical support provided by tools like ADAMFATIH should be immediately followed or preceded by structured, low-stakes peer dialogue. This combination—where technology provides the accurate, visualised output, and peer discussion provides the crucial conceptual negotiation—forms the foundation for a highly effective and motivating learning environment in complex technical disciplines.

Effective learning in technical engineering domains requires a blended instructional approach that addresses both computational complexity and conceptual reasoning. This framework is grounded in established learning theories, including Constructivism and Cognitive Load Theory, and advocates for the strategic integration of technology and classroom interaction. Specifically, instructional design should incorporate high-quality Graphical User Interface (GUI) simulation tools, like ADAMFATIH, alongside targeted, well-sequenced classroom discussions.

The primary role of the GUI tool is to function as a cognitive scaffold, reducing extraneous cognitive load by automating complex, multi-step calculations (e.g., pipeline integrity assessment based on industry codes like ASME B31G). This allows students to redirect their mental effort to the germane load—the underlying conceptual principles of design and modeling. For the tool to be effective, its design must prioritize interactivity and visual feedback, offering a clear cause-and-effect loop where students manipulate input parameters and immediately observe the calculated and visual outcomes. Student perception surveys confirm a strong preference for these dynamic, media-rich learning formats, which have been shown to lead to significant improvements in learning outcomes.

While the GUI supports accurate computation, motivation and deeper understanding are significantly enhanced by structured classroom discussion sequences, as highlighted by studies comparing different interaction methods. The instructional flow should therefore deliberately pair technology use with interactive learning. For instance, students could use the GUI to run a simulation and then immediately engage in a class-wide or peer-based discussion to analyse the conceptual implications of the results, providing continuous assessment of both understanding and motivation. Successful implementation requires a robust evaluation methodology that measures both academic performance gains and affective outcomes (e.g., usability, clarity, and satisfaction). Finally, institutions should commit to scaling up the use

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of such GUI tools across curricula and ensuring continuous user-centered development based on student feedback.

5. CONCLUSION

This pilot study examined the educational impact of ADAMFATIH, a GUI developed to help third-year engineering students master pipeline integrity concepts. Designed to align with codes like ASME B31G, the tool fosters conceptual clarity and streamlines complex calculations through simulation-based learning. The research highlights a pedagogical transition from static content to dynamic, learner-centered environments.

Key conclusions and recommendations include:

- **Academic Improvement:**
  Quantitative results showed a substantial increase in performance, with high-performing students nearly tripling in number and a significant decrease in lower-performing students.
- **Student Preference:**
  Learners strongly preferred interactive environments over text-based approaches, supporting theories that advocate for visual tools to reduce cognitive load.
- **Cognitive Scaffolding:**
  The tool functions effectively as a scaffold by providing structured guidance and real-time feedback, which is particularly beneficial for courses requiring procedural accuracy.
- **Limitations:**
  The study is limited by a small sample size (N=23), a single institutional context, and a lack of long-term retention data.
- **Future Directions:**
  Recommendations include scaling the use of such tools across other engineering modules, adopting a blended instructional approach that complements traditional methods, and conducting longitudinal studies to measure sustained learning gains.

Ultimately, ADAMFATIH represents a promising educational innovation that integrates automation and real-world design logic to address learning barriers in technical domains.

5.1 Limitations and Future Work

The findings of this pilot study must be considered in light of several limitations:

- **Sample Size and Generalisability:**
  The primary limitation is the small sample size (N = 23) drawn from a single institutional cohort. While the within-subject design allowed for significant performance tracking, the results may not be fully generalisable across all STEM curricula without further validation in larger, more diverse populations.
- **Statistical Power:**
  Although the study achieved a medium-to-large effect size (d = 0.71), the small N limited the ability to conduct more complex subgroup analyses, such as comparing outcomes based on gender or prior simulation experience.
- **Long-term Retention:** As a pilot study, data collection was focused on immediate performance gains; therefore, the long-term retention of pipeline integrity concepts over several semesters remains to be explored.

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CONFLICT OF INTEREST STATEMENT

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts and declare the absence of conflicting interests with the funders.

AUTHORS' CONTRIBUTIONS

Mohd Shahrom Ismail and Nur Asyikin Ahmad Nazri carried out the research, wrote and revised the article. Nur Asyikin Ahmad Nazri conceptualised the central research idea and provided the theoretical framework. Mohd Shahrom Ismail designed the research, supervised research progress; both of them anchored the review, revisions and approved the article submission.

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