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## Experimentation and Potential for Generative AI Tools in Gateway Mathematics

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### Abstract

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With the aid of tools like computer algebra systems, routine mathematical calculations and symbolic manipulations can be quickly and accurately performed. In the advent of rapid growth of Generative AI tools, we examine how ChatGPT performs in solving a variety of mathematical problem-types and methods of representations in gateway mathematics courses. Our survey on the current use of ChatGPT among learners and experimentation with this generative AI tool in a learning environment, compels us as educators to examine how ChatGPT incorporated in teaching and learning, can be used to enhance acquisition of factual, procedural and conceptual knowledge in gateway mathematics. Applying ChatGPT in mathematical discourse elicits some potential issues with both discipline-specific and general instructional practices while enhancing benefits associated with elements of High Impact Practices (HIPs). We focus on discipline-specific instructional practices that are characterized by problem-solving, problem-posing, open-ended questions with multiple solutions, modeling project activities, and technology integration. When applied to a class learning environment, the question of the quality of the ChatGPT output and what can be offloaded to ChatGPT becomes important to both learners and educators. Our analysis of the students' survey and the experimentation with ChatGPT shows that using mathematical problem-based tasks, with instructor-curated content and learners equipped with refined prompts enriches the quality of gateway mathematics education in AI environments.

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## Introduction

Artificial Intelligence (AI) is a product of technological advances in Machine Learning and evolution of Natural Language Programs, that simulate human intelligence, behaviors, and processes. “AI is everywhere” is a phrase used to express the extensive applications that AI has had in everyday life. AI technologies have found invaluable applications across various industries including finance, healthcare, marketing, digital spaces, navigation, automation, entertainment, and many more (Shakarian et al., 2023). More so are generative AI tools that exploded to public domain with extensive capabilities producing content and knowledge. Generative AI tools not only mimic human intelligence but also draw on existing large data to create new content. The rapid growth and breakthrough in achieving complex deep-learning models for natural language understanding and generation has been fueled by the development of Generative Pre-trained Transformers (GPT) (Yenduri, 2023). The release of ChatGPT, an AI-powered Generative Pretrained Transformer trained on vast amounts of data in 2022 created a buzz across all sectors due to its ability to offer human-like responses and its potential applications. ChatGPT provides a more natural and effective text and image input communication using deep learning techniques in generating creative output (Zhang et al., 2023), at a level far superior to any other AI model (Wen & Wang, 2023). The rapid emergence of ChatGPT models, with their unprecedented accuracy and fluency, has raised the stakes and potential to transform many industries, including education.

Advances and growth in capabilities and potential impact of AI tools in many professional fields and areas of our lives have ignited debates about ethical implications due to inherent bias, appropriateness of use and issues of academic integrity. Prior to 2022, the use and awareness of AI in higher education particularly for instruction and student learning remained low (Hutson et al., 2022). Although increasing demand for adaptive learning reinforces the need for research on Artificial Intelligence (AI) in education, there have been few approaches that engage learners in meaningful interactions (Lee & Yeo, 2022). Studies have shown positive outcomes that AI has had on higher education including improved learning outcomes, retention and time to completion (Klutka et al., 2018). In the same period, towards instruction and student learning, the benefits of AI in higher education have been shown to include personalized learning, automated grading systems, conversational AI chatbots, and AI teaching assistants (Shakarian et al., 2023). With the advent of GPTs in 2022, the questions are, will same benefits of AI tools of yester years carry into the world of GPTs for example ChatGPT that generate new content, pretrained on massive data and with unparalleled accessibility and ease of use through natural language and image inputs. The ethical implications of GPT models, like any other rapidly developing technology, need to be taken into account. Like many technologies, the AI-Powered GPTs have taken business and digital spaces by storm, and it is bound to disrupt higher education and open possibilities that carry risks, challenges and promises. In higher education, the GPT will influence students' learning, how teachers work, and the structure of the education system. The potential disruption in higher education calls for educators to embrace and employ AI-Powered GPT as transformative elements to better prepare students as well as adapt to their drawbacks (Tili et al., 2023).

In anticipation of AI disruptions in Higher Education, educators will need to carefully rethink planning, teaching and learning activities, course content and structure, and assessment types. Furthermore, in addition to the use of technology in teaching and learning, generative AI tools allow for new, previously inconceivable tasks. The AI

disruption encourages us to evaluate our approach to instruction and assessment, and ensure we are placing greater emphasis on process, authenticity, and depth. Overreliance solely on AI powered GPT tools as a source for immediate solutions without engaging in the learning process may hinder development of critical thinking skills, communication skills and skills necessary for solving complex problems. This potentially disruptive technological innovation calls for stakeholders in education, including instructors and students, to partner in addressing the emerging accessibility, ethical and pedagogical challenges of generative AI tools like ChatGPT. Though potential benefits and challenges of ChatGPT in education have been suggested; its performance has been shown to be varied across subject disciplines (Lo, 2023), and potential impact on foundational knowledge gap poses new instructional challenges (Sánchez-Ruiz et al., 2023). Suggesting a more comprehensive course level understanding of the impact of ChatGPT and other GTP tools on student learning, content, pedagogy, and best practices is needed. Positive attributes have been highlighted in the use of ChatGPT in STEM; including quality, accuracy and inclusion of higher-order problem solving associated with recent version ChatGPT 4 (Lewandowski et al., 2024). ChatGPT has been championed as a tool to think with; develop reflective and critical thinking, creativity, problem-solving skills, and concept comprehension in STEM education (Vasconcelos & dos Santos, 2023). ChatGPT, unlike mathematical software, provides ease of use and access in an environment where students can interact with mathematics without the need for computing skills or software. Studies conducted so far have focused on ChatGPT mathematical capabilities and performance (Frieder et al., 2023; Shakarian et al., 2023), which are found to be weaker than in other fields.

Historically, there have been evolving concerns in Mathematics teaching and learning towards hand-held calculator and computers; however today these technologies are an integral part of teaching and learning. Like digital technology, AI technologies are envisaged to continue to stimulate educational system and teachers to integrate AI-powered GPTs into classroom practices in order to provide students with more experiences to interact with technology as a powerful learning tool (Thurm et al., 2023). According to NCTM (2024) position on AI, the AI tools do not replace the need to teach or problem solving, rather the technologies need to create positive pressure to reimagine teaching and assessment. Additionally, teachers' roles in the digital era need to be aimed at developing crucial skills students need to cope with the demands of modern life (Wijaya, 2020).

Despite the significant impact the rise of AI tools has had on various fields of advanced mathematics, the impact of AI technology on the teaching and learning of mathematics has only registered some success in undergraduate level mathematics (Luzano, 2024). Diverse threats and opportunities have been identified for assessments in AI environment (Shakarian et al., 2023) and strong performance is limited to exam-solving abilities. Overemphasis on procedural knowledge, and neglect of conceptual knowledge and authentic problem-solving skills is a challenge associated with integration of AI in learning mathematics in the recent past; prior to recent proliferation of GPTs. There is need for a more comprehensive approach that can counteract these limitations by a) employing safeguards to mitigate these threats, b) providing compelling opportunities for teachers and learners partnering in the learning process c) harnessing the synergy between AI technologies and mathematics learning, and d) building connections and context in mathematical concepts.

This study investigates the role of ChatGPT in promoting students to develop conceptual and procedural

knowledge in gateway mathematics. In achieving that goal, the study will consider three questions in leveraging the potential of ChatGPT in advancing High Impact Practices in Teaching and Learning process:

- 1) How does ChatGPT perform in different mathematical representations in Mathematics gateway courses
- 2) How can ChatGPT be used to enhance teaching and learning of procedural and conceptual mathematics
- 3) What is the potential discipline-specific issues associated with applying ChatGPT in Mathematical discourse.

Standard educational technologies used in teaching and learning mathematics have shown promoted student engagement (Attard & Holmes, 2020), improved performance; providing opportunity for self-paced learning and immediate feedback (Bright et al., 2024). Educational technology has been shown to have a significant impact on student achievement, motivation, and attitudes (Qadir, 2022). The AI-powered GPTs in this context are poised to be effective tools for improving personalized instruction and adaptive learning (Carbonell, 2012), automating assessments and mechanisms for real-time feedback. According to Luzano (2024) and Higgins (2017), the personalized instruction, adaptive learning and timely feedback foster deeper conceptual understanding and mastery of mathematical concepts, leading to desired learning outcomes. The difficulties associated with integration of computers and Computer Algebra Systems (CAS) in the learning mathematics in the past have included a) compatibility with math content and symbols, b) lack of experience in using the CAS, c) limited appropriate teaching materials, d) acquisition of software licenses and e) unsystematic utilization among others. Potential utilization of AI-powered GPTs in mathematics has signaled a set of challenges different from those of the previous generation of technology and AI in education.

ChatGPT models have shown different performance levels in problem-solving in different advanced mathematics fields (Udias, 2024). The flexibility and ability of ChatGPT to search for mathematical objects, given information about them, is shown to be suitable for gateway mathematics courses (Susnjak, 2022). However, the extent to which the potential benefits can be traced to “what the student is learning” in a specific course content with ChatGPT models outside of problem-solving components is not clear at this point.

### **Rationale for the Study**

Studies on the performance of ChatGPT on mathematics learning has largely been focused to its computational capabilities in select mathematics word-problems (MWP) (Shakarian et al., 2023), and the correctness of solutions and accuracy of mathematical facts across various tasks that test mathematical skills (Frieder et al., 2023). In this study, we combine the elements of students’ perspectives, analysis of ChatGPT capabilities, and performance on specific types of math questions drawn from course content and assessments. The study pursues aspects of correctness, appropriateness of level, clarity, and mathematical representation across domains in learning scenarios. Studies have shed light on the considerable potential for ChatGPT to impact pedagogical practices (Sandu, 2024). Most observed aspect of AI in mathematics education is its effectiveness in teaching and learning process (Mohamed, 2022). An essential component of effective mathematics instruction requires thoughtful use of High Impact Practices (HIPs). This study further examines the impacts of integration of ChatGPT and similar AI tools into elements of High Impact Practices (HIPs) towards creating engaging learning environments.

## Methods

### Student Survey

Educational technologies, Learning Management Systems (LMS) and technology-mediated learning environments have been utilized differently depending on instructor preference. Despite the current unsystematic utilization of AI tools by instructors and students, given the versatility of the GPT tools; AI will certainly be integrated into the future of the workforce students are getting into. Towards cultivating positive awareness, leveraging AI's potential and creating opportunity to integrate AI tools into our classroom consistently; we set out to conduct this study on sections of gateway mathematics courses, considered foundational and prerequisites to upper division mathematics courses. We frame the study into three themes, firstly, to gain insights into students' perception, use, and impact of freely available generative AI tools, in particular ChatGPT 3. To accomplish this task, we used two surveys from students conducted concurrently. The first was an institutional survey applied to the general student population at Columbus State University in spring semester 2024. The second survey was administered to three sections of gateway mathematics during spring semester 2024. These surveys were aimed in part at determining whether or not the students were already using AI-powered GPTs in their courses, and to what extent the learning climate has been disrupted by in particular ChatGPT-the most readily available AI powered GPT so far.

### Experimenting with ChatGPT on Assessment of Instructional Material

Secondly, we applied ChatGPT to specific mathematics content concepts, problems from assigned homework, and select questions from three Problem Sets assigned in the spring 2024 semester. These tasks were aimed at profiling the interaction of ChatGPT with the gateway mathematics content, instructional materials, and assessment tools in our context. Even with the improvement of mathematical performance of ChatGPT across GPT-3.5 and GPT-4 versions, the mathematical quality of AI generated outputs is still under exploration.

The application of ChatGPT on the concepts was geared towards a) correctness and improvements of the ChatGPT responses with changes in user prompts and, b) experimentation with different input prompts that utilized restrictions specified to the concepts. From the homework and Problems Sets, we considered Word-problems, directly formulated problems and problems involving graphs. We evaluated the mathematical forms and representations of the ChatGPT responses on a variety of problems for consistency, appropriateness of the depth, clarity, and precision. On True/False questions in our homework and Problem Sets, we delved to generate counterexamples using ChatGPT and studied them for appropriateness of level and relevance. The nature of prompts has been shown to influence the problem-solving capabilities of AI-powered GPTs; particularly in straight forward computational tasks (Mohamed, 2022); however, influence of the GPTs on the development and acquisition of expected procedural and conceptual skills for students remains under explored.

### Incorporating ChatGPT for HIPs

Thirdly, as attested to by the Request for Information (RFI) (Gates Foundation, 2024), AI has the potential to

transform mathematics learning and instruction for all students particularly minorities, underrepresented, and underprepared. The effect and implications of the potential transformations on existing best practices, and emerging best practices as a result of using ChatGPT and other AI tools needs educators' attention. In this work, we explore the potential impact of ChatGPT on effective mathematics teaching practices that include:

- connections among mathematical representations to deepen understanding of mathematics concepts and procedures (NCTM, 2014).
- building procedural fluency and conceptual understanding (NCTM, 2014) to create mathematical proficiency necessary for success in mathematics learning.
- improved formative assessments through enabling enhanced question types (Cardona et al., 2023); that allow students to demonstrate and apply their knowledge in ways that emphasize process rather than products derived directly from the ChatGPT and other generative AI tools.

The study also points out the need for new teaching best practices and competencies to cater to the incorporation of current and future advancement of generative AI tools in teaching and learning of gateway mathematics. We study potential discipline specific issues associated with applying ChatGPT in Mathematical discourse, including High Impact Practices (HIPs).

## Results

### Analysis of Student Survey Data

The student survey conducted in three sections of gateway mathematics courses comprised seven mixed type questions that generated both quantitative and qualitative data. The survey garnered 81 respondents, with some questions eliciting less than the total number of respondents. The qualitative data of student responses was further organized around significant themes to establish the climate of students' current usage and perception to ChatGPT amid its public pervasiveness and stunning fluidity. This mathematics student survey data is studied in tandem with the institutional data conducted during the same period, spring semester 2024. The institutional student survey collected responses from 366 respondents.

To determine whether or not students are engaging in use of the AI-powered GPT already, we considered responses to our first survey question, "Have you ever used an AI tool in a course?". 60% of the respondents indicated "Yes", using AI tools in a course. This is significant given the current self-selection nature of the use of AI tools in classrooms by students. Thirty-six percent of the respondents indicated "No", not having used AI tools in a course, while 4% were unsure, responding to "Maybe". To have responded "Maybe", in our opinion, indicates students' lack of clarity on what use or no-use of AI tools in a course constituted.

From the institutional data, 38% of the students responded to the affirmative on using generative AI tools, while 62% indicated "No" to using any AI tools. The reversal of the usage data indicates unsystematic utilization of AI tools across disciplines within the institution, with the highest percentage of use cases being in STEM fields (Zhang & Aslan, 2021). The "Technology" and "Engineering" in STEM are directly influenced by emerging technologies, while "Science" and "Mathematics" are the foundational knowledge of AI emerging technologies

(Chiu & Li, 2023). This provides compelling justification to pursue the study on the impact of AI-powered GPTs, particularly ChatGPT, on gateway mathematics courses.

### *AI Tools Familiar to Students*

With the proliferation and rapid emergence of generative AI tools, we next needed to establish what tools were available to students so far. A non-exhaustive list of 18 generative AI tools currently available in the market was presented, and respondents were asked to name AI tools they have used or are familiar with so far. The results of AI tools familiar to students are shown in Table 1.

Table 1. AI Tools Familiar to Students

Generative AI tool	Have used or familiar with
ChatGPT	59%
Grammarly	30%
Mathway	19%
PhotoMath	14%
Other tools	23%
None	11%

Students had the option of multiple selections, and hence the percentages overlap, adding to more than 100%. The trend of AI tools choice resonates with institutional data. Independently when student responded to the question, “Have any of your teachers discussed the use of the following AI tools?” 52% polled ChatGPT while 28% polled Grammarly. The comparison of ChatGPT and Grammarly is not surprising since ChatGPT is content-oriented while Grammarly is predominantly language-based. ChatGPT has similarly been viewed favorably by 83% of students with a nationwide sample of students in Grades 10 through 12 (Schiel et al., 2023). The overall use of AI tools is set to increase as these cohorts of students get to college. Data on AI tools used by students is shown in Figure 1.

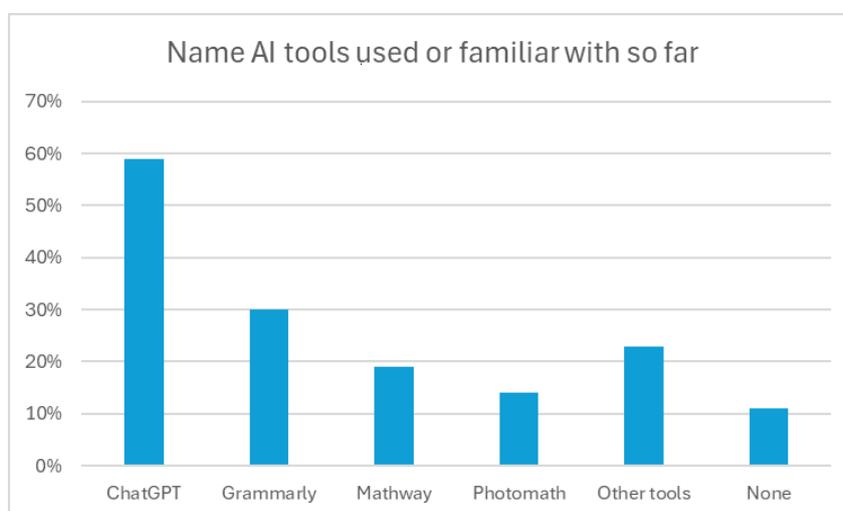


Figure 1. AI Tools Used by Students

ChatGPT is a choice for this study owing to its popularity in public domain in past years as well as its free accessibility (model 3.5 sufficient for this study) and ease of use. ChatGPT is accessible to hand-held devices such as android phones, iPad, and iPhone with an app download. The advantages include no sophisticated software or computer programs required to access this AI tool.

#### *For What Purpose Students Utilized AI Tools?*

In evaluating AI tools students are utilizing, it was essential to determine what the tools do in the context of class activities embedded in the three sections under our study. Our survey Question two, “Which of the following activities did you use AI tool for?” sought to establish for what learning activities the AI tools were utilized among “Problem Solving”, “Answer short answer questions on homework or Problem Set”, Answer Written Response Question on homework or Problem Set”, “Check solutions or get feedback on a mathematical problem,” and “All of the above”. Utilizing AI tools in “Checking solutions or getting feedback on a mathematical problem”, scored highest at 66%. The significantly low scores in utilization of AI tools in problem solving (8%) or answering specific types of questions in assignments indicate low uses of AI tools in completing complex tasks. Use of AI tools at the front end of learning, exploration, brainstorming, and problem-solving skills is suggested. This indicates that students apply AI tools with minimal or lack of guidance on usability or feasibility. The data on activities in which students used AI tools are shown in Figure 2.

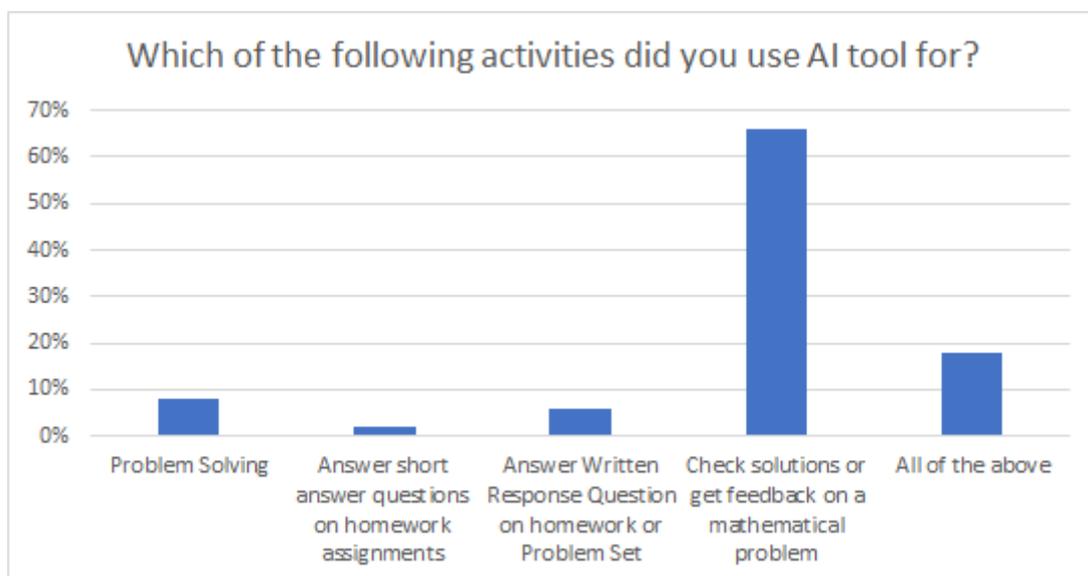


Figure 2. Activities Students Used AI Tools

#### *Students' Awareness or Usage of Some Specific AI Tools*

The survey also sought to identify students' awareness or usage of some specific AI tools applicable in their disciplines. The students responded to the question; “Have you used or heard about any of the following AI tools? Explain briefly”. The AI tools included ChatGPT, Grammarly, WolframAlpha, Mathway, Photomath and Chegg Study. Of the respondents, 90% indicated they have “heard” or “used” from the selection of six AI tools; of that

group 52% have used one of these AI tools. Only 10% indicated they have not used or heard of these AI tools. This highlights a positive awareness in the AI tools applicable to their discipline.

The awareness of specific AI tools at discipline level outpaces the institutional one, where data shows 66% of respondents indicating “heard from faculty or peers” or “read from media outlets or sources outside of the institution”. In responding to the part of the question that asked respondents to explain briefly on the AI tools they have used or heard about, checking of answers and getting a better understanding of the steps in solving a problem dominated the responses as mirrored in Figure 2.

#### *How Helpful Were the AI Tools Used to Achieve Learning Goals?*

Students identified a variety of ways in which AI tools are helpful. Of those who used AI tools, 90% indicated the tools were very useful, and 10% indicated that they did not find AI tools very useful. Checking their work, which included double checking their answers, was prevalent among the students as areas where AI tools were useful. Providing step-by-step explanations and providing similar examples were identified as help derived from AI towards solving problems.

This underscores the importance of AI tools in providing feedback and reflection which is considered a means of self-assessment and a tool for which students attach meaning to their work (Landers & Reinholz, 2015). Students indicated that ChatGPT provides examples for concepts that the textbooks or LMS do not provide; thus, ChatGPT's generative nature bridges the concept gaps and students' experience. In this context, the generative AI tools provide flexibility and adaptivity that accord personalized instruction and offer effective tutoring. Other perceived helpfulness of AI tools highlighted by students included, providing starting points whenever they are stuck, learn from different perspectives, identify misconception, create confidence and assurance, provide details, and help identify background information the user needs to pay attention to, e.g. methods or techniques to be used. Traditionally, mathematics learning starts with conceptual understanding to promote procedural fluency; however, with the use of ChatGPT, procedural tools may be used to develop conceptual skills. Even with the step-by-step explanation of problems and availability of answers, the students pointed out that there is a need to “...practice to understand the process and become better.”

#### *On How AI Might Hinder Learning*

Students identified that overreliance on AI tools may hinder their critical thinking skills and ability to actually understand an assignment. This implies that the use of AI tools without understanding the underlying concepts results in gaps in foundational knowledge and the inability to transfer the skills gained. The students pointed out the possibility of AI tools providing wrong answers, misleading content resulting in frustration and demotivation among students. While some of these limitations are being addressed with improvements such as from ChatGPT-3.5 to ChatGPT-4.0, in some areas, their ability to for deep and accurate representation of mathematics concepts is not readily available (von Hippel, 2024). Better prompting strategies have been proposed to improve the outcome of the AI responses. For mathematics, besides the loss of critical thinking and masking of problem-

solving skills acquired through human computations, the students also identified that a false sense of progress for students may result from unguided use of AI tools.

Students observed that uncharted use of AI tools will bypass authentic feedback for the instructor about the class's progress due to potential cheating, plagiarism, and extraneous information abounding in AI tools. From “It might make you complacent and it also takes a strong sense of morality to not cheat.”, “I mean it can take away from actually learning”, and “People can become dependent on it, and they can use it to cheat instead of actually grow their mind.”, underscores the potential decline in students exerting themselves towards their learning goals as a result of overreliance on AI tools (González-Calero et al., 2014). Towards assessments, students observed that while AI tools might be helpful in providing steps-by-step explanations and answers; “test are outdated and make no real world sense anymore when we have so much information at are finger tips” This highlights the fact that as AI tools evolve, their potential to revolutionize teaching and learning becomes increasingly apparent to students as well.

#### *Potential Impact of AI Tools on Your Education*

The general student perception of the potential impact of AI on their education was surveyed, with 54% indicating they envision a positive impact on their education. 22% projected negative impact while those neutral and unknown polled 14% and 8% respectively. Compared to similar but a different question in an institutional survey on the impact of AI tools to careers, and future prospects, there seems to be a reversal where only 25% indicated positive impact. The nature of step-by-step examples to learn mathematics and which is efficiently supported by AI-powered GPT tools are desirable to many students as qualitatively attested to by students' responses. This may in part have influenced the higher positive ratings of 54% for potential impact of AI on their education in the mathematics students survey. The student continued to observe; “While I think AI can hinder learning, it's really helpful when I need more instant explanations and revisions of my work without letting it do the work for me.” Here, the student emphasizes the need to work with AI tools rather than letting the AI do the work for them. “Important to be able to have a product that can assist me in understanding and completing a problem by going step by step and reverse engineering it.”

While there is more to learning mathematics than explanations and examples, the students observe the potential for AI tools to place example generation into the hands of students (Watson & Mason, 2002). Additionally, GPT provide powerful tools to complete computational tasks and potentially enhancing interactive learning (Ouaazki et al., 2023), thus “it's much more efficient to ask AI to break down a problem into digestible pieces rather than needing to refer back to a 1hr lecture, sort through class notes, schedule a tutoring session, or refer to Google/YouTube and hope to find a solution that way” student observed. This highlights the importance of tidbits derived from ChatGPT in learning mathematics. Another consideration is students' feelings towards AI-powered GPTs and their potential impact on their education. On this, the institutional survey indicated Excitement or Curiosity at 43%, Anxious or Concerned at 31% and 24% indicated neutral. The last two states of feelings indicate a potential for significant disruption by AI in teaching and learning if there are no systematic utilization or immediate interventions.

## Experimentation with ChatGPT

The ability for ChatGPT to simulate human-like interactions, break down complex concepts into tidbits, and provide real-time feedback makes it a viable tool for teaching and learning mathematics. With the rapid evolution of AI tools, and widespread use, it is imperative to rethink course content, teaching and learning activities and assignments. In this study, we apply the current course content taking into account the capabilities afforded by ChatGPT-3.5, reflect on its functionality, and consider applications to teaching in a gateway mathematics context.

### Computation

We applied ChatGPT on questions sampled from Problem Sets and homework assigned for spring semester 2024. The homework comprised of True/False, Multiple Choice, Short Answer, and Written Response-type questions. On the other hand, the Problem Sets comprised primarily of Short Answer and Written Response- type questions. The Problem Set questions included standard word problems, numerical-equation problems, and graphical problems. We applied ChatGPT to provide solutions to diverse types of questions in the assignments for semesters and analyzed the ChatGPT output. We started off by typing in ChatGPT, a general mathematical statement “Design a rectangular box of minimum surface area with volume 24” that missed some details like dimensions and units. The ChatGPT solution output is shown in Figure 3.

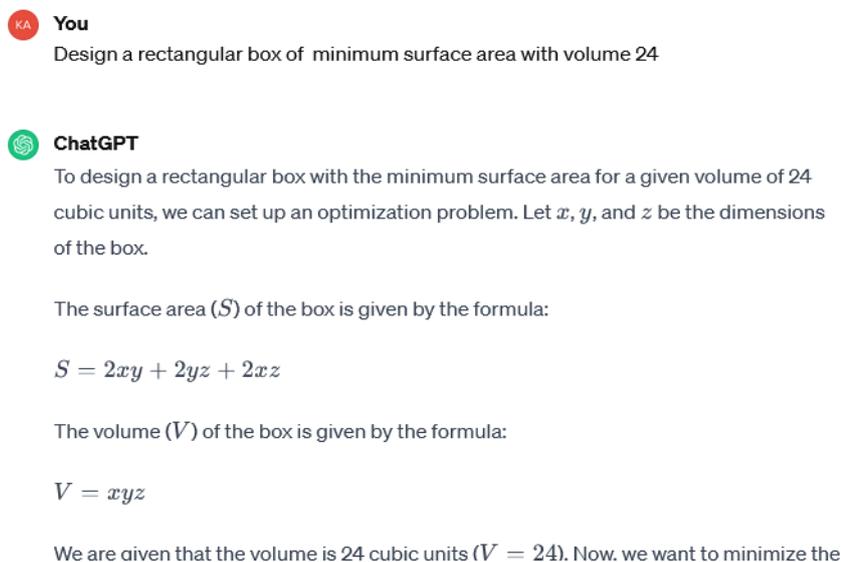


Figure 3. ChatGPT Response to the Prompt

In this output (Figure 3), it was observed that GPT paraphrased and provided a preamble to the classification of an “optimization problem” and ordered solution steps accordingly. The summary of steps and mathematical facts provided in an interactive dialogue style are envisioned to teach students how to organize key ideas into logical patterns, reflect on their work, and clarify their mathematics reasoning (Smit et al., 2023). In this case, where there are no specifications on the nature of the rectangular box, i.e. open or closed, ChatGPT defaults to a closed rectangular box. This highlights the essence of inputting refined prompts for appropriate ChatGPT response.

Multiple representation among the four domains of mathematics, verbal, graphic, algebraic and numeric, enhances teaching and learning of mathematics, promoting understanding (Mainali, 2021), and sensemaking. In Figure 4, ChatGPT could not provide a graph of the piecewise-defined function but described it instead. While the description is correct, the absence of the expected domain of representation, i.e., a graph, is a classic case of a picture worth a thousand words. This limitation observed in ChatGPT-3.5 has been remedied by newer versions of ChatGPT.

 **Anonymous**  

$$\text{graph } x^2 \& \text{\textit{if}} x < 0 \text{\textit{}} \\ 2x \& \text{\textit{if}} x \geq 0 \\ \text{\textit{end}{cases}} \text{\textit{}}$$
 The left-hand limit of  $f(x)$  as  $x$  approaches 0 from the left (denoted as  $\lim_{x \rightarrow 0^-} f(x)$ ) would be the limit of  $x^2$  as  $x$  approaches 0, which is 0.

 **ChatGPT**  
 I can describe the graph of the given piecewise function  $f(x)$  in two parts:

1. For  $x < 0$ , the function is defined as  $f(x) = x^2$ .
2. For  $x \geq 0$ , the function is defined as  $f(x) = 2x$ .

Let's describe each part separately:

1. For  $x < 0$ :
  - The graph is a parabola opening upwards since  $x^2$  is a quadratic function.
  - The vertex of the parabola is at the origin  $(0, 0)$ , and the curve extends towards negative values of  $x$ .
  - As  $x$  approaches 0 from the left ( $x \rightarrow 0^-$ ), the values of  $f(x) = x^2$  approach 0.
2. For  $x \geq 0$ :
  - The graph is a straight line with a slope of 2, passing through the origin  $(0, 0)$ .
  - As  $x$  increases from 0, the values of  $f(x) = 2x$  increase linearly.

To summarize, the graph is a combination of a parabola and a line. The left-hand limit of  $f(x)$  as  $x$  approaches 0 from the left ( $\lim_{x \rightarrow 0^-} f(x)$ ) is indeed 0, as the values of the parabola approach 0 as  $x$  approaches 0 from the left.

Figure 4. ChatGPT Response to a Piecewise-Defined Function

ChatGPT may provide more advanced solutions beyond student level. While this has the potential benefit of providing advance organizer, challenging exercises, and further readings for the students, the capability to refine the prompts and improve the quality and level-appropriateness of the responses rests on the user's mathematical skills. At some point, additional information may not be necessary for incremental learning of mathematics concepts. In Figure 5, a direct prompt to “provide a diagram” of a given polynomial function elicited first the acknowledgement from ChatGPT that “I'm sorry for the inconvenience, but as a text-based AI model, I'm unable to generate diagrams directly”. ChatGPT then proceeded to guide on how to sketch graph of the function through standard steps that involved obtaining first and second derivatives to determine intercepts, critical points, intervals of increase and decrease, and inflection points.

Provide a diagram for  $f(x)=x^3-2x^2+5$

I'm sorry for the inconvenience, but as a text-based AI model, I'm unable to generate diagrams directly. However, I can guide you on how to sketch the graph of the function  $f(x) = x^3 - 2x^2 + 5$ .

To sketch the graph of  $f(x) = x^3 - 2x^2 + 5$ , you can follow these steps:

1. **Find the y-intercept:** Substitute  $x = 0$  into the equation to find the y-intercept. In this case,  $f(0) = 0^3 - 2(0)^2 + 5 = 5$ , so the y-intercept is  $(0, 5)$ .
2. **Find the critical points:** Calculate the derivative of the function,  $f'(x)$ , and solve for  $f'(x) = 0$  to find critical points. In this case,  $f'(x) = 3x^2 - 4x$ . Set  $f'(x) = 0$  and solve for  $x$  to find critical points.

$$3x^2 - 4x = 0$$

$$x(3x - 4) = 0$$

$$x = 0, \frac{4}{3}$$

So, the critical points are  $x = 0$  and  $x = \frac{4}{3}$ .

3. **Determine the intervals of increase and decrease:** Test the intervals between critical points and beyond to see where the function is increasing or decreasing. You can use the first derivative test for this.
4. **Find the inflection points:** Calculate the second derivative  $f''(x)$  and solve for  $f''(x) = 0$  to find inflection points.

$$f''(x) = 6x - 4$$

$$6x - 4 = 0$$

$$x = \frac{2}{3}$$

So, the inflection point is  $x = \frac{2}{3}$ .

5. **Sketch the graph:** Based on the information gathered from the steps above, you can now sketch the graph of the function, making sure to incorporate the y-intercept, critical points, intervals of increase and decrease, and inflection point. You may also want to consider the end behavior of the function as  $x$  approaches positive and negative infinity.

Remember, the graph of  $f(x) = x^3 - 2x^2 + 5$  is a cubic function, so it will have a characteristic shape with certain key points.

Figure 5. Prompt Yields Standard Results Beyond Learners' Level

The multi-step word problem in Figure 6 has additional parts asking the students to rate their confidence in ability to solve the word problem and rate the importance of knowledge to solve it efficiently. As shown in Figure 6, ChatGPT provided a 10/10 confidence level in this question without restrictions. When the restrictions “Without using derivatives and using only your prior knowledge” were added, the confidence level reduced to 7/10. It is noteworthy that, even with the restrictions in place, ChatGPT used derivatives at the end of the output. ChatGPT’s confidence level on the “importance of knowing how to solve such a problem efficiently” being an 8/10, provided a helpful aspect in consideration of this question in future assessments.

**You**

A rectangular container with an open top is required to have a volume of 24 cubic meters. In addition, one side of the rectangular base is required to be 4 meters long. If material for the base costs \$8 per square meter, and material for the sides cost \$2 per square meter, find the dimensions of the container so that the cost of material to make it will be a minimum.

**Part 1**

On a scale of 1 to 10 (1 being the least and 10 the highest) how confident are you that you can solve the problem using only your prior knowledge?

**Part 2**

On a scale of 1 to 10 (1 being the least and 10 the highest) how do you rate the importance of knowing how to solve such a problem efficiently.

**Part 3**

Use only your prior knowledge to solve the problem.

- Solutions obtained from the internet or other sources will not be accepted.
- Clearly explain your steps and reasoning, you may use words, diagrams, graphs, formulas, or tables to describe your solution

**ChatGPT****Part 1: Confidence Level**

On a scale of 1 to 10, I would rate my confidence at a 10. I am confident in my ability to solve optimization problems using calculus, which is a standard method for solving problems of this nature.

**Part 2: Importance Rating**

On a scale of 1 to 10, I would rate the importance of knowing how to solve such a problem efficiently at 8. Optimization problems arise in various fields, and the ability to find optimal solutions is crucial in areas such as engineering, economics, and physics.

**Part 3: Solution**

Let's denote the dimensions of the rectangular base as  $x$  and  $y$ , where  $x$  is the length of the side given to be 4 meters. The height of the container will be  $h$ .

The volume of the container is given by the product of its dimensions:

$$V = x \cdot y \cdot h$$

We also have the constraint that the volume is 24 cubic meters:

$$xyh = 24$$

Now, we want to minimize the cost function,  $C$ , which is the sum of the cost of the base and the cost of the sides:

$$C = 8xy + 2(x + y)h$$

We can use the constraint to eliminate one of the variables. Solve the constraint equation for  $h$ :



Figure 6. ChatGPT Output for Multi-Step Word Problem

For the following conceptual question, ChatGPT failed to provide a coherent mathematical argument to support the solution provided, highlighting the fact that GPTs may provide misleading information.

**You**

At 10:17 a.m., you pass a police car at 55 mph that is stopped on the freeway. You pass a second police car at 55 mph at 10:53 a.m., which is located 39 mi from the first police car. If the speed limit is 60 mph, can the police cite you for speeding? Use concepts in calculus to explain Why or why not.

**ChatGPT**

To determine whether you can be cited for speeding, we need to analyze the information given and use calculus concepts to understand your speed at different points in time.

Let  $d(t)$  represent your distance from the first police car at time  $t$ . Since you're moving at a constant speed of 55 mph, the position function is  $d(t) = 55t$ , where  $t$  is the time in hours.

The second police car is located 39 miles from the first one, so when you pass the second police car, the distance function is  $d_2(t) = 55t - 39$ .

Now, we can find the time at which you pass the second police car. Set  $d(t) = d_2(t)$  and solve for  $t$ :

$$55t = 55t - 39$$

The  $t$  values will cancel out, indicating that there is no solution. This means that you never pass the second police car because the two functions are parallel, and the distance between them remains constant. 

Figure 7. ChatGPT Generated Conceptually Misleading Information

For question in Figure 7, the use of Intermediate Value Theorem or otherwise, is recommended and the average speed is 65 mph. While it is not clear why ChatGPT failed to solve a standard word problem; this type of output provides an opportunity for feedback and learning moment for students to reflect on, and critic AI generated solutions. Another feature of ChatGPT we applied towards the teaching and learning environment is its ability to generate examples of a mathematical concept as shown in Figure 8.

ChatGPT capability to generate relevant examples provides both instructors and students with additional examples of specified concepts. The limitation here was that standard representations and notations were not used; instead, text descriptions were provided. Additional work is required to transcript the responses into standard mathematical formulation and symbols. This has the potential to dissuade or discourage inexperienced learners from utilizing ChatGPT for this purpose.

To explore the performance of ChatGPT on external content, e.g. graphs generated by some online graphing calculators, we copied and pasted graph questions into the ChatGPT. ChatGPT responded "It looks like you have embedded a Desmos graph. How can I assist you with this graph?" When the prompt "find the limit as  $x$  approaches 4" was input, ChatGPT responded "I don't have the ability to view external content including embedded Desmos graphs..." ChatGPT output proceeded to provided interactive suggestions for possible inputs to allow progress in solving the problem. Future improvements on the functionality of the graph interface features

will help students towards fluency in numerical, graphical, and algebraic representations, which is a critical interplay in the learning of mathematics.

 **Anonymous**  
Write examples of limits of  $f(x)$  from the left

 **ChatGPT**  
Sure, here are some examples of limits from the left (left-hand limits) for various functions:

1. **Piecewise Function:**  
Consider the function  $f(x)$  defined as follows:  

$$x^2 \text{ \& \text{if } } x < 0 \text{ \}$$

$$2x \text{ \& \text{if } } x \geq 0 \text{ \}$$

$$\text{\end{cases} \}$$
The left-hand limit of  $f(x)$  as  $x$  approaches 0 from the left (denoted as  $\lim_{x \rightarrow 0^-} f(x)$ ) would be the limit of  $x^2$  as  $x$  approaches 0, which is 0.

2. **Step Function:**  
Let  $g(x)$  be a step function defined as:  

$$1 \text{ \& \text{if } } x < 2 \text{ \}$$

$$3 \text{ \& \text{if } } x \geq 2 \text{ \}$$

$$\text{\end{cases} \}$$
The left-hand limit of  $g(x)$  as  $x$  approaches 2 from the left (denoted as  $\lim_{x \rightarrow 2^-} g(x)$ ) would be 1.

3. **Rational Function:**  
Consider the rational function  $h(x)$  given by:  

$$h(x) = \frac{2x-1}{x}$$

Figure 8. ChatGPT Capability to Generate Relevant Examples

The student survey outcome and the experimentation with ChatGPT on actual instructional and assessment materials suggest that further explorations will be needed to fully understand the scope and challenges of application of ChatGPT to mathematics content and its representation both to the student and the instructor.

### HIPs Considerations

The impact of AI on established HIPs has not received much attention owing to the rapid advancements in AI tools. Comprehensive study on how the elements of HIPs integrated in teaching and learning materials are impacted or supported by generative AI tools is limited. Faculty and their students should engage in teaching and learning activities that promote HIPs in generative AI environments.

In reviewing the current elements of High Impact Practices (HIPS), and analysis of the ChatGPT outputs, we established that:

- a) To place expectations at an appropriately high level, generative AI tools provide great potential for exploring high level material with the appropriateness guided by well-designed prompts and/or guidance by instructors.
- b) Significant investment of time and effort by students can be achieved through students pursuing complex

tasks in contextualized projects. In such projects, students apply ChatGPT to explore questions and related complexities of the project.

- c) Frequent, timely, and constructive feedback is achieved through the adaptive and interactive nature of ChatGPT. The interactions and feedback have the potential to allow students to learn, to monitor, and adjust their approaches to learning.
- e) Periodic structured opportunities to reflect and integrate learning through Lab activities guided by feedback from ChatGPT.

give step by step instruction for geogebra to construct a slop of secant line



To construct the slope of a secant line using GeoGebra, follow these steps:

1. **Open GeoGebra:**  
Launch GeoGebra and select the Geometry workspace.
2. **Create a Function:**  
Input a function into the input bar at the bottom. For example, type ``f(x) = x^2`` and press Enter.
3. **Create Two Points on the Function:**  
Use the "Point" tool (the dot icon in the toolbar) to place two points on the function. Click on the function graph twice to create points A and B.
4. **Draw the Secant Line:**  
Select the "Line through Two Points" tool (the icon with two points connected by a line). Click on points A and B to draw the secant line between them.
5. **Calculate the Slope:**
  - Use the input bar to calculate the slope of the secant line. Type ``slope = (y(B) - y(A)) / (x(B) - x(A))`` and press Enter.
  - This creates a new variable ``slope`` which GeoGebra will display.
6. **Display the Slope:**
  - To display the value of the slope on the canvas, type ``Text["slope: " + slope, (x(A)+x(B))/2, (y(A)+y(B))/2]`` in the input bar and press Enter. This places a text box with the slope value between points A and B.

Figure 9. ChatGPT Instructions for Students' Interaction with Other Software

This study applied ChatGPT to a pre-project designed to engage students, leading to a milestone course project. The assignment's initial steps ask respondents to rate their confidence in solving the subsequent parts of an optimization problem. Analysis of the ChatGPT output was conducted and the results used to revise the course project that incorporates use of ChatGPT. In the two sections of the courses, GeoGebra and Desmos were used

for exploratory learning in the mathematics labs. On lab activities, we applied ChatGPT to provide instructions, responses and feedback to allow students interaction with the exploratory software as shown in Figure 9.

The step-by-step interaction between the student, ChatGPT, and the software helps the student develop a deeper understanding of the mathematics concepts and provides opportunities to explore applications of mathematics in class environments. Student achievement has been shown to be higher with learning supported by explorations as compared to problem solving (Sokolowski et al., 2015). The labs are integral to active learning sessions and provide students with a reflective and contextualized environment supported by ChatGPT.

## **Challenges of ChatGPT in Teaching and Learning of Mathematics**

### **Ethical Challenges**

The accuracy and reliability of the information generated by earlier versions of ChatGPT and AI tools in general have been brought to question. Besides the errors abound in use of AI tools, there are concerns towards potential of generative AI tools propagating biases across historical inequalities, cultural differences, user backgrounds (Hrastinski, 2019), (Akgun & Greenhow, 2022) and entry behavior. Coupled by the user privacy and data security concerns, there are unintended consequences that may stem from generative AI adoption and dependency in education, that include loss of human decision-making capabilities, laziness (Ahmad et al., 2023), loss of autonomy and academic integrity. Despite the potential benefits attributed to AI tools, students do not have equitable access to the technology needed to benefit from generative AI tools. The unique feature of text-based conversational responses from ChatGPT provides a level of access beneficial to the majority of users. The caveat here is that the quality of responses primarily depends on the quality of the prompts input (Gao et al., 2023). This may exacerbate gaps among students in readiness and foundational knowledge. Students with limited ability to create targeted ChatGPT prompts when overwhelmed with extraneous or incorrect information and beyond their level of preparedness may find less utility in the generative AI tools and be demotivated to learn. Responsible and effective generative AI usage requires planning, learning, and frequent assessment informed by comprehensive guidelines and policies at the course and institutional levels.

### **Technical Challenges**

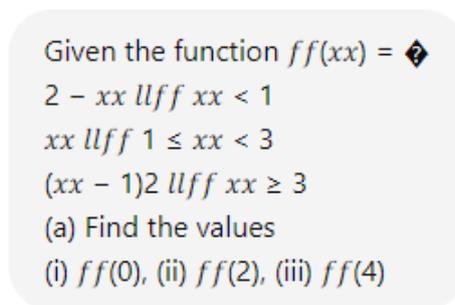
Representation from one mathematical form to another is crucial in learning and teaching of gateway mathematics. The ability of ChatGPT to represent different mathematical forms has been shown to be a limitation for particularly the ChatGPT-3.5 version. For example, expressing responses in graphical form or inputting graphical information is not readily done in this version of ChatGPT. While descriptions are provided in ChatGPT responses, it may require a student to interpret that response into a visual graph. Figure 4. above shows an instance where ChatGPT responses are not in closed form, as students are accustomed to seeing. Such a situation necessitates the learner to possess the ability to interpret that response into closed-form mathematical equations and expressions. In problem-solving, the natural tendency for the learner will be to input closed-form mathematical equations and expressions in ChatGPT as presented in textbooks or assignments; however, it is not intuitive how the student can achieve this. One of the alternatives we considered was to copy and paste into

ChatGPT. And while ChatGPT provides responses when copy-and-paste is utilized, the input is transformed into a form different from what was copied. For example, copying and pasting into ChatGPT the prompt in figure 10, yielded the output in Figure 11.

$$\text{Given the function } f(x) = \begin{cases} 2 - x & \text{if } x < 1 \\ x & \text{if } 1 \leq x < 3 \\ (x - 1)^2 & \text{if } x \geq 3 \end{cases}$$

(a) Find the values  
 (i)  $f(0)$ ,      (ii)  $f(2)$ ,      (iii)  $f(4)$

Figure 10. Piecewise Defined Function Prompts



Given the function  $ff(xx) =$   
 $2 - xx \ llff \ xx < 1$   
 $xx \ llff \ 1 \leq xx < 3$   
 $(xx - 1)2 \ llff \ xx \geq 3$   
 (a) Find the values  
 (i)  $ff(0)$ , (ii)  $ff(2)$ , (iii)  $ff(4)$

Figure 11. Output of ChatGPT to the Prompt in Figure 10

The difference between the input question form and the ChatGPT output form and syntax presents a disconnect and confusion for a learner reviewing the material. If a student cannot write symbolically, can they write verbally and vice versa? Even equipped with the fluency between verbal and symbolic representations, the introduction of mathematical symbols noise as depicted in figure 11. above is likely to alarm the most experienced users. Another aspect that raises a challenge is the ability for a student to write in mathematics, language, and symbolism. Without the ability on the learner's part to communicate with or discern from ChatGPT, correct mathematics terminology, order of operations, symbols or forms; an unnecessary level of complexity is introduced, and errors are propagated.

### Pedagogical Challenges

While leveraging the power of generative AI tools in the realm of teaching and learning, the educators will need to ensure that the essential activities that constitute learning remain with the student. Essential learning activities including critical thinking, analysis and synthesis, problem-solving, reflection, collaboration, and demonstration are impacted by generative AI in different ways. Though problem-solving, critical thinking or other skills may be gained, gaps in foundational knowledge are exacerbated due to overdependence on generative AI tools. Overreliance on ChatGPT, like any other emerging technologies, may hinder learning affecting student's decision-making, critical thinking, and analytical reasoning (Zhai, et al., 2024). Considering this challenge, it is important for instructors to work in partnership with students to determine what learning activities are to be offloaded to AI. The instructor has the fundamental task to ensure that the activities remain intentional, meaningful, and useful in the learning environment supported by generative AI tools. To engage students in learning activities that are likely

to result in achieving the learning outcomes in the generative AI environment, instructors will need to be equipped to respond and determine, what changes and when new information come with minimal disruption to students and the learning activities.

Integrate 1/x over [0, 1]

The integral of  $\frac{1}{x}$  from 0 to 1 is improper because  $\frac{1}{x}$  approaches infinity as  $x$  approaches 0. To evaluate this integral, we can express it as a limit:

$$\int_0^1 \frac{1}{x} dx = \lim_{a \rightarrow 0^+} \int_a^1 \frac{1}{x} dx.$$

Now, we can compute the integral:

$$\int \frac{1}{x} dx = \ln|x| + C.$$

Thus, we have:

$$\int_a^1 \frac{1}{x} dx = [\ln|x|]_a^1 = \ln(1) - \ln(a) = 0 - \ln(a) = -\ln(a).$$

Now taking the limit as  $a$  approaches  $0^+$ :

$$\lim_{a \rightarrow 0^+} -\ln(a).$$

As  $a$  approaches  $0^+$ ,  $\ln(a)$  approaches  $-\infty$ , so  $-\ln(a)$  approaches  $+\infty$ . Therefore,

$$\int_0^1 \frac{1}{x} dx = +\infty.$$

In conclusion, the integral diverges:



Figure 12. ChatGPT Response

**Question**

Integrate 1/x over [0, 1]

**Gauth AI Solution**

**Answer**

$$\ln|x| + C$$

**Explanation**

$$\int \frac{1}{x} dx$$

↓ Evaluate the integral using  $\int \frac{1}{x} dx = \ln(|x|)$

$$\ln|x|$$

↓ Add the constant of integration  $C \in \mathbf{R}$

$$\ln|x| + C$$

Figure 13. Gauth App Output

Extraneous information and sometimes beyond the appropriate level of the learner results from prompts that are not well refined. Poorly refined prompts often produce irrelevant or overly complex content and context. Creating effective prompts requires more practice and interaction with the body of knowledge that matches the learners' cognitive level. Instructor support to build these skills and guidance is required, allowing adequate time for task completion, encouraging exploration and recognition of learning acquired in the process of experimenting with different prompts. The limitation, even with well-refined and targeted prompts, may be to focus more on prompts and less on content and problem solving. Additionally, even across the AI tools, the accuracy and quality of the information generated can vary for the same input, which negatively impacts learning outcomes (Hasanein & Sobaih, 2023). For example, we compared ChatGPT response in Figure 12, to that generated by Gauth App, an AI calculator first launched in 2019 and touted as "the best homework helper" and downloadable in smartphones. In Figure 13, Gauth App generated an algorithmic solution lacking the underlying mathematical concepts and resulting in a faulty incomplete solution. Potentially, this phenomenon leads to an inability to adapt to non-standard problems or problems requiring creative solutions.

Adaptability of the AI tools like ChatGPT prompted by feedback and user interaction to refine its responses overtime (Frieder et al., 2023), requires the ability to determine what are the students learning in generative AI environments. With the capabilities associated with ChatGPT and other generative AI tools predicated on problem solving in gateway mathematics, it is not clear how these tools affect the acquisition of procedural and/or conceptual knowledge. While it has been demonstrated that conceptual knowledge for the expert impacts problem-solving; contrasting with problem solving largely being independent of concepts for the learner (Gerace, 2001), over relying on problem-solving aspects of ChatGPT and other generative AI tools presents a pedagogical challenge to acquisition of conceptual and procedural knowledge. A student's prior mathematical knowledge that is robust, accurate, and activated at the appropriate time provides a strong foundation for building new mathematical knowledge. To provide opportunities and environments that support authentic learning, educators will need pedagogical approaches that emphasis systematic utilization of generative AI tools to aid students to acquire, organize, align, and apply that knowledge.

## Discussion

This study combines the elements of students' perspectives of AI tools, ChatGPT capabilities on problem-solving different types of mathematics problems, and high impact practices in a contextualized learning scenario. The anticipated widespread use of generative AI tools invites instructors to design courses and assessments that take into account capabilities afforded by these AI tools, while preserving the integrity of the learning taking place. This necessitates looking at in context, our pedagogy, integrity of course content and assessment, and accessibility issues. As demonstrated by students' survey in this study, only a section of the students is aware of or using AI tools despite the influx of new and updated generative AI technologies, not to mention the broad public debate it has ignited. Educators on the other hand have mixed responses towards use of AI tools and by large still lag behind in reimagining teaching and assessments approaches that are beneficial to students in generative AI environment. Given the potential power and the rapid advances in AI tools, the ensuing underutilization of the tools and the cloud of uncertainty among educators, there is evidence of need for creating positive awareness around use of AI

tools in teaching and learning. ChatGPT has so far shown the highest utilization among students compared to other tools applicable in mathematics, primarily due to its accessibility, flexibility, and ease-of-use. The survey shows that students' use of ChatGPT and other generative AI tools is tentative, with the majority using it to check their work. The responsible use of AI is also hampered by lack of guidelines and policy, particularly academic integrity. Some students expressed concerns that AI tools can take away from actual learning through extraneous information, inaccurate information, or overreliance on it at the expense of learning with it. This points to the question "What are the students learning?" Which underscores the need for promoting AI tools exploration by integrating use of generative AI tools into curricula, wherein instructors and students partner to evaluate tools like ChatGPT and their output critically. The disparity in the usage of the generative AI tools among the students coupled with their attitudes and perception will affect their ability to utilize the tools for effective learning outcomes. An implementation plan needs to be in place to ensure generative AI tools usage aligns with educational goals, in such a way that essential activities that constitute learning remain with the student. Determining what can be offloaded to generative AI to ensure student success, with minimal disruption, is a natural step towards leveraging ChatGPT capabilities.

In applying ChatGPT to our Problem Sets questions, it is evident that the task of computation and simplification can be delegated to the AI tool. The scenario suggests the need to formulate questions that go beyond computation and connect concepts to procedures in meaningful ways. Additionally, providing questions as advance organizers for example; What knowledge do you need to solve this problem? What applications do you see for this concept? elicits interactions with ChatGPT that has potential to develop deeper conceptual understanding. The interactive nature of ChatGPT responses to procedural questions provides opportunity for multiple avenues to build conceptual understanding, depending on the quality of the prompts. The feedback from ChatGPT responses is key to helping students organize and apply knowledge in other contexts, as attested to in our student survey. Our study findings indicate that effective integration of AI tools at the classroom level requires educators to critically re-evaluate course objectives, class activities, assessment practices, question formulation, and the alignment of assignment objectives to ensure meaningful and ethical learning outcomes.

The ability of ChatGPT to create multiple examples or counterexamples on a concept while explaining solution process has been lauded by students and carries the promise of personalized instruction. As noted in NCTM's position on procedural fluency in Mathematics (NCTM, 2024), the interplay of conceptual understanding and procedural fluency requires at the disposal of the student, a repertoire of strategies. Beyond problem-solving, ChatGPT and other generative AI tools provide the opportunity to develop the ability to effectively identify and dissect problems, exploring their boundaries and creatively redefining them to create solution spaces (Acar, 2024).

ChatGPT is positively identified by students as providing such strategies and aiding in transfer of skills to solve similar problems. This capability is also demonstrated in the experimentation with ChatGPT on the Problem Sets we assigned in the sections. ChatGPT application to isolated problems provides responses that are with limited context and may not align with learner's level or meet learning goals. ChatGPT responses in mathematics while interactive have tended to be in standard structure and limited in human touch afforded by human tutors. In essence to realize the intended impact of ChatGPT at the instructional level, educators will need to design courses,

assignments, teaching and learning activities that consider capabilities afforded by ChatGPT, while anchored in sound pedagogy. The role of HIPs in learning mathematics (Shukla et al., 2024), coupled with the potential for ChatGPT to promote student learning, requires developing a framework that considers the student's needs and learning outcomes in generative AI environments such as ChatGPT.

This study has identified challenges associated with specific types of mathematics problems in ChatGPT environments, disparity in use of AI tools among students, limited coherence of what can productively be offloaded to ChatGPT and to achieve the desirable learning outcomes. As ChatGPT among other AI generative tools emerge as a revolutionary tool reshaping teaching and learning interactions, with information and content knowledge, there is need for an expert eye and intervention to examine its role and confronting the challenges that arise in an academic learning environment, where such tools are applied. Upon implementing the use of ChatGPT in class environments, the future direction of this work will be on leveraging the approach of flipped classroom (Shukla & McInnis, 2021), with the power of ChatGPT to improve student learning outcomes. There is potential to overcome some of the initial hurdles in mathematical capabilities of ChatGPT including word problems, graphs and sense-making with new iterations of ChatGPT including MathGPT. The extent to which the newer iterations of ChatGPT will impact learning outcomes remains out of the time scope of this study.

## Conclusion

This study highlights the significant potential, capabilities, and scope of usage of ChatGPT in teaching and learning environments. The disparity in usage, unsystematic utilization and implementation challenges of ChatGPT among students and faculty provides classroom-level considerations in leveraging the power of current generation of generative AI tools like ChatGPT. Besides the ethical, technical and pedagogical challenges to be addressed for ChatGPT's effective use in classroom environment, there is a need for content curation with High Impact Practices as guardrails to better incorporate ChatGPT in teaching and learning of foundational mathematics. To minimize the disruption in the implementation of ChatGPT and other generative AI, partnering with students allows for better alignment with their learning needs and outcomes. As the results of this study show, many students, faculty and institutions are yet to engage meaningfully with ChatGPT for structured education purposes. Incrementally embedding components of individualized learning and assessment strategies into the courses promotes students' engagement with ChatGPT for their learning.

This study provides a foundation for further work on implementation strategies of ChatGPT in classroom environment, and its integration into active teaching and learning activities, authentic assessments and scalable personalized learning. The onus on the educators is to determine how can the capabilities of ChatGPT in teaching and learning integrate and scale up to the level of teaching and learning activities, course content and structure, assessment and curriculum while maintaining integrity and ensuring ease of use and access of these generative AI-technology. Further, the responsibility of educators extends to non-superficial addressing of limitations associated with AI tools to include overreliance, taking away from foundational knowledge, reliability of ChatGPT outputs and generating of problem-solving tasks that require deeper cognitive engagement.

## Recommendations

Our recommendations point to mitigating steps taken in creating an environment where ChatGPT is applicable as a teaching and learning tool in meaningful ways. Creating positive awareness by introducing ChatGPT in supportive ways that allow students to learn with ChatGPT and not learn from it. Students' responses associated learning from AI tools with complacency, comfortable safety net, overreliance, and bypassing authentic feedback about one's progress. The awareness is also enhanced by allowing students to experiment with ChatGPT in low-stakes or no-stakes tasks before expecting them to use it for graded assignments and learning activities. The learning process requires the faculty and student to learn from each other, clarify and determine what can be off-loaded to ChatGPT through instructor guidance and experimentation while ensuring that essential activities that constitute learning, for example problem-solving, critical analysis, and reflection remain with the student. To encourage exploration beyond the classroom, and students investing significant amounts of time and effort over extended periods of time; we recommend giving students guided opportunity to complete contextualized course projects using ChatGPT. These explorations allow students to control their own learning journey by asking deeper questions and generating and testing ideas in collaborative assignments and projects.

Central to the implementation and the leveraging of ChatGPT in learning environments is the need for educators to curate and contextualize content to motivate students to apply ChatGPT outputs to local and real-world problems so that learning is relevant and meaningful. Organizing and making connections between pieces of knowledge generated through ChatGPT to a coherent body of knowledge that students are better able to retrieve and apply effectively are skills that need to be developed. As evidenced, refined and precise prompts help ChatGPT generate better and useful output, thus practicing precise prompting is essential to teach students how to write clear learning questions as prompts and engage creatively. Appropriate use of AI tools holds immense potential and promise in education considering the tools' generative capabilities and ability to enhance teaching and learning.

In harnessing the potential and realizing the promise in the AI environments, educators must rethink and reshape the ways in which teaching and learning is designed and experienced. The pervasive influence of artificial intelligence will require educators to contend with the fact that teaching and learning can no longer be confined to the transmission of established knowledge; rather, it must foster adaptability, critical and ethical reasoning, creativity, and the capacity for lifelong learning. The challenges of designing learning environments suited to uncertain and rapidly evolving futures of generative AI tools, positions the educators to reconceptualize learning activities and assessments not as static processes but as dynamic ones that prepare students to learn alongside intelligent systems while navigating the complexities of their academic journey.

## Statements and Declarations

**Conflict of Interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Artificial Intelligence-Supported English as a Foreign Language Learning: A Narrative Review of Personalisation, Feedback, Engagement and Pedagogical Collaboration

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### Abstract

The rapid advancement of artificial intelligence (AI) has substantially reshaped educational practices substantially, particularly within English as a Foreign Language (EFL) learning contexts. This narrative review synthesises peer-reviewed research published between 2020 and 2025 to examine how AI supports EFL learners across six key dimensions: learning personalisation and adaptation; assessment and feedback; student engagement and motivation; study support and skills development; teacher–student–AI pedagogical collaboration; and critical challenges and ethical considerations. Drawing on recent high-quality peer-reviewed journal articles, the review employs a thematic synthesis approach to integrate diverse theoretical perspectives, empirical evidence and pedagogical insights. The findings indicate that AI-supported technologies can enhance EFL learning by enabling adaptive instruction, delivering timely and formative feedback, fostering learner engagement and motivation, and supporting self-regulated learning and language skill development. Simultaneously, the review underscores the importance of human-centric pedagogical design, highlighting that AI is most effective when positioned as a complement to, rather than a substitute for, teacher expertise and learner agency. Key challenges – including academic integrity, ethical concerns, data privacy, algorithmic bias, over-reliance on technology and inequitable access – also are identified as significant constraints on effective AI integration. Overall, this review offers an integrative and pedagogically grounded account of AI-supported EFL learning and poses implications for instructional practice, teacher education and future research aimed at promoting responsible, equitable and sustainable uses of AI in language education.

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## Introduction

The increased use of artificial intelligence (AI) in education globally has changed how English is taught as a foreign language dramatically. It has generated new ways for teachers and students to use technology to help each other learn the language, as well as provided teaching support (Al-Bogami & Alahmadi, 2025). Additionally, because AI can analyse a large amount of data and create a programme for each student that meets their specific needs, it allows both teachers and students to develop much more successful and tailor-made teaching and learning experiences than they could have developed otherwise (Al-Bogami & Alahmadi, 2025; Merino-Campos, 2025). The improvements to educational results that have been achieved through better access to personalised learning opportunities and immediate feedback from AI use and the resulting learning have led to the need for further evaluation of AI's ongoing development and its impact on English as a Foreign Language (EFL) educational context (Al-Bogami & Alahmadi, 2025).

AI advances in English language learning (ELL) have increased how an individual's ELL experience can be enhanced in many ways. Through AI, personalisation and adaptation of learning experiences can be developed and customised to a learner's profile and experience in the context of learning materials (Merino-Campos, 2025). Learners also can enhance their motivation and engagement in the learning experience by being able to access learning environments aligned with their interests (Liu et al., 2025). When it comes to assessments, AI enables changes in how traditional assessment practices are conducted, providing an automated mechanism to assess, score and respond to learner progress in real time through provision of formative evaluations, ultimately accelerating the learner's language development process (Al-Bogami & Alahmadi, 2025; Zou et al., 2025). Additionally, AI-enhanced environments support and foster student engagement and motivation through interactive and personalised ELL experiences (Dinh, 2025; Schei et al., 2024). As learners develop their academic vocabulary through incorporation of cognitive support (Al-Obaydi et al., 2025; Dinh, 2025), AI enhances students' ability to study independently. Development of these multiple dimensions of learner experience through AI also establishes a new teacher–student–AI collaboration paradigm that has led to adjustments in the teacher's role and the relationship between the teacher and learner in leveraging AI within their instructional practices (Al-Bogami & Alahmadi, 2025; Li et al., 2024). Nevertheless, as noted in extant studies, ethical dilemmas, privacy and data protection, algorithmic bias and a systematic approach to preparing teachers for integration of AI need to be considered to ensure successful implementation (Eden et al., 2024; Kyambade et al., 2025; Merino-Campos, 2025).

While extant research on AI in education has proliferated, the literature on AI-supported EFL learning is highly fragmented. Researchers have not yet explored how learners view generative AI (particularly in light of recent technological developments) in the context of higher education and EFL learning, as evidenced by Yan et al. (2024). Significant discrepancies exist in terms of geographical location, i.e., to date, most extant research has been completed in East Asia, with very little generated in South America, Middle Eastern regions and other areas, thereby limiting researchers' ability to generalise their findings across multiple educational contexts (Alghasab, 2025; Nelson et al., 2025; Schei et al., 2024). Furthermore, additional systematic analysis of AI research is needed within higher education, specifically in the area of EFL teacher training and curriculum design, to enable

researchers to better identify research trends, locate literature gaps and anticipate areas for future research (Akhmadieva et al., 2024). Furthermore, very little empirical research currently exists to help understand how students' motivation to utilise AI tools is derived from perceived usefulness, intrinsic value and expected success when completing language-related activities (e.g., translation) (Dinh et al., 2025). All of this illustrates how fragmented the literature on AI in education is, currently comprising an array of methodologies and varying levels of international representation. Ethical considerations are an additional challenge due to concerns over the quality of AI-generated material, AI's lack of sensitivity towards pragmatic usage and privacy issues, among many other concerns (Alghasab, 2025). Additionally, issues associated with academic integrity, including concerns over legitimate authorship and plagiarism, are another significant and unaddressed area of scrutiny (Alghasab, 2025; Buele & Llerena-Aguirre, 2025; Nelson et al., 2025).

Technological advances are being made rapidly, and many different findings have been reported. A complete cultural overview of the AI field and its effects on EFL education is very important and timely. Additionally, while methodological rigor can be added to systematic review methodologies, the restrictive criteria may limit how much breadth and rapidly evolving changes to new discoveries and methods in the AI field in EFL can be accessible from systematic reviews. Narrative reviews can aggregate broader groups of evidence and reveal emerging themes from varied areas of research that possibly would not be easily accessible through a narrower scope (Bond et al., 2024). Additionally, a narrative overview of the research on how AI influences EFL education allows researchers to observe trends, develop patterns of thought and identify similar research findings that possibly could help researchers, policymakers and practitioners identify what does and does not work regarding education using AI in EFL (Labadze et al., 2023). Narrative synthesis helps map the AI field in higher education due to the ability to profile a wide range of empirical and conceptual contributions (Bond et al., 2024).

This narrative review aims to bring together peer-reviewed literature that has been published between 2020 and 2025 regarding how AI has impacted EFL learning to elicit a comprehensive understanding of AI's relationship to EFL learning. The main areas of emphasis for this narrative review include how AI facilitates creation of personalised or flexible learning experiences for EFL learners; AI's effectiveness in delivering assessment and constructive feedback; how AI can be leveraged to increase EFL learners' motivation and engagement; use of AI as a means of helping EFL learners acquire effective study skill strategies; identifying key ethical issues associated with AI and academic integrity; bias and data privacy issues associated with the use of AI with EFL learners; and discussing how teachers, EFL learners and AI may work together in new and innovative ways.

This literature review contributes greatly to the literature on AI and EFL by providing (1) a comprehensive overview of the application of current AI technology in EFL for researchers and educators (Bond et al., 2024); (2) a summary of major gaps in current empirical research and what future research should focus on, thereby helping to develop future research agendas (Bond et al., 2024); and (3) a more comprehensive perspective on both the benefits and challenges to educators from AI integration into EFL courses by informing pedagogical practices and policy formulation (Bond et al., 2024). Generally, this review aimed to help facilitate effective and responsible application of AI in EFL instructional practices to create an equitable, ethical and rewarding language learning experience for all students.

## Methodology

### Review Design and Rationale

Through a narrative review methodology, this article examines various extant studies on AI and its influence on students' EFL learning. Due to the wide range of pedagogy, research-based evidence and education contexts represented in the literature on AI-assisted EFL learning, a systematic review was deemed inappropriate. Instead, the authors opted to conduct a thematic and theoretical synthesis of extant AI-supported EFL learning studies. This synthesis identified both commonalities and discrepancies among various AI-supported EFL studies, thereby including identification of basic factors that may underpin EFL by AI, as well as tensions and emerging themes. By reviewing the data in this manner, the authors have provided an overview of a potentially broad theme related to AI's effects on EFL education that researchers, policymakers and educators alike can utilise (Bond et al., 2024; Labadze et al., 2023).

### Literature Search Strategy

The literature search utilised substantial databases commonly employed within the realm of educational technology and applied linguistics research (e.g., Web of Science and Scopus). Searches were conducted to identify peer-reviewed articles published from 2020 to 2025 to identify new developments regarding AI use in supporting EFL learners. The search terms incorporated aspects of AI, together with general EFL or ELL, as well as student support (SS) and learning processes (LPs). Searches of these databases were conducted in succession, with reference lists of relevant studies reviewed to locate additional studies that aligned with the defined inclusion criteria below.

### Inclusion and Exclusion Criteria

Studies were included in the review if they:

- were peer-reviewed journal articles
- focussed on AI-supported EFL or ELL
- examined student-related outcomes or LPs
- addressed at least one of the review's focal themes

Studies were excluded if they:

- were conference papers, book chapters, reports or opinion pieces
- focussed exclusively on technical AI development without pedagogical implications
- addressed AI in education without specific relevance to EFL or ELL contexts

Following these criteria, the thematic synthesis utilised approximately 27 peer-reviewed journal articles that focussed on AI-assisted learning in EFL.

### Analytical Thematic Synthesis Approach

The use of analytical thematic synthesis facilitates creation of frameworks for analysis/study of research articles

by examining the articles' themes and types (or methods) of learner support developed or used in the articles, as well as grouping all the articles by their themes and types of learner support through code identification and grouping (or grouping by codes). The synthesis also identifies concepts and relationships between studies and articles by combining ideas/concepts from studies with ideas.

## Results

### AI-Supported Learning Personalisation and Adaptation in EFL

AI has become and continues to be a key component of how EFL is taught. AI allows EFL educators to create and provide learners with access to personalised and adaptive learning experiences based on each learner's needs and preferences, as well as their own unique experiences while acquiring EFL. Introducing adaptive learning paradigms with AI enables EFL education to move away from a traditional 'one size fits all' approach and towards a more responsive model that meets each learner's individual needs, as well as their time-dependent patterns of engagement with learning through use of ongoing analyses of performance data. In addition, the aforementioned reading of student data gives EFL teachers the ability to provide information about how best to formulate specific learning paths for each student to achieve the most effective learning outcomes possible (Gligorea et al., 2023). According to Gligorea et al. (2023), AI-based personalisation in EFL offers considerable advantages because it provides higher-quality learning results compared with other methods. The results from this study demonstrate that using AI systems produces an individualised learning experience for students. Efficient sequencing of materials within the AI system facilitates increased learner participation and performance, as seen through measurements of language proficiency and assessment scores. AI systems also continue to analyse learner data to provide appropriate instructional materials and targeted intervention at the correct time during the LP (Mustafa et al., 2024). AI systems' ability to adapt to learners' individual needs continually is particularly valuable in EFL contexts, in which learners differ significantly in their language backgrounds, proficiency levels and learning preferences. AI language learning tools can motivate learners by supporting their goals, interests and current abilities (Liu et al., 2025). An example of this motivation is the use of tools to create authentic communication scenarios and contextualised materials that enable learners to visualise and build their ideal second language selves (Liu et al., 2025).

AI systems adaptively calibrate task difficulty and linguistic complexity based on learners' ongoing performance so that task challenges continue to align with learners' zones of proximal development, thereby enabling sustained engagement, as well as incremental progress and long-term mastery of language skills (Liu et al., 2025). AI systems not only provide learners with the basic content they need to develop language skills, but also analyse vast amounts of educational resources to recommend supplemental materials and create personalised learning content. Consequently, EFL learners benefit by having timely, relevant and meaningful instructional content made available to them, thereby improving the efficacy of their learning experience overall (Gligorea et al., 2023). Notable examples of such AI-driven systems include Duolingo – which retains learners' motivation using intelligent tutoring systems, adaptive algorithms and game-like elements (Stošić et al., 2025) – and Coursera, which personalises learners' learning pathways with adaptive course recommendations tailored to learners' interests, prior knowledge and learning goals (Stošić et al., 2025). As such, 'intelligent learning environments',

which integrate expert systems with computational and/or mathematical models, provide very efficient and highly personalised learning experiences (Gligorea et al., 2023).

AI-enabled personalisation can help educators in many ways, particularly those teaching large or heterogeneous classes in which it is difficult to provide individualised support for every student (Nabhani et al., 2025). By leveraging AI tools, educators can create more time for higher-order instructional and facilitative roles that they need to play by streamlining tasks such as monitoring and providing feedback on student performance (Nabhani et al., 2025). Significant challenges are associated with implementation and use of AI-enhanced personalisation, including algorithmic bias, issues related to student and teacher data security, and technical difficulties involved in designing and building sophisticated AI-based systems (Gligorea et al., 2023; Merino-Campos, 2025). Consequently, there has been a growing need to develop effective training programmes for teachers so that they can utilise AI tools in a responsible, ethical and pedagogically sound manner in their EFL classrooms (Merino-Campos, 2025). AI-enhanced personalisation and flexibility likely will remain an exciting and evolving field of study and practice in EFL.

### **AI-Based Assessment and Feedback in EFL Learning**

AI is poised to transform existing instructional methodologies in the EFL discipline by providing new forms of dynamic, efficient and personalised assessment. Rather than applying static assessment methods, such as oral or written tests, AI technology allows for providing immediate feedback to learners based on their performance, as well as guiding them towards developing an individualised learning pathway. Most AI-based systems also provide cognitive scaffolding to learners, aiding their comprehension and language development, including grammar and reading comprehension (Al-Bogami & Alahmadi, 2025; Dinh, 2025). Additionally, by automating many assessment aspects, including grading, AI systems can decrease the administrative workload placed on instructors substantially, while providing data-based evidence of student performance and achievement trends (Al-Bogami & Alahmadi, 2025).

In EFL contexts, AI-supported assessment involves using several different technology tools and applications, particularly to assess speaking proficiency. Several companies offer automated score and feedback based on speech recognition technology – including platforms such as Duolingo, Liulishuo IELTS and EAP Talk – all of which allow learners to receive continuous feedback on their spoken output and make adjustments as needed to improve their oral proficiency (Zou et al., 2025). Automatic Speech Recognition (ASR) technology provides users with visual feedback on their spoken output and highlights any areas where improvement is needed, making error detection and correction quicker and easier. Using these tools will be supported by data, as well as demonstrated by using empirical evidence in relation to fluency, lexical complexity, grammatical accuracy and discourse coherence (Zou et al., 2025).

The benefits of using AI tools to write assessments include providing full and ongoing support for both formative and summative assessments. For example, Automated Essay Scoring (AES) typically are used during large-scale summative assessments. Various online tools that provide Automated Writing Evaluation (AWE) and/or

Automated Corrective Feedback (ACF) are at the writer's disposal (e.g., Grammarly, Criterion, Google Translate, QuillBot and Wordtune) (Alghasab, 2025; Gardner et al., 2021). Using AI systems to grade short-answer responses has shown promise as well, as AI systems grade responses with consistency and impartiality, thereby positively impacting student performance on assessments (Grassini, 2023). To provide learners with ongoing targeted formative feedback to encourage skill development and facilitate revisions, the data obtained from learners' writing is collected and analysed systematically (Gardner et al., 2021).

AI's future in assessing EFL holds promise, but also many limitations. While AI potentially can interpret the meaning of 'standard' vocabulary used in foreign language tests, it often struggles with more subtle meanings found in idiomatic expressions, cultural references and other more abstract meanings in text. As would be expected, this is particularly true of translation tasks, in which human assessors always are needed to verify or confirm translated texts' quality (Dinh, 2025). Therefore, AI-generated translations' inconsistency can present a challenge to EFL test results' reliability (Dinh, 2025). Additionally, the rise of AI-supported writing tools offers increasing opportunities to violate academic integrity and represents the risk of plagiarising others' work and misrepresenting learners' actual language skills (Liang et al., 2025; Nelson et al., 2025). If learners continue to rely heavily on AI-generated feedback, over-reliance on AI and cognitive offloading may develop, which can hinder development of critical thinking and independent writing skills (Alghasab, 2025). Finally, feedback generated by AI may not always be concise and could be overly repetitive or inaccurate, and automated scoring systems may have difficulty scoring creative and higher-level writing (Alghasab, 2025; Gardner et al., 2021).

Moreover, in terms of ethical issues relating to AI in the EFL assessment area, protecting student data can be viewed as an ethical issue due to concerns regarding algorithmic discrimination and lack of information on how the automatic evaluation model was generated (Eden et al., 2024; Kyambade et al., 2025). AI systems have been demonstrated to produce better results on standardised test assessments than on more complex (i.e., university-level) assessments because they are trained using available datasets (Grassini, 2023). When it comes to gauging more complex forms of assessment, humans still must be involved to ensure that valid and fair assessments occur (Grassini, 2023). Furthermore, increasing evidence has been demonstrating that AI detection systems can identify AI-generated written work with greater accuracy than humans can. This situation poses a challenge to current assessment practices and leads to questions about current methods being used to teach writing to students (Liang et al., 2025). Based on this evidence, it appears that building digital literacy and re-evaluating existing procedures for assessment to promote responsible use of AI and protect the EFL learning environment's integrity are crucially important (Liang et al., 2025).

### **AI-Supported Student Engagement and Motivation in EFL Contexts**

Currently, many EFL students use AI as an integral component of their English language acquisition process, and such use of AI provides opportunities to enhance student engagement in this challenging field through technology-enhanced environments, as well as create more motivational ways to learn the English language. AI can create opportunities to create a dynamic, personalised, stimulating and enjoyable learning environment through technology-enhancements that can improve student motivation and interest in language learning dramatically (Liu

et al., 2025). By providing learners with the tools they need to create an individualised experience, thereby promoting competence and providing immediate feedback (in a supportive manner), AI can forge a pathway for maintaining motivation throughout the entire language acquisition journey (Liu et al., 2025).

AI uses the personalisation of learning experience and motivation to engage learners by developing motivational, personalising and engaging learning experiences. AI-based language learning products enable learners to create personalisation and development plans tailored to each learner's goals, interests and abilities to envision themselves as successful users of a foreign language (Liu et al., 2025). AI's adaptive capabilities support learning and ensure that learners are being challenged constantly within their Zone of Proximal Development (ZPD), thereby giving them the opportunity to attain success and continuously pushing them to achieve (Liu et al., 2025). Extant studies have found that learners participating in AI-enhanced informal digital learning of English have reported increased self-efficacy in their ability to acquire and learn a foreign language, enjoy learning and using a foreign language, and increase their confidence and motivation in practising language skills (Liu et al., 2025). Additionally, feedback from success provided through AI use increases learners' self-efficacy, thereby encouraging them to continue their second-language learning (Liu et al., 2025).

AI applications (particularly chatbots/conversational agents) exert significant influence on learners' motivation. A common issue with traditional learning environments is that learners do not always have access to expert speakers or required learning materials. Online AI chatbots offer learners effective, interactive models of expert speakers to better meet these needs (Yan et al., 2024). The learner's perception of the ease of using an AI tool and its ability to provide structured responses with appropriate explanations contributes significantly to learner motivation and engagement (Schei et al., 2024). For example, ChatGPT has demonstrated improved writing performance and increased learner motivation (relative to traditional instruction) (Liu et al., 2025). ChatGPT, as a learning tool for vocabulary development, also has produced higher motivation for learners than traditional methods of learning vocabulary because ChatGPT provides them with a fun and attentive environment for their learning needs (Liu et al., 2025). In addition, through development of 'ideal L2 selves' and promotion of foreign language enjoyment, AI-supported informal digital learning of English can support learner motivation (Liu et al., 2025).

AI use in motivating and engaging learners depends largely on individual and contextual factors surrounding these learners. One way in which students will be motivated to use AI tools is through their perceptions of the tools' usefulness, intrinsic value and probability of success with specific activities, such as a translation assignment (Dinh, 2025). While AI chatbots are being adopted for increasing use in language learning, teachers remain important. According to self-determination theory, using AI tools can help learners by offering support for their needs for autonomy and competence through personalised learning and real-time feedback, but teachers are critical in meeting learners' larger psychological needs, providing instructional support and situating AI use within a meaningful instructional context (Li et al., 2024; Liu et al., 2025). Therefore, successful integration of AI into EFL classrooms must include a thoughtful combination of affordances offered by technological advances and pedagogical expertise to support maximum engagement and motivation for students.

## AI for Study Support and Skills Development in EFL

AI provides transformative study support and skill development for EFL students. For example, AI tools (e.g., software programs, chatbots) act as cognitive scaffolds during the language acquisition and academic/linguistic skills development stages (Alghasab, 2025). These tools enable the learner to progress from the foundational first stage through all stages to development of the higher-order cognitive processes necessary for successful communication of ideas when studying independently.

AI supports numerous aspects of the writing process, including production and editing of written works, in addition to a variety of other areas of written production (Perkins, 2023). Many digital writing assistant products use AI to provide users with more than just basic error correction, i.e., they can help identify structural and linguistic problems, as well as provide users with suggestions on how to improve clarity and coherence in writing, generate ideas, expand vocabulary and verify accuracy in their writing (Alghasab, 2025). As a result, AI tools provide a continually supportive environment throughout various stages of the writing process, allowing for development and articulation of ideas in a clearer and more precise manner in English (Alghasab, 2025). In addition, as long as AI tools are integrated properly and ethically into academic writing policies, such tools' availability for continuous/formative support remains unquestionable (Perkins, 2023).

AI dramatically has changed how language learners seek help to improve their speaking skills, mainly through tests of automated systems that use technology that recognises speech and analyses scores in real time, with scoring and measuring in subcategories such as pronunciation, fluency level, vocabulary complexity, grammar accuracy and coherence level (Zou et al., 2025). Use of these systems can provide immediate feedback to learners so they can continue to develop as they receive specific suggestions on how to improve their spoken performance (Zou et al., 2025). ASR technology offers additional methods of visual feedback on produced speech by providing the learner with ways to recognise and make corrections to produced speech as readily as possible. Learners can speed up their own language development and increase their confidence when communicating with these tools. AI systems' flexibility and multimodal capabilities enable a highly effective and immersive contextual learning level (Zou et al., 2025).

Conversational AI enables improved vocabulary and grammar development through Intelligent Tutoring Systems' ability to provide individualised feedback and personalised instruction. This immediately resulted in identifiable gains in reading and grammar for EFL students (Al-Bogami & Alahmadi, 2025). Many generative AI resources, such as ChatGPT, are more effective at vocabulary development than traditional methods, as these resources learn and adjust to each student's input on the fly and provide an extensive context for vocabulary-learning opportunities (Abdelhalim & Alsehibany, 2025). These tools also encourage retention of vocabulary, increased student autonomy and motivation because of their personal and immersive way of engaging students in language practice through an interactive platform, resulting in more in-depth cognitive engagement during language practice (Abdelhalim & Alsehibany, 2025). With this in mind, ChatGPT has become prominent as a tool for immediate, individualised feedback and incredible language learning experiences.

Beyond discrete language skills, AI also helps learners develop independent learning capacities and support broader academic endeavours. In particular, AI-mediated second language learning tools allow for learner-centred personalised pathways and instant feedback that enhance learners' perceptions of autonomy and competence, thereby motivating learners intrinsically and producing positive emotional states related to learning (Liu et al., 2025). Furthermore, immediate error detection and corrective feedback promote effective learning and positively affect how learners perceive themselves (Liu et al., 2025). AI can empower educators to provide students with AI-based instructional activities designed to encourage students to achieve their target second-language identities (e.g., simulating professional interactions or utilising task-based activities) and instil a sense of self-efficacy in their English-language LPs long after they have left the classroom (Liu et al., 2025). AI use also helps learners develop self-regulatory skills, such as critical thinking, listening comprehension and grammar knowledge (Alghasab, 2025). By providing such support to EFL learners, educators can provide them with increased control over their LPs, thereby creating autonomous learners who persistently engage in the process of learning a second language (Abdelhalim & Alsehbiany, 2025).

### **Teacher–Student–AI Pedagogical Collaboration**

The rise of AI in the EFL market means that educators need to rethink their approaches to working together, as well as ways in which to build more meaningful relationships with their learners through the use of technology. As this ecosystem develops at such an extraordinary pace, educators must redefine their role and use AI as a co-collaborator to provide new opportunities for success for their students (Al-Bogami & Alahmadi, 2025; Li et al., 2024). In addition, as AI technologies become an integral part of learning environments, collaborations between educators and students likely will evolve into new models. Moreover, students often are viewed as cocreators with AI, but it is through the AI-learner relationship that it has been demonstrated to provide students with more potential to take control of and empower themselves to be better-informed about how and when to learn (Al-Bogami & Alahmadi, 2025).

Teachers play an increasingly complex and involved role in AI-based EFL learning, rather than a diminishing one. Instead of removing teachers from the equation, introducing AI into EFL classrooms creates additional roles for EFL teachers to play as instructional design experts, facilitators, assessors and resource developers (Li et al., 2024). For example, teachers as instructional design experts develop objectives for student learning and create assignments that cohere with these objectives while also taking advantage of AI-based tools (e.g., designing prompts to integrate into learning tasks using AI-based chatbots) (Li et al., 2024). Teachers as facilitators support learners' use of AI-based tools during learning, set or clarify learning objectives, create opportunities for learners to engage actively in their learning environments and supervise each student's progress during the student's engagement with AI-based activities (Li et al., 2024). Teachers also take on the role of resource developers by adapting, curating and refining instructional materials created, adapted or used by learners (e.g., editing AI-produced writing to address linguistic/strategic resources) to correspond with individual learners' proficiency levels and instructional needs (Li et al., 2024). Additionally, teachers will continue to play a central role in assessing learners' linguistic performance after they have completed an AI-supported task, as well as providing feedback that supports learners' subsequent learning (Li et al., 2024).

Students' AI use also exerts a strong influence on how they will work together. By using metaphors to explain how they view AI, particularly in terms of generative abilities, learners tend to compare AI to an 'English teacher' or 'helper', signifying the learning potential that these resources can provide to students (Yan et al., 2024). Therefore, teachers may spend more time preparing actual teaching components and less time grading and interacting with students (Yan et al., 2024). AI also is used to tutor students in their language skills or create opportunities for students to become independent learners through real-time feedback on their writing, particularly in large classes, where teachers cannot provide each student with the same level of individualised attention as in smaller classes (Woo et al., 2025). In addition, AI is used to enhance learners' oral language capabilities by helping increase their willingness to speak and engage in oral communication (Zou et al., 2025).

While the advantages of collaboration between teachers and students and AI have been identified, obstacles to effective collaboration remain. For example, AI chatbots have advanced conversational skills, but they cannot provide the emotional support, interpersonal sensitivity and nonverbal communication that human teachers can (Li et al., 2024; Zou et al., 2025). Additionally, AI systems likely will encounter difficulties comprehending nuanced language, cultural references and deeper semantic interpretations, which can be validated only through human judgement for their accuracy and pedagogical appropriateness (Dinh, 2025). In terms of self-determination theory, AI tools can help meet learners' autonomy and competence needs through personalised learning and immediate feedback; however, teachers help satisfy learners' need for relatedness and conceptualise the guidance that AI can offer (Li et al., 2024). Moreover, teachers will establish an ethical framework for using AI tools, emphasising academic integrity, critical evaluation of AI-generated outputs and responsible engagement to mitigate the risk of plagiarism and uncritically accept generated content (Abdelhalim & Alsehibany, 2025; Al-Obaydi et al., 2025).

Finally, only teachers who implement either pedagogically sound knowledge or have a critical understanding of how AI technology can help satisfy students' language acquisition needs will establish successful pedagogical partnerships in the AI-enhanced EFL experience (Abdelhalim & Alsehibany, 2025). Teachers should demonstrate how to develop effective prompts and create opportunities for educators and students to conduct thoughtful discussions on AI outputs, as well as demonstrate how a teacher's role is one of facilitation between students and technology. This collaboration's ultimate goal is to create a collaborative education system in which AI does repetitive or fully automated tasks for the teacher (e.g., providing timely information about a student's performance on tasks or reinforcing content) while allowing the teacher to concentrate on meeting each student's unique academic, relational, emotional and developmental needs (Liang et al., 2025). AI integration supports traditional and individualised learning methods that facilitate human-to-human educational partnerships and encourage teachers to adopt a classroom model that enhances, rather than diminishes, the human-centric nature of language learning (Al-Obaydi et al., 2025).

### **Critical Challenges and Considerations in AI-Supported EFL Learning**

While AI holds great promise as a means of revolutionising EFL, many challenges accompany this new opportunity. Many different types of challenges arise from the following areas: ethical, pedagogical, technical,

structural (e.g., academic integrity challenges) and equity-related (e.g., data privacy, fairness in algorithms, reliability and accessibility).

Academic integrity and authentic authorship have become some of the biggest challenges that educators and academics face. As generative AI tools such as ChatGPT have proliferated, there has been an increase in concerns regarding the potential for academic dishonesty related to AI – a phenomenon known as ‘AI-giarism’ (Nelson et al., 2025), in which students pass off AI-generated work as their own (Nelson et al., 2025). New AI advances are creating further confusion between the idea of a ‘human’ author and the idea of an ‘AI’ author, making it even more difficult for those within educational institutions to know how to identify what has been authored legitimately (Nelson et al., 2025). Current extant research has indicated increasing concerns that AI has led to greater levels of academic dishonesty, so educators and educational institutions must foster an environment that promotes a sense of student responsibility and ethics surrounding learning, as well as provide meaningful ways to address academic dishonesty (Nelson et al., 2025). Furthermore, because AI has made it easier than ever for students to generate academic texts, students are becoming increasingly reliant on AI to complete their writing assignments – a trend that has negatively impacted their ideas on analytical reasoning and their ability to think critically (Alghasab, 2025).

Another major concern regarding data privacy and security stems from the practice of collecting, processing and storing user data as part of the AI system. Due to this, concern has been rising over how learners’ personal information will be shared, stored and protected (Kelley & Wenzel, 2025). In addition to seeking users’ consent to use their data, many platforms do not clearly state how their AI model uses data collected from learners. Therefore, there is a risk to users, whose sensitive information could be revealed accidentally because of ambiguity concerning how AI models utilise data (Grassini, 2023). Compounding these worries further are fears that social interaction between learners, parents and teachers will diminish, along with privacy risks from personal data being shared with AI systems across educational environments (Alghasab, 2025a, 2025b).

AI-supported EFL learning also is impacted by algorithmic bias and fairness, creating ethically complex scenarios. AI systems are built using historical databases with built-in bias (Eden et al., 2024; Stošić et al., 2025); therefore, they may replicate or amplify current inequalities within society and create inequitable outcomes for learners from marginalised groups. For example, training data used to build AIs may contain mostly one particular linguistic norm or cultural context, leading AIs to generate content based on their training and incorrectly categorising non-native writers’ work as being AI-generated, which can elicit accusations of academic misconduct (Farrelly & Baker, 2023; Li et al., 2025). Resolving these issues will require improvements in transparency levels within the AI design stage, ongoing evaluations of algorithms’ decision-making processes and use of fairness principles within the design to monitor AI systems (Eden et al., 2024).

Along with the aforementioned points, technical limitations and related concerns about reliability create further difficulties on a practical level. Like any system, AI systems can produce erroneous, misleading or inaccurate outputs. For example, a system can produce such faulty outputs when it moves outside of the parameters set by its training information (Alghasab, 2025). The AI system’s probabilistic model inhibits its ability to use certain

forms of language effectively, such as idioms, and communicate in a culturally appropriate manner. When the technology's limitations impact these abilities, learners and educators are presented with various misunderstandings or lower-quality instruction, contributing to reduced understanding among learners. Other technological applications also maintain certain limitations regarding (a) accuracy related to speech recognition, (b) tasks' authenticity and (c) interaction quality. When these limitations impact interactions, learners may have limited opportunities for meaningful or effective learning (Li et al., 2024; Lo & Hew, 2023). Variability in the quality of AI-generated translations decreases AI-based systems' reliability for a wide variety of foreign language learning tasks (Dinh, 2025).

To implement AI responsibly in EFL education, issues of equitable access to AI tools and teacher preparedness for using these tools need to be addressed (Kelley & Wenzel, 2025). Without equal access to AI-powered resources in the classroom, existing inequities in education will worsen (Kelley & Wenzel, 2025). Furthermore, many teachers do not possess adequate AI and digital literacy skills to create and deliver AI-generated learning experiences successfully, greatly restricting their ability to support students with AI-delivered learning experiences (i.e., Çelisk & et al., 2022; Mustafa et al., 2024). For teachers to integrate AI into their classrooms effectively, they need to receive ongoing professional development, which teaches them the knowledge and skills needed to understand AI's positives and negatives, assess AI-created learning resources and help students utilise AI responsibly and ethically (i.e., Abdelhalim & Alsehibany, 2025; Alghasab, 2025; Al-Obaydi et al., 2025). Additionally, without the right type of instructional direction, students may rely overly on AI, thereby hindering development of their critical-thinking skills, creativity and independent learning skills (Li et al., 2024). Successful resolution of the issues presented will result in equitable, ethical and advantageous AI contributions to EFL instructional practice.

## **Implications and Future Research Directions**

Integration of more AI tools into EFL will influence how lessons are taught and lead to many more research streams. Although this narrative review provides an overview of how AI can change the language learning landscape, it draws attention to some areas that still need further empirical studies to enable responsible, ethical and practical application of AI in the EFL classroom.

The importance of developing pedagogical approaches that keep pace with the rapidly evolving nature of technology and continuous teacher professional development highlights the need for teachers to redefine their role from just being a teacher to also being a designer of learning activities, facilitator of learning, assessor of student achievement and provider of resources (Li et al., 2024). Future studies should explore how to create effective teacher-training models that increase their knowledge and abilities in AI and digital literacy, as well as allow them to incorporate use of AI tools in their classrooms confidently to create pedagogically sound activities for students and critically examine AI results. Additionally, this line of inquiry should include developing ethical frameworks for AI use in education, specifically in the area of academic integrity, and developing students who engage responsibly and reflectively with AI technology (Abdelhalim & Alsehibany, 2025; Al-Obaydi et al., 2025).

The topic of academic integrity and ethics is an additional area of future research that should be considered. Due to the number of writing tools available, it is now very easy for anyone to create learning resources using AI software, which raises many questions regarding ‘AI-giarism’ – namely, how students will risk losing critical thinking skills and writing abilities if they are overly dependent on these tools (Alghasab, 2025; Nelson et al., 2025), as well as ways to establish AI detection tools, create institutional guidelines for ethical behaviour regarding AI and develop pedagogical techniques that support authentic authorship and meaningful learning. Longitudinal studies also should focus on long-term impacts from using AI on developmental processes in cognitive functioning, language proficiency and teachers and students’ academic independence.

Future studies also will focus on topics tied to algorithmic bias and equitable access to AI resources, as these two areas are also critical to research moving forward. Algorithmic bias and equitable access can be viewed as the impact that existing biases within a dataset on a wide range of consumers will make on a learner from a diverse or marginalised environmental perspective (Eden et al., 2024; Li et al., 2025). For future researchers to address these concerns adequately, a concerted effort is needed to develop inclusive, bias-free systems that provide equitable access to AI resources for all students within schools and across all geographic regions by addressing issues related to the digital divide and preventing acceleration of existing inequities within education (Kelley & Wenzel, 2025).

Research into AI tools’ capabilities for EFL students must continue by researching the technology limitations (or deficiencies) related to these AI resources. Current examples demonstrate how existing AI methods produce responses that are ambiguous at best and inadequate representations of the intended meaning at worst. Due to how AI works, when it does not correctly interpret the context of idioms, cultural references and certain nuances in the English language, it can result in improper or nonsensical responses to EFL students, causing ineffective communication and misunderstandings (Alghasab, 2025; Dinh, 2025). Future studies also must determine ways to improve AI’s Natural Language Processing (NLP) ability to produce more authentic and contextually accurate responses based on cultural context and usage, while enhancing the overall effectiveness of AI’s NLP features as pedagogically reliable and responsive to users’ changing needs, as well as reducing repetitive responses and providing more diverse options for learners (Li et al., 2024; Lo & Hew, 2023).

In addition, more empirical evidence should be collected to understand AI’s impact on student engagement and motivation further. While extant literature has indicated that AI provides individualised and potentially motivational educational experiences for learners, the manner in which learners perceive the usefulness, intrinsic value and expectations of success associated with using AI for language learning tasks must be clarified through further empirical investigation (Dinh, 2025). In addition, to help understand how AI can support students’ need for autonomy, competence and relatedness within the context of a pedagogical framework in which instructors continue to be central in their role mediating and supporting student development, future research should examine the psychological and emotional impact of students’ interactions with AI (Li et al., 2024).

AI’s role in EFL instruction becomes increasingly complex through continued integration over time; therefore, while there may be benefits associated with using AI to learn personalised building skills and work with teachers

together better as a group, any continued success for AI in this area will rely on our ability to address issues of ethics, equity and reliability, technological reliability and instructors' preparedness. Ongoing research and informed technological innovation are required to ensure positive AI contributions to EFL learning's future.

## Conclusions

AI in the EFL classroom is changing how we learn EFL today. With new AI technology available, in addition to providing new forms of EFL acquisition and enhancing EFL instruction's effectiveness, there is new potential for enhancing how EFL learners acquire the language and the EFL teacher population's effectiveness (Liang et al., 2025). As highlighted in this narrative review, AI technology is changing how EFL learners acquire the language through development of AI-supported, learner-specific personalisation and adaptive learning systems that help identify each learner's needs, create tailored learning pathways for each learner, adjust the pace of learning and develop engagement and sustenance for each learner's language development over time (Gligorea et al., 2023; Liu et al., 2025). Another aspect of how the introduction of AI technology is changing how EFL learners acquire the language and how EFL teachers evaluate that acquisition and provide feedback to EFL learners is through rapid development of potentially new AI-supported assessment and feedback systems that provide timely, consistent feedback and enhance language proficiency through reduced bureaucratic and procedural burdens for the EFL teacher population (Al-Bogami & Alahmadi, 2025; Zou et al., 2025). Additionally, using AI technology has enhanced EFL students' engagement levels by creating an interactive and personalised environment that utilises conversational agents (AI-based tools that have been designed to simulate human-like conversation) and chatbots (AI tools that allow for continuous practice by the EFL learner during development of their language skills) (Liu et al., 2025; Yan et al., 2024). Continued development of AI technology for use in EFL learner support and skills development will give EFL teachers the opportunity to use AI as a cognitive scaffold to support EFL learners in all aspects of developing their language skills, including the areas of writing and speaking, developing vocabulary, acquiring grammatical proficiency, etc. (Alghasab, 2025; Perkins, 2023; Zou et al., 2025).

Integrating AI tools into language education (EFL specifically) presents various obstacles and difficulties that need to be identified and corrected over time, even though these tools have become much more advanced. Perhaps the most challenging issue relates to concerns regarding academic integrity and originality concerning a learner's unique ideas, which potentially could lead to AI plagiarism and the possibility of cognitive offloading. Both would inhibit a learner's capacity to analyse and develop language critically without assistance (Alghasab, 2025; Nelson et al., 2025). In addition, many other challenges exist regarding data privacy and security, bias in the equalised assessment of learners through algorithms and limitations in AI technology that impact implementation of AI systems in schools. Each of these issues raises serious concerns regarding equity, reliability and ethical design of AI educational systems (Alghasab, 2025; Eden et al., 2024; Kelley & Wenzel, 2025). Because of this, as AI continues to advance within the educational arena, educators must rethink collaboration roles (as designers, facilitators and assessors) between themselves and AI technologies, as well as between themselves and their students (Li et al., 2024).

Researching and practising AI (use) to teach EFL requires paying attention to several interconnected issues

through the use of evidence-based research and practice. The future of research and practice in AI and EFL also must include (1) developing ethical frameworks, (2) reducing algorithmic biases, (3) adding linguistic and cultural sensitivity to the AI and (4) providing equal access to AI-based learning tools for all students (Eden et al., 2024; Li et al., 2025). Teachers also must receive ongoing professional development in AI literacy so they can integrate AI into their own classroom practices effectively and critically assess AI's output to guide their students in using AI in an ethical, responsible and real-world manner (Abdelhalim & Alsehibany, 2025). By leveraging technology's advantages, along with the expertise of pedagogy, language teachers will be able to utilise AI to supplement the human element of teaching/learning a language and ultimately create inclusive, ethical and impactful EFL learning environments.

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## Nurturing Reflective Thinking Skills Among Prospective Teachers Through a Learner-Educator Feedback System Using Google Keep

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### Abstract

Digital feedback tools are increasingly being explored as means of fostering reflective thinking in higher education. This study investigated the use of Google Keep as a tool to cultivate reflective thinking skills in an Environmental Science course among fourth-year college students at a public tertiary institution in the Philippines using both quantitative and qualitative data sources. Students used Google Keep in completing reflective tasks during discussions, enabling real-time learner-educator feedback. Quantitative data were gathered using pre- and post-administration of the Reflective Thinking Survey Questionnaire, Kember's Reflective Thinking Rubric, and the Technology Acceptance Model (TAM) Survey. Descriptive statistics and the Wilcoxon Signed-Rank Test were employed to analyze changes in reflective thinking. Results indicated a statistically significant improvement in students' reflective thinking skills ( $z = 3.659$ ,  $p < 0.05$ ) based on survey data. However, Kember's rubric revealed limited depth in reflective engagement, particularly in relating personal experiences to academic concepts. Findings from the TAM survey suggested strong student acceptance of Google Keep, emphasizing its perceived ease of use and functionality. Thematic analysis of responses to the Reflection Questionnaire corroborated the tool's usability and its role in promoting reflection, while also suggesting areas for interface enhancement. Overall, the findings affirm the potential of Google Keep as a practical, accessible platform for delivering feedback and cultivating reflective thinking in higher education science courses.

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## Introduction

In educational contexts, feedback between learners and educators serves as a fundamental pillar for enhancing student learning and development. It plays a critical role in monitoring progress, guiding improvement, and fostering metacognitive engagement (Li et al., 2025; Pollard & Armatas, 2025). Beyond shaping academic outcomes, feedback also strengthens teacher–student relationships, supports self-efficacy, enhances motivation, and promotes deep learning (Tampal et al., 2019). Contemporary scholarship increasingly frames feedback as a dialogic and learner-centered process rather than a unidirectional transmission of information, emphasizing students' active participation in giving, receiving, and using feedback to regulate their learning (Nicol & Macfarlane-Dick, 2007; Black & Wiliam, 1998; Sadler, 1998). However, despite its recognized value, large-scale studies conducted in the United Kingdom and Australia continue to report persistent challenges in feedback practices, particularly in terms of timeliness, personalization, and student engagement (Winstone & Boud, 2019). These challenges are especially pronounced in science education, where learners are expected to engage in reflective thinking, integrate conceptual understanding, and apply knowledge to complex, real-world problems.

When effectively designed and implemented, feedback mechanisms can scaffold learners' cognitive processes, promote higher-order thinking, and support the development of essential competencies such as critical thinking, problem-solving, and self-regulation. Empirical evidence suggests that learner-centered feedback models, particularly those that encourage students to initiate and act on feedback, lead to higher engagement and improved feedback quality (Raymond et al., 2019). These shifts reflect broader conceptual changes in feedback theory, which increasingly view feedback as a collaborative, socially situated process embedded within complex learning environments (Weller & Gotian, 2023). Central to these outcomes is metacognition, defined as individuals' awareness and control of their own cognitive processes (Flavell, 1979). Metacognitive skills enable learners to plan, monitor, and evaluate their learning, thereby fostering meaningful and sustained engagement with academic content.

The role of metacognition is particularly salient in Environmental Science education, where students must grapple with environmental crises such as pollution, climate change, biodiversity loss, and resource depletion. Environmental and crisis education aims not only to develop scientific understanding but also to cultivate responsible citizenship and environmental stewardship through inquiry-based and reflective learning experiences (North American Association for Environmental Education [NAAEE], 2016). However, environmental education also faces significant challenges arising from technology-driven production and consumption patterns and the increasing complexity of planetary crises, necessitating pedagogical approaches that move beyond traditional sustainable development frameworks toward more critical and transformative learning paradigms (Menezes, 2018; Layrargues, 2020). Teaching about ecological crises while simultaneously experiencing them creates unique pedagogical tensions, highlighting the need for learning environments that support reflection, sense-making, and critical engagement (Suarez et al., 2023).

Consistent with these demands, a meta-analysis by Antonio and Prudente (2022) confirmed that metacognitive instruction has a significant positive effect on students' academic achievement, particularly in science disciplines.

These findings reinforce the importance of instructional approaches that deliberately integrate feedback and reflection to support learners' metacognitive development. In response to the limitations of traditional feedback systems, there is a growing call for innovative strategies and technologies that can better facilitate timely, constructive, and learner-centered feedback. As Sterman et al. (2018) emphasized, educational reform requires innovation to effectively navigate increasingly complex learning environments.

The integration of digital tools, including mobile and web-based applications, offers promising pathways for addressing these challenges. Technology-supported feedback systems can provide timely, personalized, and flexible feedback, particularly in contexts where human instructional resources are constrained (Deeva et al., 2021). Such tools expand opportunities for synchronous and asynchronous interaction and enable reflective learning beyond the boundaries of time and space (Nicol, 2012). One such tool is Google Keep, a widely accessible note-taking and task management application. Owing to its flexibility, cross-device compatibility, and collaborative features, Google Keep can be repurposed as a learner–educator feedback platform aligned with social constructivist and connectivist learning theories, which emphasize knowledge co-construction through interaction within social and digital networks.

Within Environmental Science education, where reflective engagement and feedback are essential for grappling with complex environmental issues, Google Keep offers a practical and accessible means of supporting learner–educator dialogue and metacognitive reflection. By enabling students to document ideas, respond to reflective prompts, and receive timely feedback, the platform has the potential to strengthen reflective thinking while fostering active participation in learning. This study explores the use of Google Keep as a digital feedback tool to nurture reflective thinking skills in Environmental Science among fourth-year prospective teachers in a public college in Malolos, Bulacan, Philippines. Specifically, it sought to answer the following research questions:

1. How may students' reflective thinking skills be described before and after exposure to Google Keep using Kember's Reflective Thinking Survey Questionnaire?
2. Is there a significant difference in students' reflective thinking skills before and after the implementation of Google Keep?
3. How may students' reflective thinking skills be described during the intervention based on Kember's Reflective Thinking Rubric?
4. How may students' acceptance of Google Keep as a learner–educator feedback tool be described in terms of technology acceptance and system usability?
5. How may the learner–educator feedback system in Environmental Science using Google Keep be described based on students' reflections?
6. What improvements to the learner–educator feedback system using Google Keep may be suggested based on students' feedback?

## Literature Review

### Evolution of Learner–Educator Feedback Systems

Historically, feedback in education positioned learners as passive recipients of information, with teachers

assuming authoritative roles in evaluating performance and directing learning. Over time, this traditional paradigm has shifted toward more dialogic and learner-centered approaches, wherein students actively engage in giving, receiving, and using feedback to improve their learning outcomes. Nicol and Macfarlane-Dick (2007) argue that high-quality learning is closely associated with students' active participation in feedback exchanges, transforming feedback into a two-way process that supports learner autonomy and self-regulated learning. This reconceptualization of feedback is reinforced in formative assessment literature, where feedback is viewed as a critical mechanism linking evaluation to subsequent learning actions (Black & Wiliam, 1998; Sadler, 1998). Particularly in science education, well-designed feedback systems play a vital role in supporting conceptual understanding and the development of higher-order thinking skills, underscoring the need for their thoughtful and purposeful integration into instruction (Kaldaras et al., 2024; Swanson et al., 2021).

Empirical studies further substantiate this shift toward learner-centered feedback models. Raymond et al. (2019) demonstrated that transitioning from educator-driven to learner-initiated feedback significantly increased both the frequency of feedback requests and completion rates, while also improving the quality of feedback related to students' strengths. These findings align with broader conceptual changes described by Weller and Gotian (2023), who traced the evolution of feedback from a transactional exchange of information to a collaborative, learner-centered process embedded within complex socio-cultural learning environments. As learning contexts become increasingly dynamic, technology has emerged as a key enabler of these pedagogical shifts. Deeva et al. (2021) highlighted how automated and technology-supported feedback systems can provide personalized and real-time support, particularly in contexts where instructional resources are limited. However, despite their growing use across educational domains, the literature remains fragmented, indicating the need for more data-driven and student-centered feedback solutions.

Importantly, Nicol (2012) emphasized that while learning technologies do not fundamentally alter the nature or purpose of feedback, they significantly expand the ways in which feedback can be implemented. Through synchronous and asynchronous modalities, digital tools offer new opportunities for timely, flexible, and dialogic feedback interactions, while simultaneously introducing new pedagogical and design challenges for educators. Collectively, these studies underscore an ongoing evolution toward feedback systems that prioritize learner agency, interaction, and reflection—principles that are increasingly supported and amplified through educational technologies.

As feedback practices continue to evolve toward more dialogic and learner-centered approaches, their role becomes especially critical in disciplines such as Environmental Science, where learners are expected to reflect on complex real-world issues and develop informed, responsible responses.

### **Environmental Science and Crisis Education**

Engaging students in environmental science and crisis education is essential for cultivating both scientific understanding and responsible citizenship. As emphasized by the North American Association for Environmental Education (2016), inquiry-based engagement with ecological issues enhances critical thinking and fosters

environmental stewardship. Environmental crises—such as pollution, climate change, biodiversity loss, and resource depletion—demand pedagogical approaches that foreground real-world problem-solving, reflective thinking, and informed decision-making. These challenges position environmental education not merely as content transmission but as a transformative learning space where learners critically examine human–environment interactions.

At the same time, research highlights substantial pedagogical and structural challenges in environmental science and crisis education. The current planetary crisis is deeply rooted in unsustainable production and consumption patterns shaped by technology-driven urban lifestyles, necessitating forms of environmental education that move beyond conventional sustainable development frameworks (Menezes, 2018). In the United States, Morrone (2001) identified a persistent science education crisis marked by low scientific literacy, noting that environmental themes can serve as integrative frameworks to enhance student learning. More recently, scholars have emphasized that environmental education is confronted by intersecting crises—including climate collapse, antiecologism, and global pandemics—which call for paradigm shifts away from market-oriented and technocratic approaches toward more critical and reflexive pedagogies (Layrargues, 2020). Teaching about ecological crises while simultaneously experiencing them further complicates instruction, presenting both challenges and opportunities for transformative scholarship as educators reassess the content, methods, and purposes of environmental education in crisis contexts (Suarez et al., 2023).

Within this complex landscape, effective environmental science education requires not only disciplinary knowledge but also opportunities for reflection, self-monitoring, and meaning-making—processes closely associated with metacognition. Digital tools can play a pivotal role in addressing these needs by supporting reflective and dialogic learning practices. Tools such as Google Keep enable students to document observations, track project progress, and receive timely feedback, thereby supporting deeper engagement with environmental content while encouraging creativity and collaboration. When used purposefully, such technologies can enhance cognitive engagement, promote metacognitive awareness, and support contextualized understanding of environmental issues, aligning instructional practices with the reflective demands of crisis-oriented environmental education.

### **Feedback as a Driver of Metacognition**

Metacognition, originally conceptualized by Flavell (1979), refers to individuals' awareness and regulation of their cognitive processes. It encompasses both metacognitive knowledge—understanding how one learns—and metacognitive regulation—planning, monitoring, and evaluating learning strategies (Lai, 2011; Swanson, 1990; Akturk & Sahin, 2011). Research consistently demonstrates that metacognitive instruction enhances self-efficacy, promotes student ownership of learning, and improves academic performance (Sadeghi & Mohtashami, 2011; National Council for Special Education, n.d.).

Educators play a crucial role in cultivating metacognition through explicit instruction, reflective prompting, and structured feedback. Strategies such as metacognitive checklists (Schraw, 1998), reflective questioning during

tasks (Mevarech & Kramarski, 2003), and post-assessment self-reflection (Tanner, 2012) have proven effective in fostering metacognitive skills. These practices are further reinforced through collaborative learning structures grounded in social constructivist theories, wherein peer interaction and dialogue promote higher-order thinking. A meta-analysis by Antonio and Prudente (2022) affirmed the positive effects of metacognitive strategies in science education, particularly when integrated with information and communication technologies (ICTs). Digital platforms equipped with reflection prompts and feedback mechanisms can scaffold self-regulated learning and deepen students' metacognitive engagement. Given the central role of feedback in supporting metacognitive processes, there is increasing interest in digital tools that can facilitate timely, structured, and reflective feedback within learning environments.

### **Google Keep as an Educational Tool**

Google Keep, a cloud-based note-taking and organizational tool, offers substantial potential in educational settings through its user-friendly features such as color-coded notes, checklists, voice memos, and image annotation (Brown, 2024). These functionalities support learner organization, promote collaboration, and encourage creative expression. When integrated into instruction, Google Keep enables teachers and students to co-manage tasks, share timely feedback, and curate multimodal learning artifacts that enhance engagement and understanding. Its educational utility aligns with the principles of social constructivism and connectivism, which emphasize active participation, collaboration, and networked knowledge construction.

Furthermore, Google Keep supports the International Society for Technology in Education (ISTE) Standards by fostering student agency, digital collaboration, and creative communication. According to Trust (2022), the application aligns well with the SAMR model, functioning as a substitution for traditional note-taking, augmenting learning through collaborative lists, modifying instruction via multimodal note creation, and redefining learning by enabling students to share outputs beyond the classroom. Supporting this, Pilomonu et al. (2023) demonstrated the effectiveness of Google Keep in project-based learning, particularly in improving students' writing skills, thus affirming its applicability as a tool for enriching instructional practices and learner engagement. Situating Google Keep within broader e-learning environments further highlights its role as part of technology-supported feedback systems that enhance accessibility, interaction, and learner engagement.

### **E-Learning and Technology-Supported Feedback**

E-learning, defined as instruction delivered through electronic devices and digital networks, expands access to education while enhancing flexibility and learner autonomy (Kenan, 2015). The asynchronous nature of digital learning platforms supports just-in-time access to resources, continuous interaction, and individualized pacing. Applications such as Google Keep, when embedded within e-learning ecosystems, offer valuable affordances for real-time collaboration, feedback exchange, and documentation of learning processes.

Technology-enhanced feedback systems strengthen instructional practices by improving feedback timeliness, clarity, and learner engagement. Studies by Black et al. (2011) and Stuart et al. (2011) indicate that digital

feedback enables learners to revisit instructor comments, reflect more deeply on feedback, and respond constructively. Typed and digitally mediated feedback also improves legibility and reduces ambiguity compared to traditional verbal or handwritten feedback. Recent research by Zou et al. (2023) further highlights that technology-enhanced teacher, peer, and self-feedback significantly improve students' critical thinking, writing quality, and engagement, with teacher feedback delivered through digital platforms demonstrating the strongest effects.

## **Synthesis**

Taken together, the reviewed literature underscores the interconnected roles of learner-centered feedback, metacognition, and digital technologies in fostering reflective learning, particularly within science education contexts. As environmental challenges demand critical engagement and informed action, the integration of metacognitive strategies and technology-supported feedback systems becomes increasingly imperative. Google Keep emerges as a promising, accessible digital tool that aligns with pedagogical and technological frameworks supporting reflective thinking. Grounded in social constructivist principles and supported by empirical evidence, its use as a learner–educator feedback system warrants further exploration in nurturing reflective thinking skills among prospective teachers.

## **Methods**

### **Research Design**

The research utilized both qualitative and quantitative research designs. Quantitative data complemented qualitative findings to provide a comprehensive view of Google Keep's effects on the learner–educator feedback system and students' reflective thinking skills in Environmental Science. The research design was used by all participants who benefited from improving the learner-educator feedback system in Environmental Crises after the intervention of G-Keep.

### **Research Locale and Participants**

This study involved thirty-one (31) 4th-year students enrolled in a public college in Malolos, Bulacan, Philippines, during the academic year 2023-2024. Participants were selected through purposive sampling based on specific attributes, knowledge, skills, and relevance to the study's objectives. The research was conducted face-to-face with the permission of the school administration and the selected students. Most participants were female ( $n = 27$ , 87%), followed by males ( $n = 2$ , 6%) and LGBTQIA+ students ( $n = 2$ , 7%). Considering their age, the majority are 20 years old (65%), followed by 21 years old (23%), 23 years old (6%), and 24 and 25 years old (1%).

### **Research Instruments**

To evaluate the learner-educator feedback system using G-Keep and address the research questions posed in this study, researchers used questionnaires and a rubric focusing on skills like reflective thinking. These instruments

were designed to measure the system's effectiveness and nuances of the feedback system in the context of G-Keep.

### ***Pre and Post-Reflective Thinking Survey Questionnaire (Pre-RTSQ and Post-RTSQ)***

The study employed a Reflective Thinking Survey Questionnaire (RTSQ) for pre-and post-test, a quantitative research tool utilizing a Likert scale adapted from Kember et al. to assess students' reflective thinking skills before and after exposure to G-Keep. As Creswell (2002) defined it, quantitative research involves testing objective theories through variable analysis. The unidimensional Likert scale was used to gauge participant perspectives across 16 questions categorized into four sections: habitual action, understanding, reflection, and critical reflection. The Likert scale offers four response options without a neutral choice: strongly disagree, disagree, agree, and strongly agree, enabling researchers to assess the extent of agreement or disagreement regarding reflective thinking ability. The scale assumes a linear relationship between experience intensity and strength. The quantitative data from these instruments were analyzed by descriptive statistics – mean and standard deviation, and using the Wilcoxon Signed Ranks Test. Table 1 shows the number of items in each level and the sample statements of the pre-and post-RTSQ.

Table 1. Distribution of Items and Sample Statements in the Reflective Thinking Survey Questionnaire (RTSQ)

Level	Number of Items	Sample Statements
Habitual Action	4	I can perform activities on Environmental Science without having to think too much of what I am doing.
Understanding	4	The lesson on Environmental Science requires us to understand concepts taught by the instructor
Reflection	4	I question the way others approach learning, taking quizzes/exams, and performing in Environmental Science, aiming to think of a better way
Critical Reflection	4	The way I look at myself changed as a result of Environmental Science

### ***Kember's Reflective Thinking Rubric (KRTR)***

Participants' reflections in Google Keep were evaluated using Kember's Reflective Thinking Rubric, a quantitative research tool. This rubric assigns scores based on predefined criteria to guide researchers in evaluating. Like Kember's, analytical rubrics enhance student learning by providing constructive feedback and highlighting strengths and weaknesses. They effectively assess oral and written work, allowing teachers to provide targeted feedback and students to understand evaluation criteria, resulting in higher-quality outputs. The adaptation of Kember's Reflective Thinking rubric aims to provide a comprehensive and tailored assessment tool for evaluating and describing reflective thinking in the context of Environmental Crises using Google Keep during the intervention. The quantitative data gathered was analyzed by descriptive statistics – mean and standard deviation. Table 2 shows Kember's Reflective Thinking Rubric.

Table 2. Kember's Reflective Thinking Rubric and Descriptive Performance Levels

Criteria	Critical Reflection	Reflection	Understanding	Habitual Action
	4 (3.18 - 4.00   80-100%)	3 (2.78 - 3.17   70-79%)	2 (2.40 - 2.77   60-69%)	1 (1.00 - 2.39   D/F: >60%)
Reflection on Existing Knowledge (Learning Experience and Personal Insight)	Engages in a thorough examination of current knowledge, challenges assumptions, and expresses novel viewpoints based on experience.	Actively and thoughtfully reflects on established knowledge, presenting fresh insights gained through experiential learning.	Utilizes existing knowledge without endeavoring to assess or appraise it; displays comprehension but does not connect it to other experiences or personal reactions.	Provides automatic or superficial responses with minimal conscious or deliberate thought, lacking reference to existing knowledge; responses are given without an attempt to comprehend them.
Connection to Academic Concepts (Personal Experience, Class Content, Literature)	Shows an exceptional link between personal experience and class material (concepts/theories) and literature; provides proof of applying theory and reshaping perspectives.	Clearly establishes connections between personal experience and class content (concepts/theories); offers evidence of applying theoretical concepts.	Associates personal experience with class content (concepts/theories) but at a surface or abstract level.	Fails to establish connections between personal experience and class content (concepts/theories) or relevant literature.
Evidence of Development (Shift in self, or knowledge about what is learned)	Expresses a shift in their viewpoint regarding themselves or a specific issue/concept/problem arising from the encountered experience.	Expresses fresh comprehension and insights concerning oneself or a particular issue/concept/problem stemming from the acquired experience.	Displays restricted or superficial insight into oneself or a particular issue/concept/problem due to the encountered experience.	Presents no proof of gaining insights into oneself or a particular issue/concept/problem as a result of the experienced situation.

### *Technology Acceptance Model Survey Questionnaire (TAMSQ)*

The study utilized the Technology Acceptance Model Survey Questionnaire (TAMSQ) to gauge students'

acceptability of Google Keep as a learner-educator feedback app in environmental crises. The Technology Acceptance Model (TAM), developed by Fred Davis, focuses on perceived usefulness and perceived ease of use as crucial factors influencing technology adoption. Derived from TAM, TAMSQ has two categories: technology acceptance and system usability. Technological acceptability explores user perceptions regarding the usefulness and ease of use of G-Keep. On the other hand, system usability has two subcategories: attitude toward using it and behavioral intention of use. The former explores the users' trust, personal initiative, characteristics, and context. The latter explores the behavioral intention of use of the user of the proposed technology. This structured questionnaire provides insights into technology acceptance dynamics and offers a systematic approach to assessing user perspectives. The quantitative data from these instruments were analyzed using descriptive statistics, such as mean and standard deviation. Table 3 shows the indicators, number of items in each level, and sample statements.

Table 3. Indicators, Number of Items, and Sample Statements of the Technology Acceptance Model Survey Questionnaire (TAMSQ)

Indicator	Number of Items	Sample Statements
Perceived Usefulness (PU)	5	The advantages of Google Keep, which is used as a feedback app, outweigh the disadvantages.
Perceived Ease of Use (PEOU)	5	the user interface of the system was clear and intuitive
Trust	5	It ensures the privacy of its users.
Personal Initiatives and Characteristics (PIC)	5	I found using Google Keep to be an efficient tool for the learner-educator feedback system.
Context	5	Google Keep proved to be meaningless and irrelevant to my studies.
Intention to Use (IU)	5	Google Keep can be adapted into a feedback app, I am inclined to integrate it into my future engagements and teaching.

### ***Reflective Questionnaire (RQ)***

A reflective questionnaire with four (4) open-ended questions is utilized, emphasizing the importance of reflection in education. Scholars like Kolb (1984) and Helyer (2015) highlight how reflection aids in transforming experiences into concepts and recognizing ongoing learning. The questionnaire serves to gauge the impact of the teaching and learning environment on reflective thinking, crucial for student improvement and skill development. A systematic procedure guided the study's aims, comprising pre-implementation, during-implementation, and post-implementation phases. Numerical data collection was employed throughout the implementation to evaluate causality and outcomes, determining if there was a significant change in the learner-educator feedback system post-intervention.

### Teaching Intervention

To nurture prospective teachers’ reflective thinking skills, the researchers implemented a Google Keep–supported learner–educator feedback intervention using the 7E instructional model. The class is grouped with 5-6 members. G-Keep was used in the exploration phase, where peer and instructor feedback were quickly given. Individual exploration was done on day one, and collaborative sharing and synthesizing group responses were done on Day 2. The extension phase also used G-Keep, where the participants reflected on their learning. After a day, the researchers assess their reflection and provide feedback on the participants’ responses.

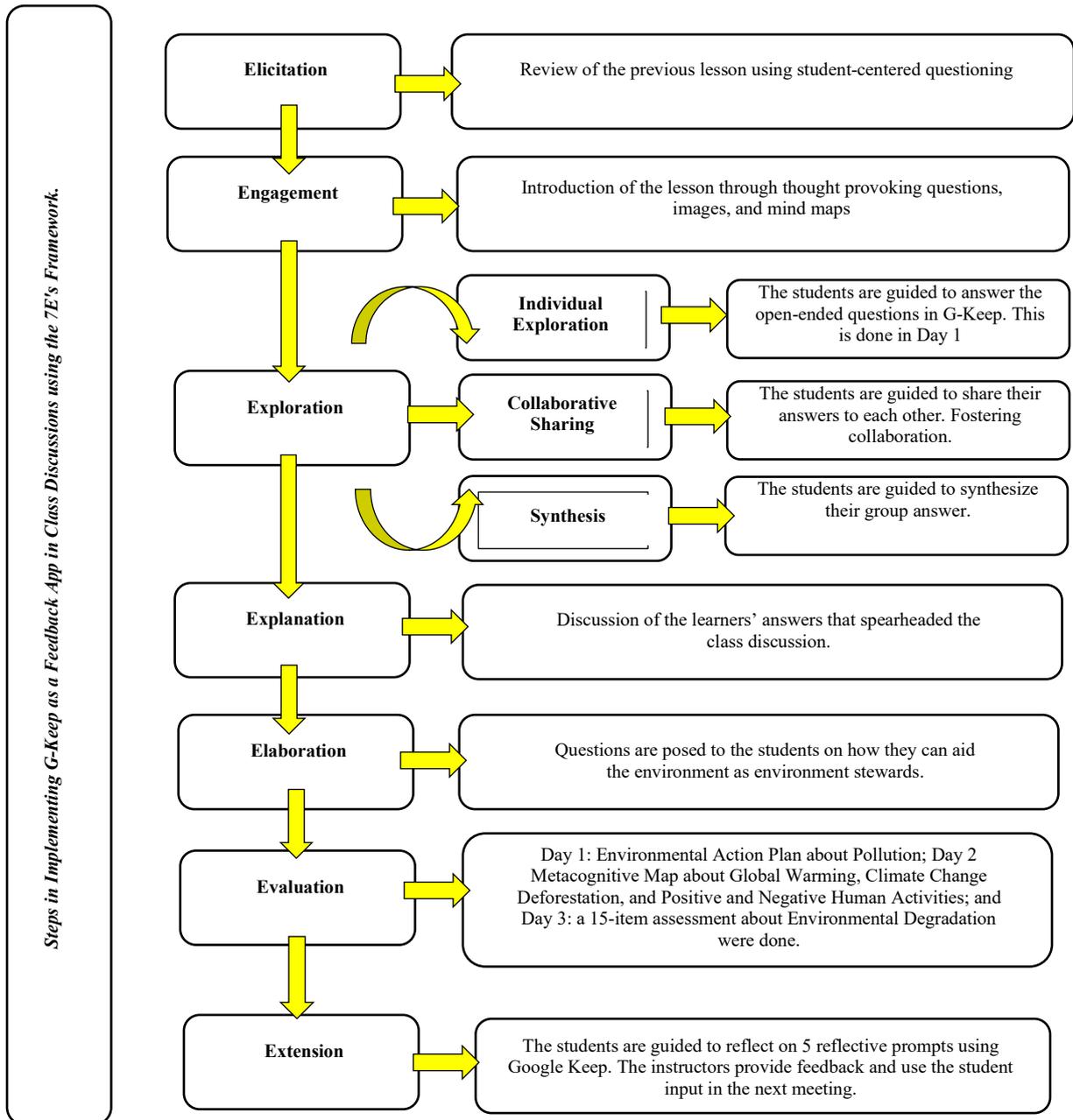


Figure 1. Implementation Framework of Google Keep as a Learner–Educator Feedback Tool

The study aimed to nurture reflective thinking skills in prospective teachers through a learner-educator feedback

system using Google Keep. The researchers implemented a teaching intervention based on the 7E instructional model with groups of 5-6 members. G-Keep was utilized during the exploration phase for quick peer and instructor feedback. Individual exploration occurred on Day 1, followed by collaborative sharing and group synthesis on Day 2. The extension phase involved reflection on what was learned, with researchers providing feedback the following day. Figure 1 shows the summarized steps in implementing G-Keep as a feedback app.

**G-Keep Interface**

Google Keep, the application that was used in the study, is a multimodal note-taking, organizing, and list-making tool that works with Google Drive, Google Classroom, Google Forms, and Google Hangouts. Educators may utilize the app to assist students in managing group projects, tracking their learning progress through collaborative to-do lists, and encouraging their students to show off their creative skills by writing notes. (Trust, T., 2022) Instructors create labels based on their needs, whether categorizing notes by activities, evaluation, or reflective inquiry prompts, allowing the participants to organize their perspective labels easily. Additionally, G-Keep is collaborative; it can make changes by editing notes and instantly reflecting on all participants on each label. Moreover, instructors can leave feedback within the context of the notes. Figure 2 shows the main screen of G-Keep, which presents notes in a visual card format.

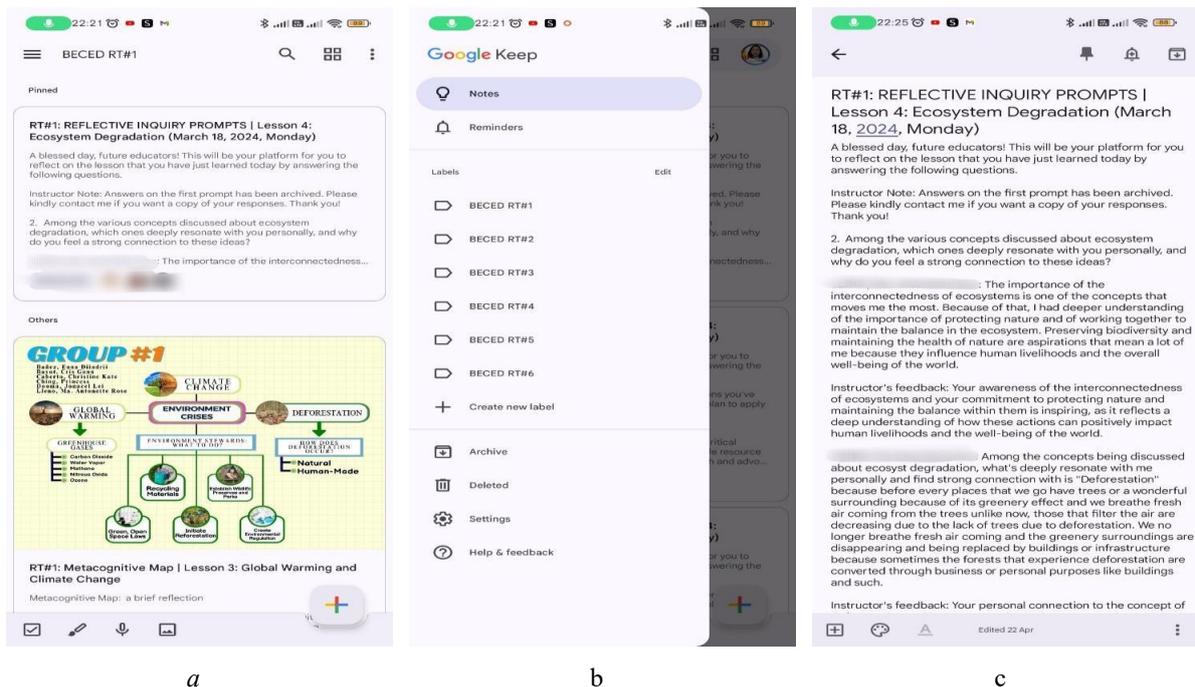


Figure 2. G-Keep Interface. (a) G-Keep Main Interface, (b)G-Keep Side Bar (c) G-Keep Notes

**Research Procedure**

This section discusses the steps that the researchers followed in conducting their study. The researchers created A systematic procedure that guided them in targeting the study's aims. The method comprises three phases: pre-implementation, during implementation, and post-implementation.

### Pre-implementation

In Figure 3, the pre-implementation process is outlined. The researchers followed the four steps before proceeding with the discussion. The researchers contacted the dean of the target college, the college secretary, and the teacher of the target class. They had a verbal inquiry to ask permission to conduct a study in their college. After that, a consent letter was given to the personnel mentioned before the researchers started the study. After asking for permission from the mentioned personnel, a meeting was conducted to plan for the target group of participants participating in the study. When a group of participants was established, a letter of approval was given to ensure that they were willing to participate in the study. The collected data and information were confidential and used in the study only. First, the participants were oriented on the research and were introduced to G-Keep and how to use it as a learner-educator feedback app in environmental crises. The pre-RTSQ was given to the participants to describe their reflective thinking skills prior to exposure to G-Keep; this was analyzed with the post-RTSQ to determine the significant change in students' reflective thinking prior to and after exposure to G-Keep, which is discussed later in the paper.

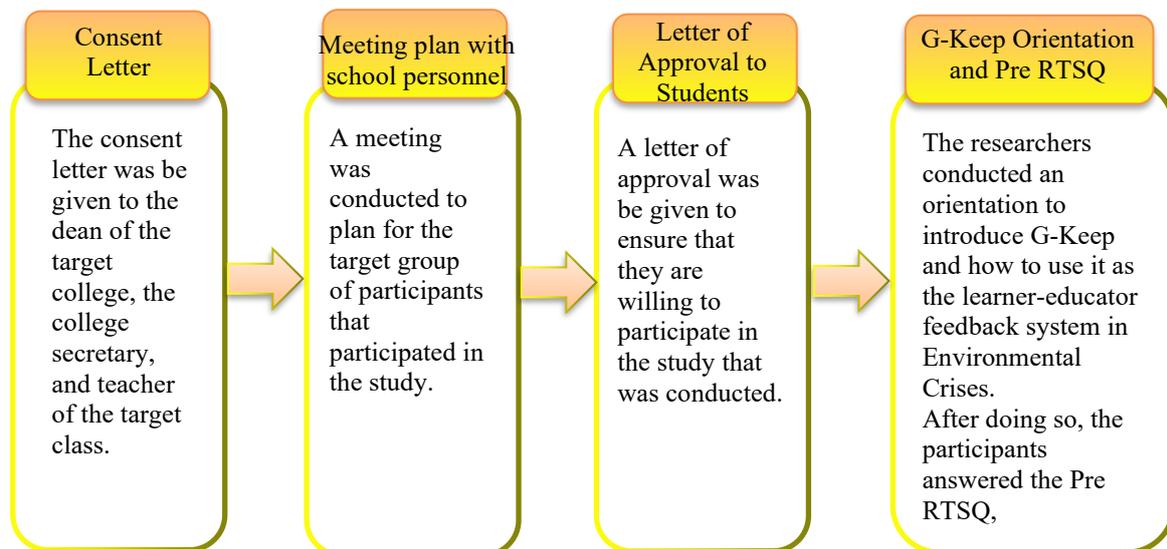


Figure 3. Pre-implementation Flowchart

### Implementation

In Figure 4, the implementation process was outlined. The researchers discussed each topic of environmental crises for two weeks. During the first week, the researchers introduced the topic by implementing elicit and engaging activities for the class. After doing so, the discussion of the first topic, anthropogenic impact and different types of pollution, was initiated. After the discussion, the students completed their reflection, which allowed them to reflect and ask for feedback using G-Keep. After the class, the researchers supplemented the input needed by the learners. After doing so, the researchers assessed the students' reflections using Kember's reflective thinking rubric. This routine was the same in the second week. The only difference is that the class further addressed the learners' concerns about the previous topic using the contents from G-Keep, and the topics discussed were global warming, climate change, deforestation, positive and negative human activities, and

ecosystem degradation, respectively. In week 3, the researchers further examined the concerns raised during the previous topic and implemented the post-implementation of this research.

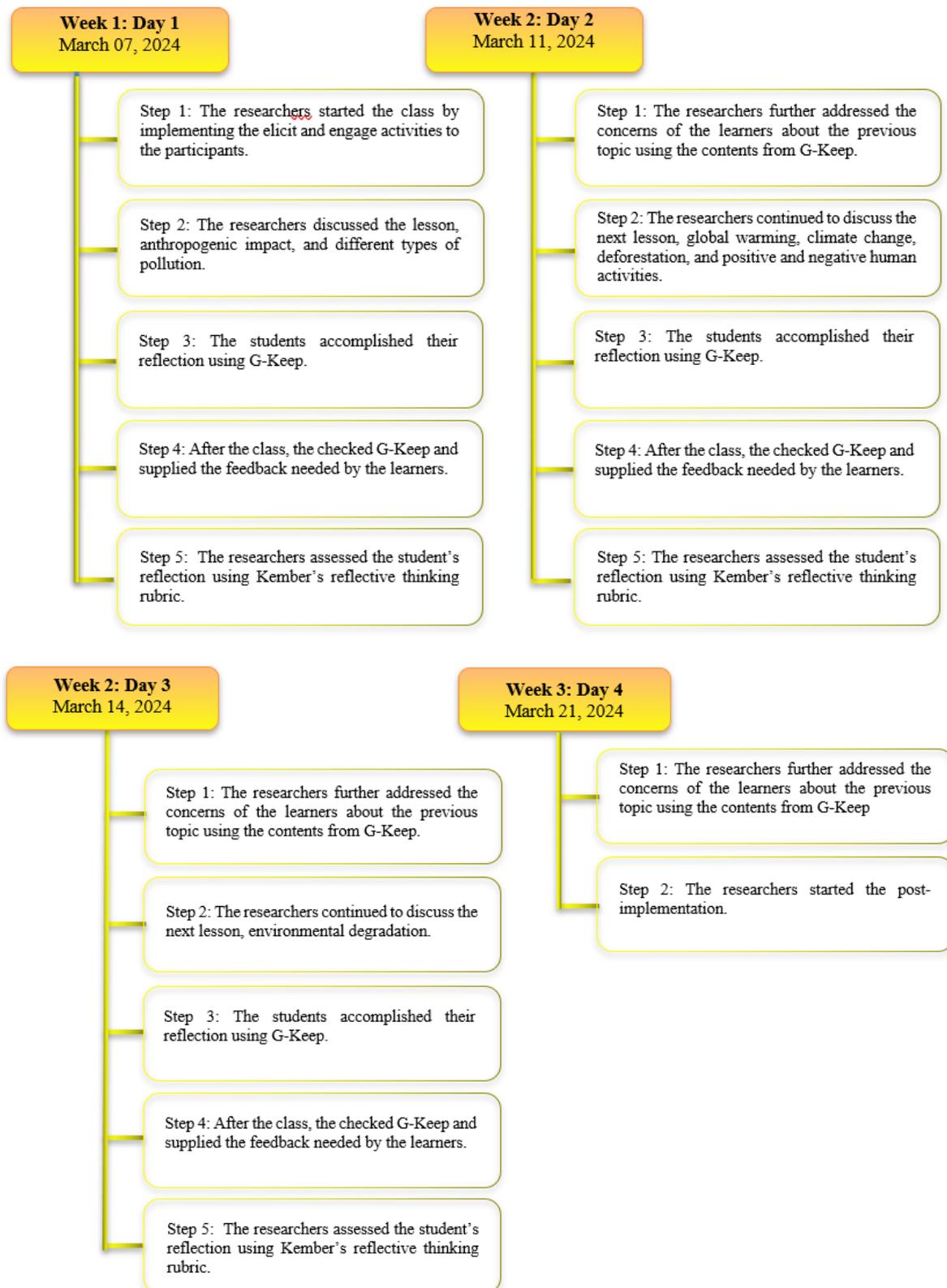


Figure 4. Implementation Flowchart

**Post-Implementation**

Figure 5 presents an overview of the post-implementation process. Data based on the participants' answers was collected. The post-RTSQ was given to the participants to determine whether there was a significant difference in the learner-educator feedback system after the implementation of G-Keep. After doing so, the TAMSQ was answered by the participants. The participants also answered the Reflection Questionnaire (RQ) to share their experiences and feedback about the learner-educator feedback system in environmental crises using G-Keep.

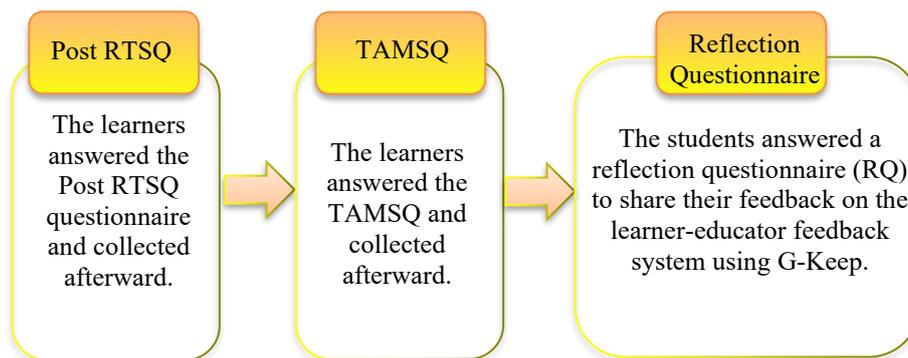


Figure 5. Post-Implementation Flowchart

**Results**

This section presents the quantitative and qualitative results on the effectiveness of G-Keep as a learner-educator feedback system in fostering students' reflective thinking skills.

**Quantitative Findings**

*Pre - Reflective Thinking Survey Questionnaire*

Table 4 presents the changes in students' reflective thinking skills before and after the exposure to G-Keep.

Table 4. Wilcoxon Signed-Rank Test for the Difference between Pre-RTSQ and Post-RTSQ of Students with regards to Levels of Reflection

Levels of Reflection	Pre-RTSQ	SD	Post-RTSQ	SD	MD	z	Asymp. sig	r	p-value	Verbal Interpretation of r
Habitual Action	2.82	.48	3.59	.39	0.77	-4.57	.00	-0.81	0.0001	Large effect
Understanding	3.65	.35	3.73	.44	0.08	-1.21	.23	-0.21	0.23	Small effect
Reflection	3.35	.36	3.60	.50	0.25	-2.70	.007	-0.48	0.0070	Small effect
Critical Reflection	3.34	.43	3.60	.54	0.26	-2.49	.01	-0.44	0.013	Small effect
<b>Overall</b>	<b>3.29</b>	<b>.32</b>	<b>3.63</b>	<b>.43</b>	<b>0.11</b>	<b>-3.66</b>	<b>0.00</b>	<b>0.65</b>	<b>0.0003</b>	<b>Large effect</b>

Note: No. of items = 16; at N = 31 \*significant at  $\alpha = 0.05$ ; effect size (Cohen's d) is  $(r=z/\sqrt{2N})$ ,  $0.10 > r > 0.30$  (small effect),  $0.50 < r < 0.30$  (medium effect), and  $r > 0.50$  (large effect).

The table shows that the pre-RTSQ mean score was recorded at 3.29 (SD=.32) while the post-RTSQ mean score was at 3.63 (.43). The results revealed that there was a significant difference between the overall mean scores in the Pre-RTSQ and Post-RTSQ of the students in relation to the different levels of reflection before and after being exposed to G-Keep as a learner-educator feedback system in learning Environmental Crises. The data given in the table above rejects the null hypothesis of this study. This data indicates that the students exhibited significant improvement in their overall reflective thinking in different levels of reflection after using G-Keep as a learner-educator feedback system, as evidently shown by the scores acquired during the Pre-RTSQ and Post-RTSQ ( $z = -3.66$ ,  $p\text{-value} = 0.0003$ ). This result provides strong evidence that Google Keep enhances the learner-educator feedback system in Environmental Science. Using G-Keep as a learner-educator feedback app resulted in effect sizes  $r = 0.65$ , which indicates a large and positive effect size in students' reflective thinking. The  $p\text{-value}$  of 0.0003 indicates that the results obtained were statistically significant compared to the alpha level of 0.05. Hence, this implies that using G-Keep as a learner-educator feedback system greatly impacts the students' reflective thinking skills. The results indicate that using G-Keep as a learner-educator feedback system prosperously amplified the students' reflective thinking about the different levels of reflection: Habitual Action, Understanding, Reflection, and Critical Reflection, where Understanding was highly manifested.

The quantitative findings indicate that exposure to Google Keep led to a significant improvement in students' reflective thinking across all levels of reflection. This result confirms earlier findings that technology-supported feedback and metacognitive scaffolds can enhance reflective thinking and self-regulated learning in science education (Hattie & Timperley, 2007; Antonio & Prudente, 2022). Similar to Zou et al. (2023), the immediacy and clarity of digitally mediated teacher feedback appear to play a critical role in supporting learners' reflective engagement. Allowing the participants to reflect on using their mobile phones showcases the integration of mobile learning in education, which has a positive impact on the student's academic achievement (Daher & Salhab, 2023). This notable increase is caused by the reflective inquiry prompts located on the app and the feedback that the educator provides to the participants. Structured reflection prompts combined with immediate feedback enabled learners to monitor and evaluate their learning effectively.

Moreover, reflection prompts were also implemented during the exploration phase of the class, which contributed to nurturing their reflective thinking skills. Reflection goes beyond assessment and focuses on self-improvement. It involves a deeper level of thinking processes to enhance one's performance and learning. (Watanabe-Crockett, 2018.)

### ***Describing Students Reflecting Thinking Skills using KRTR***

Table 5 presents the students who demonstrated a level of understanding in reflecting on existing knowledge (REK), with a grand mean score of 2.76 (SD = 0.05). However, they primarily utilized existing knowledge without critically assessing or connecting it to other experiences or personal reactions (Kember et al., 2008.) Regarding the Connection to Academic Concepts (CAC), the grand mean score was 2.30 (SD = 0.21), suggesting that students showed habitual action in their reflection. They failed to connect personal experiences and class content or relevant literature (Kember et al., 2008.) For Evidence of Development (ED), the grand mean score was 2.52

(SD = 0.17), indicating an understanding level of reflection similar to REK. The students display restricted or superficial insight into themselves or a particular issue/concept/problem due to the encountered experience (Kember et al., 2008.)

Table 5. Grand Mean Score and Standard Deviation of Students' Scores on the three criteria: Reflection on Existing Knowledge (REK), Connection to Academic Concepts (CAC), and Evidence of Development (ED), based on Kember's Reflective Thinking Rubric, across all lessons on Environmental Crises.

Criterion	M	SD	Levels of Reflection
Reflection on Existing Knowledge	2.76	.05	Understanding
Connection to Academic Concepts	2.30	.21	Habitual Action
Evidence of Development	2.52	.17	Understanding

As for describing their reflective thinking skills during the intervention, utilizing the three (3) criteria from KRTR, the results describe the reflective thinking skills of the learners to be utilizing their newfound knowledge. However, despite the observed gains, students demonstrated limited depth in reflective engagement, particularly in connecting personal experiences to academic concepts. This contrasts with studies that report deeper levels of critical reflection when reflective activities are implemented over longer durations or with sustained individual reflection phases (Kember et al., 2008; Chen et al., 2020). The relatively short intervention period and the collaborative nature of reflections in this study may have constrained opportunities for deeper critical reflection. Moreover, it was also observed that due to how the reflection process using G-Keep was organized - the students were grouped. They can see each other's reflections; this may be a factor for them to be influenced by their peers' reflections and not rely on their own.

### Technology Acceptance Model Survey Questionnaire (TAMSQ)

The data from Figure 6 highlights that perceived ease of use registered the highest score, with a mean of 4.57 and a standard deviation of 0.51, indicating a solid perception of "to a great extent." This finding corroborates Wilson's (2019) study, suggesting that perceived ease of use holds a more significant influence on intention than perceived usefulness, supported by the higher t-value associated with perceived ease of use.

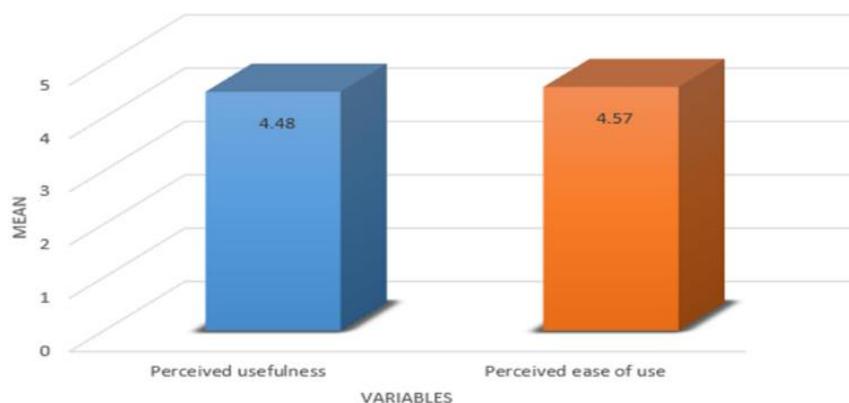


Figure 6. Students' Technology Acceptance of Google Keep Based on the TAMSQ

Conversely, perceived usefulness obtained the lowest score, with a mean of 4.48 and a standard deviation of 0.64, also interpreted as "to a great extent." The data revealed that students find G-Keep easy to use and valuable when reflecting and obtaining feedback about their reflections on environmental crises. Since an application was utilized, it is imperative to measure the students' acceptability of it. The quantitative data from TAMSQ suggests that in terms of technology acceptance, G-Keep was easy to use and navigate. Using Google Keep is as simple as putting a sticky note on a wall—simple and gets the job done (Kingcott, 2018).

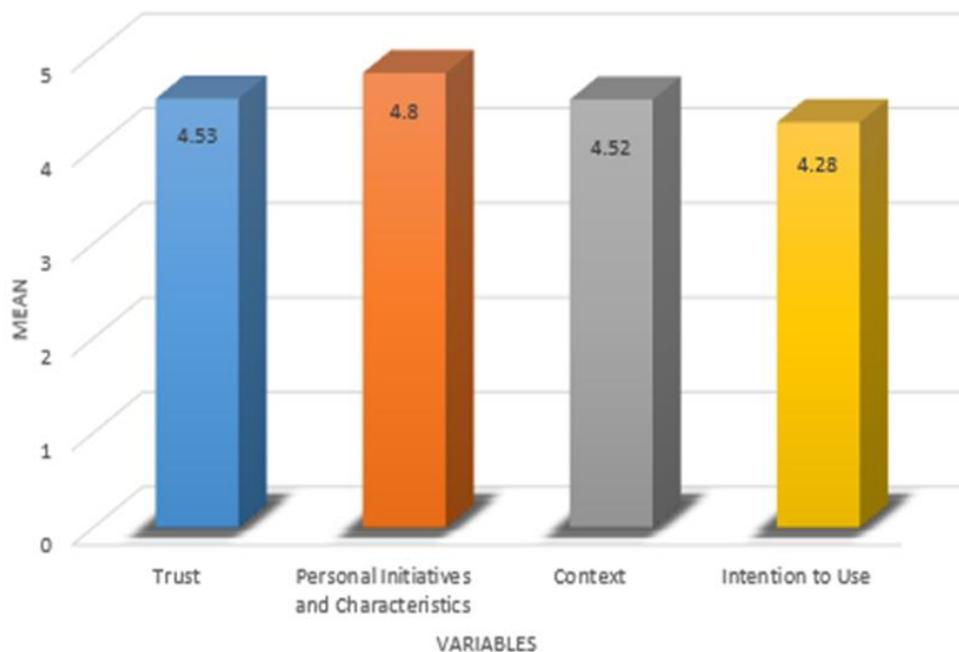


Figure 7. Students' Perceived System Usability of Google Keep Based on the TAMSQ

According to Figure 7, Personal Initiatives and Characteristics obtained the highest mean score of 4.8 with a standard deviation of 0.54, indicating a perception of "to a great extent." The results suggest that learners possess personal initiatives and characteristics conducive to using G-Keep as a feedback system. Conversely, the intention of use garnered the lowest mean score of 4.28 with a standard deviation of 0.91, also interpreted as "to a great extent." However, students express their intention to utilize G-Keep for future educational purposes. In summary, the overall average mean of 4.53 with a standard deviation of 0.21 defines the perception as "to a great extent," indicating that students highly accept G-Keep as a feedback app for nurturing reflective thinking skills for Environmental Crises. Considering the behavioral intention of use, the data reveals that students had a positive attitude towards using G-Keep. The result is observable among the participants - their openness to new experiences led them to use G-Keep during the intervention.

## Qualitative Findings

### *Thematic Analysis*

The qualitative data from the reflection questionnaire were classified under the following themes: (1) significant experiences, (2) difficulties, (3) most effective features/s, and (4) suggestions.

Table 6. Thematic Analysis of Students' Significant Experiences in Using Google Keep

Theme	Sub-themes	Codes	Sample Responses
Significant Experiences	Reflection and Organization	Enable me to reflect	Participant 1: "Using Google Keep enable me to reflect deeply on the lesson and also collaborate with my classmates, and get feedback from our teachers - Sir Cyfer and groupmates."
		Organize my thoughts	Participant 22: "Google keep helped me a lot to organize my thoughts or answer and it also help me to be aware to my groupmates answer."
		Helps in understanding	Participant 11: "For me, my significant experience is using Google keep as a learned-educator it really does help me a lot understanding the knowledge that instructor shared."
	Collaboration and Communication	Collaborate with my Classmate	Participant 7: "Using google keep it was easily to reflect and collaborate with others."
		See Each Other's Ideas	Participant 18: "We can see each other idea about the topic."
		Feedback made me feel validated	Participant 31: "It's rewarding to see and receive feedbacks from th instructors, makes me feel validated."
	Feedback	Made Learner Educator Feedback Easier	Participant 26: "I think Google keep makes the feedback system in learner-educator easier."
		Get feedback	Participant 17: "The significant experiences I've experienced while using Google Keep is I can easily get immediate feedback on my reflection."
		Easy to use	Participant 12: "It is easy to put our reflection about the topic"
	Usability and Efficiency	Effective and Efficient	Participant 16: "Effective to use in making reflections and less time in writing the answering questions."
		Good to use	Participant 8: "My significant experiences while using Gkeep. The gkeep is good to use for students because gkeep is many benefits for the student specially educators"
		Convenient	Participant 20: "I think using G keep as a feedback system is really convenient"
	Enjoyment and Engagement	Fun and enjoy	Participant 9: "It's fun and all the learning that I've learned i put them easily in the google keep. I had a great time using Google keep."
Environmental	Environmentally	Participant 27: "This is very helpful to me and also	

Theme	Sub-themes	Codes	Sample Responses
	Awareness	Friendly	environmental friendly because its paperless”
	Knowledge Expansion	Expand my knowledge	Participant 28: “I've been using G-Keep since I was a 1st year college. And this experience expand my knowledge of using G-Keep.”
	Challenged Faced	Answer Erased	Participant 21: “At first, my experience was mixed with confusion and excitement, because I was confused when my answer were erased but then, I enjoyed using Google Keep.”

The data from Table 6 indicates that the phrases "get feedback" and "easy to use" received the highest frequency, with a frequency of 8. The data reveals that students' significant experiences include obtaining feedback from their instructor and the ease of use of G-Keep. Meanwhile, the phrases "Helps in understanding," "Made Learner Educator Feedback Easier," "Environmentally Friendly," "Expand my Knowledge," and "Hard time" each received the lowest frequency, specifically with a frequency of 1.

From the themes that emerged from the qualitative data, Google Keep serves as a platform for reflection and providing feedback due to its collaborative features and ease of use, as participants 7 and 12 stated in Table 6. Implementing Google Keep in a classroom setting, teachers may assist students in managing group projects, tracking their learning progress through collaborative to-do lists, and encouraging their students to show off their creative skills by writing, and these notes may be in the form of reflection. (Trust, 2022).

Table 7. Thematic Analysis of Students' Reported Difficulties in Using Google Keep

Theme	Sub-themes	Codes	Sample Responses
Difficulties	Technical Issues	Getting erased	Participant 16: “The challenges i face when i utilizing the google keep the other answer erased while we are typing.”
		Disappearing	Participant 3 Our reflections were sometimes unintentionally disappeared and sometimes the prompts need to be accomplished were not reflected to the account
		Technical errors	Participant 4 The difficulties I experienced is there are some technical errors like the answers are getting deleted unintentionally.
		Slow	“Participant 12 This challenges that I face in using Google keep when we put an answer in the Google keep sometime is slow you always make sure to have copy of your answer in your phone.”
		Internet connection	Participant 10: “My difficulties is we need internet connection in answering the questions in Google keep. I make sure that we have a good connection.”
		Phone unit	Participant 22: “The difficulties/challenges that I faced is my

Theme	Sub-themes	Codes	Sample Responses
			cellphone unit is Huawei so I don't have a playstore so I can't download the app and sometimes my answer suddenly become clear.”
	Copying Tendencies	Tendency to copy	“Participant 5 The answers are open with other members. There are tendencies to copy the answers or accidentally remove it.”
	No Technical Issues	None	Participant 18: “I don't have any difficulties/challenges on learning about environmental crises.”

The data from Table 7 demonstrate that the phrase 'getting erased' obtained the highest frequency. The research shows that students experience difficulties, such as responses being suddenly erased while using G-Keep. Furthermore, the phrases 'slow' and 'phone unit' have the lowest frequency. Limitations of the app also emerged, such as their responses being erased, as participants 4 and 16 mentioned stated in Table 7. The student researchers observed that when multiple participants edited the same Google Keep note simultaneously, some responses were unintentionally overwritten or erased. To address this issue, future implementations may assign individual notes for initial reflection or require students to draft responses offline before posting them to shared notes. Moreover, some of the participants need access to an internet connection or have a weak one, rendering them unable to use G-Keep properly during or after the discussion. This occurrence is included in the limitation of the application.

Table 8. Thematic Analysis of Students' Perceived Most Effective Features of Google Keep

Theme	Sub-themes	Codes	Sample Responses
Most Effective Feature	Enhanced Creativity and Expression	Very helpful	Participant 1: “I think the most effective feature is where we can collaborate with each other in one place is very helpful for us to get immediate feedback that we can't really have or get all the time in the classroom setting.”
		Promote creativity	Participant 3.: “Feedbacks can be express in a creative way and it promotes creativity among learners and educators while being immersed in the technology.”
		Can type and insert picture	Participant 7” The most effect is we can insert picture's and text collaboratively.”
	Facilitated Collaboration	Shared and collaborate	Participant 17: “The specific feature If Google Keep as learner- educator feedback system that i find most effective is we can collaborate easily and we can know the feedback immediately.”
	Improved Effectiveness	More effective	Participant 12: “Its very effective and very useful it can help me to write answers unlike in the pen and paper we need to use correction.”
	Reflective Thinking and	Can reflect and give	Participant 16: “ i easily see their comments and reactions on our answers through that comments i can

Theme	Sub-themes	Codes	Sample Responses
	Feedback	feedback	improve what i need to improve more.”
	Notable Information Management	Can note important thing	Participant 8. :The most effective is lesson on Environmental Crises is us have advantage so keep notes and important thing.”
	No Specific Response	No answer	

Table 8 shows that the phrases “reflect and give feedback” attain the highest frequency. The data showed that the learners get feedback quickly from the instructor using G-Keep while “promote creativity,” “more effective,” and “can note important things” got the lowest frequency. Following the implementation of G-Keep, the following are the verbatim responses from our participants regarding the unique features that the students find most compelling. The following statements stated in Table 8 were evident to the participants since they were engaged in the reflecting process. Moreover, they appreciated the feedback from their instructor. They are expressive when they receive feedback from their work, which makes the features of Google Keep. This multimodal note-taking app promotes collaboration among their peers (Trust, T. 2022) which is beneficial to them in nurturing their reflective thinking skills in Environmental Crises lessons.

Table 9. Thematic Analysis of Students’ Suggestions for Improving the Use of Google Keep

Theme	Sub-themes	Codes	Sample Responses
Suggestions	User Satisfaction	Satisfied	Participant 7: "For me, I am satisfied on what google keep has. So that, for me, I have no suggestion be added to enhance."
		Features are Good	Participant 9: "For me all the features are good and was a good feedback experience for both learners and educators.”
	Ease of Use and Functionality	Easy to Use	Participant 32: "None, because i find it easy to use and I am satisfied with the app."
		Process of Inserting the Answer	Participant 12: "None, only the process of insert our answers in the reflection in the Google keep."
	Desired Additional Features	Color, Fonts, and Design	Participant 29: "For me its so plain and not interesting to open. More features like color, icon and pocket, should be added."
		Add Chat box	Participant 6: "Maybe the could add a comment box feature where collaborator/facilitators can give comments/feedback in a more systematic way.
		Monitoring history	Participant 1: "The feature/s that needs to be enhanced in Google Keep is the sudden disappearance of the text we're typing and I think it would be better if there are options for text fonts, colors, and themes, for us to make creative and

Theme	Sub-themes	Codes	Sample Responses
			more visually pleasing notes about Environmental Crises.
			Lastly, I think it would be great if the edit history can be monitored so that the teacher can know if students were able to really participate and if their answers are really from them."
		Privacy	Participant 4: "Maybe to add more privacy in one's answer."
	Accessibility and Compatibility	Availability to all cell phones	Participant 22: "I don't have any suggestion features but I hope it will be available even in Huawei or any cellphone unit that don't have playstore"
	Innovation and Uniqueness	Innovative	Participant 24: "None the app is very innovative"
	No Specific Response	None No answer	

Table 9 shows that the phrase 'color fonts and design' obtained the highest frequency, indicating that learners suggest adding features like color, icons, and pockets to enhance the feedback system between learners and educators when utilizing G-Keep. Meanwhile, the words 'availability to all' acquired the lowest frequency, indicating that most learners can access G-Keep. Following the implementation of G-Keep, the following are the verbatim responses from our participants regarding additional features they suggested. Participant 29 suggested integrating options to modify the visual aesthetics of Google Keep, which was a theme that also emerged from the qualitative data. Although the teacher-researchers oriented the participants that Google Keep has options to change the visual appearance of their Google Keep notes, no one changed it and focused on the reflective prompts. Moreover, G-Keep offers ample themes and backgrounds (Romero, 2022); however, they are limited.

Despite the positive findings, several limitations should be acknowledged. The study involved a relatively small, purposively selected sample from a single institution, which may limit the generalizability of the results. Additionally, the short duration of the intervention and the use of collaborative reflection tasks may have constrained the development of deeper critical reflection, while technical issues such as erased responses and internet connectivity challenges may have influenced students' reflective outputs.

## Conclusion

This study explored the use of Google Keep as a digital feedback tool to foster reflective thinking skills among prospective teachers in an Environmental Science course. Drawing from a mixed-methods approach, the findings provide compelling evidence that integrating Google Keep into classroom instruction can enhance learner-educator feedback systems and support the development of students' reflective thinking. Quantitative results showed a statistically significant improvement in students' reflective thinking, particularly in habitual action, reflection, and critical reflection. The large effect size observed suggests that the platform contributed meaningfully to students' metacognitive engagement and self-assessment. While Kember's Reflective Thinking

Rubric indicated some limitations in students' depth of reflection, particularly in connecting personal experiences to academic concepts, the data also highlight that reflective growth was evident, albeit emerging.

Students expressed strong acceptance of Google Keep, as evidenced by high scores in perceived ease of use, personal initiative, and system usability. Thematic analysis of qualitative feedback further emphasized the platform's intuitive interface, collaborative features, and its ability to facilitate immediate and meaningful feedback exchanges. However, several technical and contextual challenges, such as erased entries, device compatibility issues, and tendencies for peer influence during group reflections, underscore the need for thoughtful implementation and platform support.

Overall, this study affirms the potential of Google Keep as a practical, accessible, and pedagogically sound tool for promoting reflective thinking in science education. The integration of structured reflection prompts with immediate feedback helped create an interactive, student-centered learning environment. As learners engaged in metacognitive activities, they became more aware of their thought processes, learned to evaluate their performance, and demonstrated increased agency in their learning journeys.

Future research should consider longitudinal studies and comparative designs to examine the sustained effects of digital feedback tools on reflective thinking. Moreover, refining implementation protocols—such as individual reflection phases and technological safeguards—can further enhance the depth and authenticity of students' reflections. As educators navigate the integration of educational technologies, tools like Google Keep offer promising pathways to support metacognition, feedback, and meaningful learning in the digital age.

## **Recommendations**

Based on the findings and insights of this study, several key recommendations are proposed to guide future implementation, instructional practice, and research. First, it is essential to provide comprehensive orientation and technical training to both students and instructors before integrating Google Keep into the classroom. This includes familiarization with the app's functionalities, collaborative features, privacy settings, and visual customization tools to ensure effective and confident usage. Educators are also encouraged to design reflective activities that initially emphasize individual reflection before collaborative sharing. This strategy may mitigate tendencies toward peer influence and foster deeper, more authentic connections between learners' personal experiences and academic content.

To address the technical limitations identified—such as disappearing responses and device incompatibility—teachers should implement backup mechanisms, such as maintaining offline records or using alternative apps for documentation. Additionally, exploring comparable educational platforms (e.g., Microsoft OneNote, Notion, or Padlet) may offer similar pedagogical benefits while enhancing accessibility and flexibility across devices. Embedding metacognitive scaffolds—such as reflective prompts, rubrics, and feedback checkpoints—within Google Keep is recommended to enhance reflection quality. Establishing feedback loops, where students' reflective inputs are explicitly acknowledged and used to inform subsequent instruction, can reinforce the value

of reflection as a dialogic learning process.

Moreover, the study recommends leveraging Google Keep's integration with other Google Workspace tools—such as exporting notes to Google Docs for extended reflection or incorporating Google Classroom for centralized feedback collection. These synergies can help educators create more connected and interactive digital learning ecosystems. Finally, future research should consider longitudinal and comparative studies to examine the sustained impact of using digital feedback tools on students' reflective thinking and academic performance. Employing quasi-experimental designs or including control groups could provide more robust evidence of causality. By implementing these recommendations, educators and researchers can advance the pedagogical potential of digital technologies in fostering metacognition, feedback engagement, and reflective learning in diverse educational contexts.

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## The Use of Artificial Intelligence in Early Intervention

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### Abstract

The use of Artificial Intelligence (AI) is steadily increasing. This paper explores the extent to which AI is currently utilized in Early Childhood Intervention (ECI) services. Data were collected through an online survey conducted in German-speaking countries (Germany, Austria, Switzerland) and Turkey (n = 123). Results indicate that up to 50% of professionals in ECI services already use AI, predominantly ChatGPT. AI use is associated with younger age and professional background. Home visitors report less frequent use compared to professionals working in kindergarten settings. Non-users primarily cite a lack of information and general skepticism toward AI tools. Among users, AI is applied in methodological research, translation processes, and, to some extent, in planning interventions. Time efficiency is perceived as the main advantage of AI use; however, concerns remain regarding the validity of information and data protection. Overall, there is a clear demand for more training and well-defined guidelines concerning the handling of personal data when using AI in professional practice.

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## Introduction

The use of artificial intelligence (AI) is currently a widely discussed topic and is expected to play an increasingly significant role in special education in the future (cf. Knaus 2024, EDF 2024). This raises the question of the extent to which AI has already been integrated into early intervention practices in German-speaking countries, or what meaningful applications might emerge.

However, scientific engagement with the use of AI in early childhood intervention appears limited. Most studies emphasize the prospective potential of AI in special education, often with a focus on school settings (Francesc et al. 2019; Alkan 2024). The latter highlights that:

- students are provided with personalized, adaptive learning programs,
- software programs can identify and respond to individual strengths and weaknesses,
- AI tools can adapt to individual learning styles.

Furthermore, dialogue functions between AI and learners as well as data mining (the analysis of large data sets) are emphasized. Reviews on specific applications in (special) educational contexts mention:

1. support for (differential) diagnostic processes,
2. automated processing of information and data,
3. alternative and augmentative communication,
4. management processes, and
5. individualized planning of support processes.

Few studies focus specifically on preschool-aged children, such as Bostelmann (2023), who reflects on the potential use of AI in kindergartens, or Naranjos Velazquez (2023), who examines early support services. The author mentions the use of AI for gathering information (e.g., identifying suitable network partners) and for translation functions (e.g., simplifying documents for parents).

## Support for Diagnostic Processes

Most research concerning AI in early diagnosis relates to autism spectrum disorder (ASD). In a meta-analysis, Wei et al. (2023) identified 261 studies focusing on "eye tracking" as a diagnostic indicator for ASD. The general conclusion is that AI can distinguish children with ASD from typically developing peers based on differing gaze patterns. Other studies analyze movement patterns, including stereotypies (Semeon et al. 2021), through video analysis, detecting differences even before clinical symptoms become apparent. Seventeen indicators proved significant for AI-based distinction—such as increased directional changes and faster, shorter movements in children with ASD.

Lai et al. (2020) found structural retinal differences (e.g., larger optic disc diameters) in children with ASD using machine learning. These could be detected in high-resolution images via AI. Similarly, Schäfer (2023) identified thinner retinal layers in the macula region among children with ASD, although no functional impairments were

observed. Tariq et al. (2018) developed a mobile app that used machine learning to identify ASD in home video recordings with 87% accuracy. Kojovic et al. (2021) trained AI to distinguish between typical and atypical interaction behavior, achieving 80% accuracy in detecting ASD based on body posture, reduced gestures, eye contact, emotional expression, and communication. Stanley et al. (2025) trained AI tools on sentence patterns from clinical ASD diagnostic reports and were able to identify repetitive or stereotypical expressions associated with ASD.

Krawitz et al. (2025) described AI's ability to detect atypical facial structures in children with possible genetic diagnoses, sometimes referred to medically (and controversially) as "funny-looking face" (FLF). Reich et al. (2021) highlighted AI's potential in detecting neurological problems in preterm infants via fidgety movements. These low-amplitude, moderate-speed, and variable-acceleration movements in awake infants are crucial prognostic markers. Using five-second video clips, AI achieved up to 80% accuracy in identifying such patterns—compared to at least five minutes of observation required by trained professionals.

### **Automated Information Processing, Management, and Methodological Suggestions**

Using traditional internet search engines for support planning (the so-called “Dr. Google” approach) is not revolutionary. While scientific platforms such as Cochrane Library, ResearchGate, or Google Scholar offer more reliable content, information from other sources must be critically evaluated for validity and potential bias. AI significantly enhances data processing and information generation—even though risks such as "hallucinations" (fabricated information) or embedded advertising persist. Tools such as ChatGPT, Gemini, Mistral, or DeepSeek can, with minimal input, provide (usually valid) methodological suggestions tailored to a child's support needs in a school or early childhood setting.

Review articles emphasize professional ethical considerations such as:

- transparency regarding how information is generated,
- validation of the information's accuracy,
- prioritization of interpersonal interaction in support processes,
- and a critical stance toward the use of AI in general.

In addition to information retrieval, AI is capable of generating and summarizing data, especially in the context of ASD support:

- AI can measure a child's engagement during learning processes, response time, or task completion (Kumar et al. 2025), particularly in ABA (Applied Behavior Analysis) programs. AI handles the vast amounts of observational therapy data far more efficiently than humans.
- Cox et al. (2023) demonstrated how 48 ASD-relevant behavioral indicators enabled AI to achieve behavior analyses and predictions with 95–99% accuracy.
- Ghafghazi et al. (2021) described AI-enhanced platforms that individually support planning and evaluation in ABA therapy.
- AI can interpret data from wearable tools (e.g., motion sensors, EEGs) and alert parents to potential

developmental anomalies.

- AI also has potential in educational policy—e.g., for data management in international comparative education studies (Pedro et al. 2019).

### **AI in Alternative and Augmentative Communication**

Technologies such as Bliss symbols, communication devices, and specialized apps have long played a vital role in special education. The emergence of AI represents a technological leap forward (Evengaline & Moorthy 2023). Between 2012 and 2022, 359 scientific articles addressed "speech or communication support tools." Drigas et al. (2012) already noted the use of AI across various diagnoses. Hackbarth (2024) sees countless industrial applications for combining generative AI with tools like text-to-speech, facial recognition, and eye-tracking to facilitate intuitive, personalized communication for individuals with complex learning needs. One notable project is "L2Tor" (<http://www.l2tor.eu>), which supports second-language acquisition in kindergartens via a "social robot." Due to the wide range of technologies, this article does not offer an in-depth discussion, although the publications clearly reflect a strong link between AI and industrial technology.

### **AI in Management Processes**

Numerous studies address AI in management processes, including risk and information management, workforce deployment, and innovation. A Google Scholar search for "AI and management processes" yielded over 6.3 million results. However, it is difficult to assess the extent of AI integration in management processes in kindergartens or special education schools due to limited literature. A 2023 pilot project in Carinthia (Austria) highlighted that AI allowed more time for direct support of beneficiaries (in this case, adults with disabilities). Vital parameters and support documentation were dictated into a smartphone via an app and automatically transcribed into ICF-oriented administrative documentation.

### **AI in the Support Process**

Devi et al. (2022) reviewed AI's individualized use for children, particularly in school contexts, and noted:

- tutoring and tracking systems (i.e., learners receive AI-generated feedback and support),
- the potential for global access to education through AI-assisted platforms,
- administrative applications.

The authors also addressed potential negative reactions from learners toward such systems.

### **Research Question**

This examination suggests that the use of AI in early intervention remains largely conceptual (cf. Knaus 2024). Notable exceptions include:

- A) Diagnostic processes involving AI, primarily concerning children with ASD, usually within research institutions or clinical settings;

B) Information management, specifically the retrieval and preparation of relevant support information for children and families—although empirical data here are scarce.

This leads to the central research question:

To what extent has AI "arrived" in early intervention settings, and how do professionals utilize it in this context?

## Methodology

### Sample

The study was conducted using quantitative research methods and a random sample. It was based on a multicenter online survey conducted in Germany, Austria, Switzerland, and Türkiye between May and June 2025. Early intervention centers in Germany, Austria, Switzerland, and Türkiye were contacted through a random sample and asked to complete a short online survey on the use of artificial intelligence in early intervention. In accordance with the Declaration of Helsinki, no personal data was collected from the participants. A total of 123 experts (aged 20 to 64,  $M = 38.37$ ,  $SD = 10.83$ ) participated in the study. Of these, 99 (80%) worked in the field of early intervention, and 24 (20%) worked in the field of inclusive primary education (see Graph 1). Participants were from early intervention (46 or 37%) and primary school (24 or 20%) settings in the DACH region, and from early intervention services in Türkiye (53 or 43%).



Graph 1. Use of AI Depending on the Professional Field

### Instruments

The study used an 18-question questionnaire focused on the research questions. Thirteen questions included AI questions, and five included demographic questions about the participant. The questions in the form were compiled into a question pool by the researchers based on a literature review and finalized after consulting with experts. The online questionnaire included AI-related questions:

- a) Knowledge and use of AI,
- b) Reported reasons for non-use,
- c) Reported type of tool used,
- c) Reported area of use,
- d) SWOT analysis of use,
- e) Future perspectives on use,
- f) Useful support for the increased use of AI in Early Childhood Intervention.

Additionally, the anonymized sociodemographic questions included:

- g) Age of the respondent
- g) Function at the Center where the respondent works
- h) IT familiarity (multiple choice question)

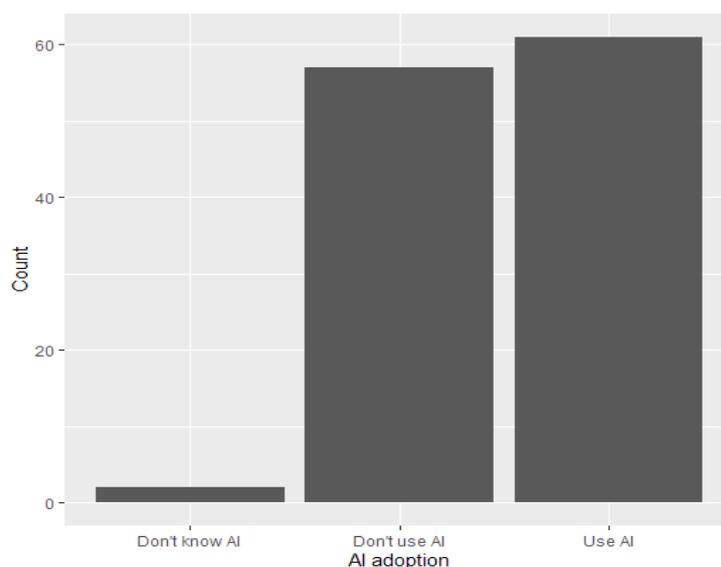
## Data Analysis

This study used a quantitative research method to examine the attitudes and behaviors of early intervention professionals toward AI use, based on demographic factors and their familiarity with IT. Demographic variables and AI use behaviors were presented descriptively (frequency, percentage). Then...

## Results

### Use of AI in Early Childhood Intervention

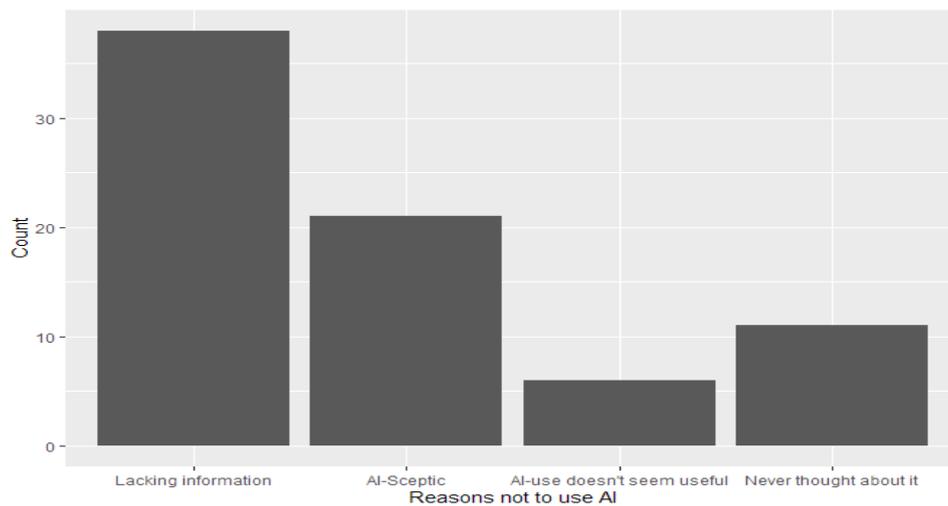
50% (n=61) of the participants reported to use AI, in their professional context of Early Childhood Intervention. 46% (n=57) do not use AI and 4% (n=5) didn't know the term AI (see Graph 2).



Graph 2. Use of AI

Significant correlations between age and use of AI ( $r = -.31, p < .001$ ) and IT-Affinity ( $r = .34, p < .001$ ) could

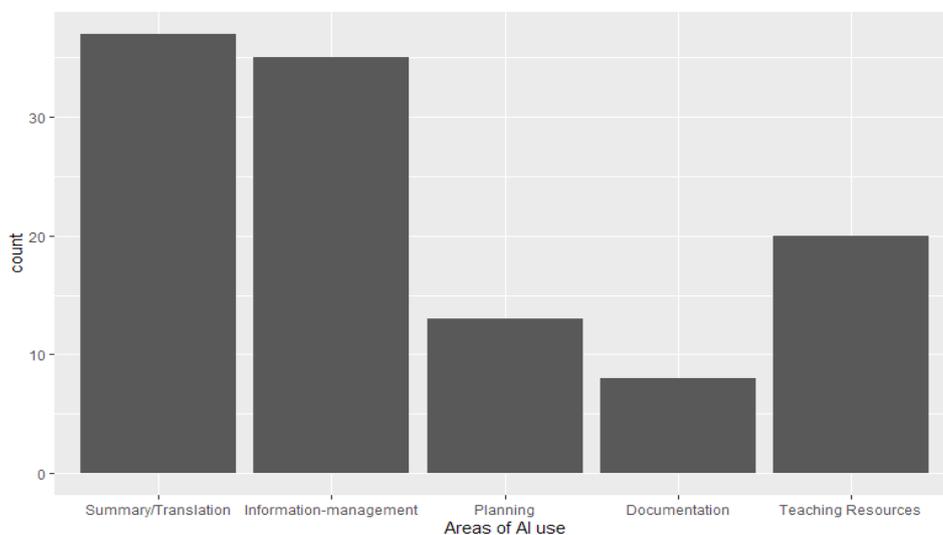
be found. Younger and IT-affin professionals used AI to a higher extent. Also the three sample populations differ significantly from each other regarding AI use ( $\chi^2(2) = 17.33, p < .001$ ), with the primary educators having the highest proportion of AI users (79%), followed by Early Childhood professionals in and professionals in early intervention in the German speaking area. Graph 3 summarizes the reasons for non AI-use: a) lack of information regarding AI (67% or n=38), being generally skeptical about AI use (37% or n=21), belief that AI would not be useful for them (11% or n=6) or never having thought about using AI (19% or n=11).



Graph 3. Reasons for Non AI-use

### Used AI tools in Early Childhood Intervention

Respondents mostly use ChatGPT (98% or n=60) and Google Gemini (28% or n=17), with some also using Perplexity, the French Mistral, or others. Professionals report that they use these tools to summarize and translate documents (61%), to manage information (57%), to generate teaching resources (33%), to plan interventions (21%), or use AI within documentation processes (13%) (see Graph 4).



Graph 4. Areas of AI Use

## SWOTs- Analysis (Stait 1972)

Professionals reported following strengths of AI use in primary education and early intervention: Speed (44%, n=27), Translation/summary of documents (across languages or into easy language) (15%, n=9) Weaknesses were seen concerning the issue of data protection of AI contents (12 or 20%), validity (10 or 16%) and addressing highly personal aspects (6 or 10%). The respondents perceived opportunities to look for specific methods and teaching resources (22 or 36%) and efficiency (saving time) that could be spent with children and families (17 or 28%). The possible lack of skills (20 or 33 %), fake information and hallucinations (16 or 26%) and the lack of privacy (10 or 16%) were identified as threats.

## Future AI use in Early Childhood Intervention

62% (or n=38) respondents can imagine an increased use of AI in their work in the future. 15% (n=9) are undecided, 3% reject the future use of AI. Those who might use AI more intensively wish to have training in the different ways to use AI and the request the necessary infrastructure (26% or n=16). Also issues of validity (18% or n=11) and data protection for their clients (7 or 11%) have to be addressed.

## Conclusion

The initial research question—whether artificial intelligence (AI) has found its way into early childhood intervention—reveals a heterogeneous picture. Half of the surveyed professionals in German-speaking countries and in Turkey report already using AI in their professional early intervention work. This proportion is slightly higher than what general population statistics suggest (using Austria as an example), where 31% report using AI, with a relatively low usage frequency of 4%. Younger individuals appear more open to AI applications—an age-related trend also reflected in the present study: younger and IT-affine professionals report higher usage rates compared to their older counterparts. This may be attributed to the fact that older professionals do not belong to the generation of digital natives and may display more apprehension towards AI technologies.

Differences were also observed across professional domains (though these may require further investigation to establish significance). AI-generated or AI-assisted processes (e.g., in the context of research, translation, or information management) are primarily characterized by their time efficiency (cf. Ajuwon et al., 2024). This perception is echoed in the current study. AI tools thus hold considerable theoretical efficiency potential—especially in terms of human resource allocation—particularly for processes often regarded as administratively "burdensome," such as completing forms.

On the other hand, the professional quality (i.e., validity) of AI-generated documents and concerns related to data protection are commonly perceived as limitations or even risks. For instance, AI could potentially identify a child based on pattern recognition using variables such as age, place of birth, diagnosis, nationality, first language, or temporal and spatial information—posing a threat to fundamental data protection principles. When applying AI in personalized planning processes, strict attention must therefore be paid to data privacy regulations. Close

collaboration with data protection experts will be essential to prevent both identification and stigmatization. It must also be considered a basic requirement that professionals using AI possess the necessary competencies to communicate its use transparently, assess the validity of outputs, and derive evidence-based and meaningful interventions accordingly. Some participants in this study expressed concerns that the use of AI might eventually lead to the "rationalization" of professionals themselves or a loss of expertise. At the same time, nearly all scientific literature agrees that AI must not and cannot replace the interpersonal interaction between professionals and clients.

What remains to be critically examined, however, are the potential effects of perceived (administrative) efficiency gains on the deployment of professionals. Whereas professionals in early childhood intervention have reported, based on anecdotal evidence, that tasks such as research or document preparation previously took about 1.5 hours, the use of AI could reduce this workload to an estimated 15 to 30 minutes—including preparation and validity checks. Initial pilot results (see Land Kärnten, 2023) suggest that professionals perceive the availability of more time resources—enabled through AI—as relieving, as it allows more time to be spent on primary beneficiaries (i.e., children, clients, patients, etc.).

## Recommendations

To date, the use of AI in early childhood intervention appears limited and has received little academic attention. Anecdotal evidence from students in training and continuing education suggests they are positively surprised by the capabilities of these tools. Yet it is likely inevitable that AI will increasingly be used—initially perhaps in the preparation of professionals, for translating texts, or for generating methodological intervention proposals (Pretis & Todorova, 2025). Whether AI will also be adopted in intervention planning or evaluation will largely depend on data protection clarifications and training opportunities. While the risk of professionals being “rationalized away” by AI in early childhood intervention is considered relatively low, a certain degree of unease remains regarding future developments. This may relate to the use of social robots (Thiessen et al., 2023), the rise of online counseling (via chatbots), or the growing influence of social media. It also remains an open question how AI will impact professionals’ workloads. However, the assumption that AI will have no effect on the future of early childhood intervention can be strongly challenged.

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## Integrating Web 2.0 Tools into Science Teaching: Implications for Conceptual Understanding and Student Perspectives

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### Abstract

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The aim of this study is to develop a guiding material supported by Web 2.0 tools for the "Conduction of Electricity" unit in the 6th grade science course and to examine conceptual learning and student opinions about the process. The action research method, one of the qualitative research designs, was used in the study. The sample of the study consisted of 21 6th grade students. A Conceptual Understanding Test consisting of 15 open-ended questions developed by the researcher and a semi-structured interview consisting of 5 open-ended questions were used as data collection tools. According to the results of the Wilcoxon signed-rank test conducted on the conceptual understanding pre- and post-test scores, a statistically significant difference was obtained ( $z=-4.02$ ,  $p<.05$ ). After further analysis of the conceptual understanding test, it was determined that students made significant progress from the "No Understanding" level to the "Complete Understanding" level on the basis of all acquisitions; interactive and student-centered teaching practices supported by Web 2.0 tools strengthened conceptual understanding. In addition, student opinions reveal that Web 2.0 tools contribute positively not only to academic achievement but also to students' attitudes towards learning, class participation, digital competence, and interdisciplinary skills.

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## Introduction

People's need for communication and information sharing is growing rapidly in the modern era, which is sometimes referred to as the information age. Rapidly developing technical advancements have started to be used in education as instruments that can satisfy these demands in recent years. Social networks have developed into communication platforms that incorporate both visual and aural components because of the extensive use of technology and the internet (Ekemen, 2022). The use of technology in the classroom has become increasingly significant in this setting. Technology-based instruction has many benefits over traditional teaching techniques, including increasing student engagement, improving material accessibility, and grabbing their attention. According to a study by Akbaba (2019), students' interest in science and their attitudes toward technology use were positively impacted by science instruction aided by Web 2.0 technologies. Similar results have also been documented in the literature (Arslan & Yildirim, 2021; Can, 2021; Köse et al., 2021; Sarı, 2019; Yildirim, 2020). For these reasons, it is observed that investments allocated to the use of technology in education in Türkiye have increased since the 2010s. The equipping of educational environments with technological tools can be cited as an example of this trend. Through the FATİH Project, initiated by the Ministry of National Education (MoNE) in 2010, classrooms were provided with specific infrastructure, and educational content was enriched through the establishment of web-based platforms. Subsequently, in 2022, various updates were introduced to the Education Informatics Network (EBA) system by the Ministry of National Education, with the EBA Academic Support module being restructured to incorporate content aimed at supporting students' individual learning processes. In the same year, the nationwide expansion of interactive whiteboards in secondary schools and high schools continued, and digital content platforms were developed by the Directorate General of Innovation and Educational Technologies (YEĞİTEK) of the MoNE and made available for teachers' use (Önal, 2022).

An examination of the Türkiye Century Maarif Model, introduced through changes made in 2024 and implemented in 2025, reveals that one of the objectives of science education is to cultivate individuals who can adapt to evolving technologies and are aware of digital transformation. The Science Curriculum aims to enable students to comprehend scientific developments within the context of digital transformation, adapt to technological innovations, and use technology effectively with an awareness of environmental responsibility. An analysis of the program's content indicates that teachers are expected to prepare in advance for relevant digital content and activities before commencing lessons. Furthermore, in cases where digital content is not directly available for learning, the program emphasizes the importance of integrating models, visuals, animations, and simulations into the learning environment (MoNE, 2024). In the teaching process, Web 2.0 tools can make a significant contribution to achieving these objectives. This is because Web 2.0 tools make the learning process more engaging, ensure active student participation, and foster interactive learning environments. Therefore, integrating Web 2.0 tools and other technologies into lessons can enhance students' academic achievement and increase their motivation towards the subject (Wankel & Blessinger, 2013). These tools facilitate interaction among students, between students and teachers, and with other resources, offering a student-centered approach (Can, 2021). In recent years, it has been observed that teachers have been using Web 2.0 tools more actively and that students' interest in technology and technological applications has increased alongside the use of these tools. The integration of Web 2.0 tools into the learning process not only increases students' engagement with the subject

but also supports conceptual learning processes and enables adaptation to the requirements of the digital age in education (Alp, 2019; Baki, 2022; Conole & Alevizou, 2010; Demirezer, 2022; Ekemen, 2022). An examination of these studies reveals that Web 2.0 tools are effective in making abstract concepts—such as those encountered in science—more concrete, enhancing student motivation, and fostering the development of 21st-century skills (Efe et al., 2022; Gürleroğlu, 2019). It has also been identified that these tools enrich the learning process through gamification, visualization, and interactivity; increase academic achievement; enhance interest in the subject; and promote positive attitudes towards technology (Bolatlı & Korucu, 2018; Gürleroğlu & Yildirim, 2022; Korkut, Mantaş & Yildirim, 2021; Timur et al., 2020). These findings demonstrate that Web 2.0 tools can be effective in teaching processes. “Conduction of Electricity” unit is one of the subjects that students find abstract and challenging to understand, according to studies (Acet & Akyüz, 2020). According to reports, students find it difficult to understand the unit's concepts, which include electrical resistance, conductivity, insulation, the impact of a conductor's type, length, and cross-sectional area on a bulb's brightness, and the structure of the bulb (Günaydın, 2019). Kriek and Gaigher (2006) discovered, in particular, that students struggled to connect the idea of electrical resistance to other events. Additionally, the wealth of research on enhancing students' motivation, academic performance, and attitudes about the "Conduction of Electricity" unit lends credence to this conclusion (Günaydın, 2019; Ivanjek et al., 2021; Kazaklı, 2020; Yildiz et al., 2020). It is therefore considered that developing a guiding material to support teachers in using these tools more effectively and systematically would facilitate their instructional practices, provide guidance in employing them across different subject areas, and positively influence students' conceptual understanding of “Conduction of Electricity” topics. Accordingly, this study aims to develop Web 2.0-supported instructional materials for the “Conduction of Electricity” unit, to examine students' conceptual learning, and to determine their views regarding the process.

## Method

The present study utilized an *action research* framework, recognized broadly within qualitative paradigms for its cyclical and reflective nature (Kemmis & McTaggart, 1988; Stringer, 2014). Action research entails a collaborative and iterative process whereby practitioners—such as educators, school leaders, or instructional specialists—and researchers jointly identify and address issues specific to their educational contexts. This approach incorporates successive phases of planning, implementation, observation, and reflection with the dual intention of enhancing practice and producing situated knowledge (Carr & Kemmis, 1986). Within this scope, the study adopted the *technical/scientific/collaborative action research* variant, a subtype designed to rigorously evaluate or pilot interventions framed by established theoretical constructs (Corey, 1953). Under the mentorship of a researcher proficient in the theoretical domain, practitioners introduced an innovative instructional method. Throughout the implementation, the researcher conducted systematic observations and data collection to analyze outcomes, facilitating evidence-based assessments that bridge the divide between conceptual frameworks and practical application. In such studies, there is intensive interaction between the researcher and the practitioner regarding the implementation process. In technical/scientific/collaborative action research, the primary aim of the researcher is to provide a detailed description of this process (Yildirim & Şimşek, 2013). In the present study, the principal researcher sought to comprehensively describe the process by implementing guidance material supported by Web 2.0 tools in the school where they are employed. The steps followed in the action research process are

presented in detail in Table 1.

Table 1. Action Research Process of the Conducted Study

Determination of the Research Problem	The research problem was defined as the development of guidance material supported by Web 2.0 tools focused on the unit ‘Conduction of Electricity’, as well as the investigation of students’ conceptual learning related to this topic.
Formulation of Action Research Questions	Does the use of activities designed with Web 2.0 tools influence students’ conceptual understanding of electricity conduction? What are the students’ perceptions regarding the implementation process of the prepared activities?
Data Collection	Initially, while preparing the activities, an extensive review of the literature was conducted concerning both the topic of electricity conduction and studies related to Web 2.0 tools.
Data Analysis and Interpretation	Following the literature review, the collected data were analyzed and interpreted, thereby forming the theoretical foundation of the study.
Development of the Action/Implementation Plan	At this stage, 26 activities supported by Web 2.0 tools related to conduction of electricity were developed. After a pilot implementation and necessary adjustments, the activities were finalized for the main application. Additionally, five lesson plans for in-class use of the activities were prepared. To evaluate the effectiveness of the study, a Concept Understanding Test and semi-structured interview questions—developed based on expert opinions—were finalized through pilot studies.
Development of the Monitoring Plan	The Concept Understanding Test was administered as a pre-test before the main application and as a post-test following the implementation. Semi-structured interviews were conducted with six students selected based on their high, medium, and low post-test scores, focusing on the process and conceptual understanding. Audio recordings were made during the interviews.
Implementation of the Action Plan and Monitoring	In this phase, a total of 42 sixth-grade students—21 from the pilot study and 21 from the main study—participated in the implementation of the activities prepared with Web 2.0 tools, following the predefined plan.
Analysis and Evaluation of the Implementation	At this stage, the researcher analyzed the results of the implementation, evaluating the effectiveness of the activities and the plan, identifying problems encountered during the process and their causes, and discussing potential measures to address these issues.

### Sample

Convenience sampling was employed in this study due to considerations of accessibility and practicality. This non-probability sampling technique enables efficient and timely data collection by selecting participants from cases that are readily available to the researcher within their immediate context. Such an approach is particularly advantageous when alternative sampling strategies are impractical or infeasible (Yildirim & Şimşek, 2013). The

research was conducted through two distinct phases: a pilot study and the main implementation, both carried out at the institution where the principal investigator is employed. One branch of the school was randomly selected to participate in the pilot study, while the other branch was designated as the site for the main implementation. Consequently, the sample comprised 21 sixth-grade students from the main implementation branch of Şehit Erhan Dural Girls Anatolian Imam Hatip High School during the spring semester of the 2023–2024 academic year. In addition, semi-structured interviews were conducted with six students purposively selected from the main study group based on their high, medium, and low scores on the Concept Understanding Test. These interviews aimed to gain deeper insights into the students' conceptual comprehension and their experiences with the learning process facilitated by Web 2.0-supported activities.

### **Implementation Process**

In this study, a teacher's guide material was developed for the 6th-grade Science unit entitled "Conduction of Electricity" grounded in the constructivist learning theory's 5E instructional model and enhanced with Web 2.0 tools. The instructional design comprised a total of 12 class hours, with detailed lesson plans created and executed accordingly. A variety of pedagogical strategies were employed, including direct instruction, question-and-answer sessions, collaborative group work, active learning techniques, classroom discussions, and prediction-observation-explanation sequences. The integration of Web 2.0 technologies facilitated a dynamic and interactive learning environment. The instructional process was structured around diverse activities such as word clouds, concept cartoons, animations, digital presentations, and gamified applications. During the engagement phase, students collaboratively constructed a word cloud using the Wordart application to activate prior knowledge, followed by a guided discussion designed to capture and maintain student attention. In the exploration phase, students participated in prediction-observation-explanation activities supported by worksheets and hands-on experiments. Working in groups, they conducted experiments, documented their observations, and shared findings within the classroom to solidify conceptual understanding. The explanation phase included viewing an animation video sourced from the EBA platform, complemented by detailed scientific explanations delivered through a Canva-supported presentation. To deepen understanding, the elaboration phase featured interactive, game-based learning activities developed via the Wordwall platform. Finally, the evaluation phase involved individual assessments conducted with the aid of Plikers response cards.

### **Data Collection Instruments and Analysis**

In this study, two primary data collection instruments were utilized: a Concept Understanding Test designed to assess the impact of the developed activities on students' conceptual comprehension, and semi-structured interviews aimed at capturing students' perceptions regarding the implementation process.

#### *Concept Understanding Test*

The Concept Understanding Test consisted of 15 open-ended questions. The alignment between the test questions and the learning outcomes is presented in Table 2.

Table 2. Learning Outcomes and Corresponding Question Numbers

Learning Outcome	Question Numbers
6.7.1.1. Classifies materials based on their ability to conduct electricity by using a designed electric circuit.	1, 2, 3
6.7.1.2. Explains, with examples, how the electrical conductivity and insulation properties of materials are used in daily life.	4, 5, 6
6.7.2.1. Predicts the variables affecting the brightness of a bulb in an electric circuit and tests these predictions experimentally.	7, 8, 9
6.7.2.2. Defines electrical resistance.	10, 11, 12
6.7.2.3. Recognizes that the filament inside a bulb has resistance.	13, 14, 15

To ensure the validity and reliability of the developed test, feedback was obtained from two science teachers, and a pilot study was conducted. Based on the received feedback, necessary revisions were made, and the final version of the test was prepared.

The students' responses to the Concept Understanding Test were analyzed in two stages. First, each student's answers were categorized and scored according to the categories employed in the study by Abraham, Williamson, and Westbrook (1994) (Table 3). Subsequently, the Wilcoxon signed-rank test was applied to compare students' pre-test and post-test scores, and the results were presented in tabular form. Additionally, frequency tables were generated based on the categorized data according to the learning outcomes derived from the Concept Understanding Test. The total possible score for each student ranged from 0 to 60. Each student's level of understanding was individually evaluated for each question, scored accordingly, and the overall achievement score was computed.

Table 3. Scoring Categories Used in the Concept Understanding Test

Numeric Score	Understanding Category	Description
4	Complete Understanding (CU)	Responses that fully encompass scientifically accepted concepts
3	Partial Understanding (PU)	Responses that include some scientifically accepted concepts
2	Partial Understanding with Specific Misconception (PUMC)	Responses showing partial understanding but containing a specific conceptual misconception
1	Specific Misconception (MC)	Responses that contain conceptual misconceptions
0	No Understanding (NU)	Blank, meaningless, repetitive, irrelevant, or ambiguous responses

### *Semi-Structured Interviews*

Two types of interviews were conducted in this study. Students were asked about their views regarding the implementation process. Interview data collected from six students—selected based on high, medium, and low

scores on the Concept Understanding Test—were analyzed using content analysis, a qualitative data analysis method that involves systematic coding and categorization to identify themes and patterns within textual data (Creswell & Poth, 2018; Elo & Kyngäs, 2008). The findings were organized into tables according to the variables of “theme,” “category,” “code,” “participant, Student1(S1),.....Student N (Sn)” “sample student statements,” and “frequency.” During the analysis, no predetermined coding scheme was employed; instead, natural codes were inductively generated based on students’ expressions, following the conventional content analysis approach (Hsieh & Shannon, 2005).

## Findings

### Findings Obtained from the Concept Understanding Test

The pre-test and post-test results of the Concept Understanding Test, which was administered to 6th-grade students to examine their conceptual understanding within the “Conduction of Electricity” unit, were analyzed comparatively using the Wilcoxon signed-rank test in SPSS 25.0. The results are presented in Table 4.

Table 4. Wilcoxon Signed-Rank Test Results for Scores Obtained from the Concept Understanding Test

Pre-post test	N	Mean rank	Sum of ranks	Z	p
Negative ranks	0	.00	.00	-4.02	.000*
Positive ranks	21	11.00	231.00		

\*p<.05

According to the Wilcoxon signed-rank test, the change in students’ scores on the Concept Understanding Test was statistically significant ( $z = -4.02, p < .05$ ). The effect size, calculated based on Cohen’s (1988) criteria, was large ( $r = .62$ ). The median scores increased from the pre-test ( $Md = 28.57$ ) to the post-test ( $Md = 49.67$ ). Finally, this section presents frequency tables and bar charts that show the distribution of students’ responses to the pre- and post-tests of the Concept Understanding Test across categories (CU, PU, PUMC, MC, NU) for each learning outcome.

Table 5 provides the frequency distribution of students’ responses to Questions 1, 2, and 3—aligned with Learning Outcome 6.7.1.1—across these categories.

Table 6. Frequency Distribution of Student Responses to Questions Corresponding to Learning Outcome 6.7.1.1

6.7.1.1 Classifies materials based on their ability to conduct electricity by using a designed electrical circuit.	Question No	Pre- Test					Post- Test				
		CU.	PU.	PUMC.	MC.	NU.	PU.	PU.	PUMC.	MC.	NU.
	1.	5	7	5	0	4	17	3	0	1	0
	2.	7	8	2	0	4	18	2	1	0	0
	3.	12	0	7	0	2	18	0	3	0	0

In the pre-test, the number of students demonstrating Correct Understanding (CU) was 5 for Question 1, 7 for Question 2, and 12 for Question 3. For Question 1, 7 students fell into the Partial Understanding (PU) category, while 5 students were classified under Misconception (PUMC). In Question 2, 8 students were categorized as PU and 2 students as PUMC. Additionally, No Understanding (NU) category, indicating responses devoid of scientific meaning, accounted for 4 students in Questions 1 and 2, and 2 students (9.5%) in Question 3. In the post-test, the number of students classified as CU increased markedly to 17 for Question 1, 18 for Question 2, and 18 for Question 3. The PU category included a total of 3 students across the first two questions, whereas the PUMC category was represented by 3 students in Question 3. Notably, no students fell within these categories for Questions 1 and 2. Moreover, the NU category was not observed in the post-test responses.

Table 6 provides the frequency distribution of students' responses to Questions 4, 5, and 6—aligned with Learning Outcome 6.7.1.2—across these categories.

Table 6. Frequency Distribution of Student Responses to Questions Corresponding to Learning Outcome 6.7.1.2

6.7.1.2 Explains, with examples, how the electrical conductivity and insulation properties of materials are used in daily life.	Question No	Pre- Test					Post- Test				
		CU.	PU.	PUMC.	MC.	NU.	CU.	PU.	PUMC.	MC.	NU.
	4.	9	2	9	0	1	16	0	5	0	0
	5.	6	4	9	0	2	19	0	2	0	0
	6.	20	0	1	0	0	19	2	0	0	0

The percentage of students who showed Complete Understanding (CU) on the pre-test varied from 14% (9 students) to 95% (20 students). Notably, Question 6 exhibited a high level of achievement (95%), whereas only 9 students attained CU in Question 4, and this figure further declined to 6 students for Question 5. Across Questions 4, 5, and 6 in the pre-test, only 3 students (approximately 4.7%) were categorized under No Understanding (NU). Following the intervention, post-test results showed an increase in CU category membership to 16 students for Question 4, 19 students for Question 5, and 19 students for Question 6.

Table 7 presents the frequency distribution of student responses to Questions 7, 8, and 9, which correspond to Learning Outcome 6.7.2.1.

Table 7. Frequency Distribution of Student Responses to Questions Corresponding to Learning Outcome 6.7.2.1

6.7.2.1. Predicts the variables affecting the brightness of a bulb in an electric circuit and tests these predictions experimentally.	Question No	Pre- Test					Post- Test				
		CU.	PU.	PUMC.	MC.	NU.	CU.	PU.	PUMC.	MC.	NU.
	7.	1	3	7	4	5	17	0	3	1	0
	8.	1	3	6	5	6	8	1	12	0	0
	9.	5	6	0	4	6	18	1	0	2	0

For Question 7, only one student (4.8%) was classified in the CU category; the majority of students' responses

were distributed primarily across the PU, PUMC and NU categories, with proportions of 33.3%, 19.0%, and 23.8%, respectively. A similar pattern was observed in Question 8, where the CU rate remained at 4.8%, while the proportion of students in the NU category increased to 28.6%. Although the CU rate for Question 9 increased slightly to 23.8%, the proportion in the NU category remained constant, with a substantial number of students' responses distributed across the MC and PU categories.

In the post-test, the proportion of students classified under the CU category increased to 81% for Question 7 and 85.7% for Question 9. Notably, no students remained in the NU category for these two questions. Although the CU rate for Question 8 rose to 38.1%, 57.1% of the students were still categorized under PUMC. The proportion of students achieving CU prior to the intervention ranged between 4.8% and 23.8%, whereas post-intervention rates increased substantially to 81.0% and 85.7% for Questions 7 and 9, respectively. Meanwhile, the proportion of students in the NU category, which ranged from 23.8% to 28.6% in the pre-test, was completely eliminated in the post-test. It is noteworthy that 12 students remained in the PU category for Question 8.

Table 8 presents the frequency distribution of student responses to Questions 10, 11, and 12, which correspond to Learning Outcome 6.7.2.2.

Table 8. Frequency Distribution of Student Responses to Questions Corresponding to Learning Outcome 6.7.2.2

6.7.2.2.		Pre- Test					Post- Test				
Defines electrical resistance.	Question No	CU.	PU.	PUMC.	MC.	NU.	CU.	PU.	PUMC.	MC.	NU.
		10.	0	1	0	1	19	10	0	4	3
	11.	0	4	5	5	6	9	0	6	4	2
	12.	0	0	1	2	18	11	1	6	0	3

Analysis of the pre-test data revealed that no students (0%) achieved the Complete Understanding (CU) category for Question 10, with only one student (4.8%) classified under Partial Understanding (PU). Additionally, one student (4.8%) was categorized as having MC, while the vast majority, 19 students (90.5%), fell into the No Understanding (NU) category. A similar pattern was observed in Question 11, where no students attained CU, 4 students (19%) were in the PU category, and five students (23.8%) each were classified under Partial Understanding with Specific Misconception (PUMC) and MC categories. Notably, 6 students (28.6%) remained in the NU category. For Question 12, only one student (4.8%) was in the PUMC category, 2 students (9.5%) were in MC, and the majority, 18 students (85.7%), were categorized as NU. In the post-test, the number of students achieving CU for Question 10 increased to 10 (47.6%), while those in the NU category decreased significantly from 19 to 4 students. For Question 11, 9 students (42.9%) reached CU, and 6 students were classified as PUMC, with the NU category reducing to 2 students. In Question 12, 11 students (52.4%) achieved CU, only 3 students (14.3%) remained in the NU category, and 6 students (28.6%) were classified as PUCM.

Table 9 presents the frequency distribution of student responses to Questions 13, 14, and 15, which correspond to Learning Outcome 6.7.2.3.

Table 9. Frequency Distribution of Student Responses to Questions Corresponding to Learning Outcome 6.7.2.3

6.7.2.3. Recognizes that the filament inside a bulb has resistance.	Question No.	Pre- Test					Post- Test				
		CU.	PU.	PUMC.	MC.	NU.	CU.	PU.	PUMC.	MC.	NU.
	13.	2	9	0	1	9	18	3	0	0	0
	14.	0	0	1	7	13	12	0	4	3	2
	15.	8	1	7	0	5	7	2	12	0	0

According to the pre-test results, only 2 students (9.5%) achieved the Complete Understanding (CU) category for Question 13, with the highest proportion, 9 students (42.9%), classified under Partial Understanding (PU). Additionally, 1 student (4.8%) was categorized as MC, and 9 students (42.9%) fell into the No Understanding (NU) category. For Question 14, no students reached the CU category (0%), while 1 student (4.8%) was classified under Partial Understanding with Specific Misconception (PUMC), 7 students (33.3%) under MC, and 13 students (61.9%) under NU. In Question 15, 8 students (38.1%) achieved CU, 1 student (4.8%) was in PU, 7 students (33.3%) in PUMC, and 5 students (23.8%) in NU. In the post-test, the number of students in the CU category for Question 13 increased to 18 (85.7%), with only 3 students (14.3%) remaining in PU. For Question 14, 12 students (57.1%) attained CU, while the remaining students were mostly distributed across PUMC (19.0%), MC (14.3%), and NU (9.5%) categories. For Question 15, the number of students in CU remained at 7 (33.3%), whereas 12 students (57.1%) shifted to the PUMC category.

In order to gain deeper insights into students' perceptions of the instructional process, semi-structured interviews were conducted, and the data obtained from their responses were subjected to a systematic qualitative analysis. This analytical process, consistent with the principles of qualitative research design, involved identifying recurrent themes, categorizing related concepts, and assigning corresponding codes. The resulting framework not only organizes the qualitative findings but also facilitates the interpretation of patterns emerging from the participants' perspectives. The synthesized results are presented in a comprehensive matrix that integrates the dimensions of Theme, Category, Code, Participant, Student Opinion, and Frequency. This matrix, shown in Table 10, serves as a structured representation of how students articulated their experiences and viewpoints regarding the integration of Web 2.0 tools into science education. By aligning these elements, the table enables both the systematic comparison of participant responses and the identification of prevalent trends across the dataset.

Upon examination of Table 10, it is evident that, under the theme of General Attitudes and Perceptions, students expressed that they found the lessons enjoyable, frequently stating that "lessons should always be like this." Regarding the theme of Effects of Web 2.0 Tools on Learning, students indicated that these tools facilitated understanding, promoted permanent learning, and increased their interest in the lesson. One student remarked, "While solving the tests, I recalled the topics we covered in class," highlighting the perceived connection between the lesson content and assessment performance. It was also noted that the tools contributed to improving students' technological literacy. On the other hand, certain challenges were reported, particularly related to time and technical issues, as reflected in comments such as "There was not enough time; we wanted to play the games longer" and "Accessing the internet took our time." Applications such as Canva, Quizizz, Kahoot, and PhET were

well received by the students. Finally, they emphasized that Web 2.0 tools could also be beneficial in other subjects, including Mathematics, Turkish, Social Studies, and English.

Table 10. Theme/Category/Code Matrix for Science Education Supported by Web 2.0 Tools

Theme	Category	Code	Participants	Example Student Statements	Frequency (f)
<b>Science lessons supported by Web 2.0 tools</b>	General attitudes and perceptions	Positive attitude	S1, S2, S4, S11, S15, S18	It was very enjoyable; I wish all lessons were like this.	6
		Negative attitude	–	–	0
<b>Impact of Web 2.0 tools on learning</b>	Contribution to learning	Supports permanent learning	S1, S2, S11, S15, S18	After the lesson, I understood and solved the tests better.	5
		Facilitates understanding	S1, S2, S4, S11, S15, S18	While solving the tests, I remembered the lessons we studied and realized I understood them better.	6
		Increases interest in the lesson	S11, S15, S18, S1	We always wanted to have science lessons.	4
		Provides interactive content	S2, S4, S11, S15, S18	When using Web 2.0 tools, we actively participated by typing answers on the screen. For example, with Quizizz, we took an active role in competitions.	5
		Advantages of Web 2.0 tools	Contribution to the teaching process	Improves digital literacy	S1, S15, S18
<b>Disadvantages of Web 2.0 tools</b>	Challenges and limitations	Time management issues	S1, S2, S11, S15, S18	We wanted to play the games longer, but the lesson ended quickly.	6
		Technical problems / infrastructure deficiencies	S1, S2, S18	Connecting to the internet took our time. We wanted smaller groups, but couldn't due to connection issues.	2
<b>Preferred Web 2.0 tools</b>	Frequently used and liked tools	Quizizz	S15	It was fun to compete with the whole class.	1
		PhET	S11	The simulations caught my	1

Theme	Category	Code	Participants	Example Student Statements	Frequency (f)
				attention. I could build my own circuit as I wished.	
		Canva	S1, S2, S4, S11, S15	It was great to create my own unique designs with Canva.	5
		Kahoot	S18, S4	It is suitable for group work and makes in-class competition exciting.	2
<b>Challenges in using Web 2.0 tools</b>	Problems encountered during use	Technical difficulties (internet, devices, freezing)	S11, S15, S18	There were times when the internet didn't work, and some classmates' computers froze.	3
		Time-consuming nature	S1, S2, S11	The applications were fun, but since we ran out of time, we had to move on to another activity.	3
		Need for prior training on the tools	S15, S18	Our teacher provided training on the tools, but it still took me some time to learn some of them.	2
<b>Use of Web 2.0 tools in other subjects</b>	Expanding application to other lessons	Mathematics	S1, S2, S11, S15, S18	I would understand mathematics better and solve problems faster.	5
		Social Studies	S1, S4	Since Social Studies relies on memorization, I would understand it better.	2
		Turkish	S4, S15, S18	We could develop our vocabulary with word clouds and create our own designs.	3
		English	S1, S18	Learning vocabulary would be easier, and all lessons would become more enjoyable.	2

## Discussion and Conclusion

This study employed a conceptual understanding test to investigate the impact of Web 2.0-enhanced instructional materials on students' conceptual learning. Analysis of the pre-post test results, supported by the Wilcoxon signed-rank test findings (see Table 4), revealed a statistically significant improvement in students' post-test scores compared to their pre-test scores ( $z = -4.02, p < .05$ ), indicating a positive effect of the intervention. These

results align with previous studies (Baki, 2022; Gürleroğlu & Yildirim, 2022; Köse et al., 2021) reporting that Web 2.0 tools foster conceptual understanding, academic achievement, and positive attitudes toward technology.

The observed increase in students' ability to provide higher-order responses underscores the value of integrating cognitive and visual supports into instruction. In this respect, the Web 2.0 tools utilized in the present study appear to have made a notable contribution. Consistent with this, prior research has demonstrated the effectiveness of Web 2.0-based approaches in promoting conceptual development. For example, Can (2021) found that conceptual cartoons supported by Web 2.0 tools enhanced students' science achievement and attitudes, while Alp (2019) reported significant gains in conceptual understanding following a Web 2.0-supported Scratch-based learning process. These findings corroborate the marked increase in "Complete Understanding" levels observed in the current study. Moreover, Demirezer (2022) reported that Web 2.0-supported activities positively influenced conceptual achievement alongside visual literacy and spatial skills. Collectively, these results provide robust evidence that Web 2.0 tools can substantially enhance conceptual learning outcomes.

Analysis of students' responses to the conceptual understanding test, based on the learning outcome 6.7.1.1 ("Classifies materials according to their ability to conduct electricity using an electric circuit they have designed"), revealed notable improvements in understanding the concepts of electrical conductivity and insulation. In the pre-test, the proportion of students in the "No Understanding" (NU.) category for Questions 1, 2, and 3 was 19%, 19%, and 9.5%, respectively; these rates were entirely eliminated in the post-test. Concurrently, the "Full Understanding" rates rose to 81%, 85.7%, and 85.7% for the same questions (see Table 5). Conductivity and insulation are among the challenging concepts in science education, often remaining at an abstract, rote-learning level due to their limited observability in daily life. Previous research (Alp, 2019; Yildirim, 2020) has demonstrated that the visual and interactive affordances of Web 2.0 tools can effectively address such abstract-concept misconceptions. In the present study, the guide material—particularly through the integration of PhET simulations—enabled students to virtually test and observe conductive and insulating materials within an electric circuit, promoting experiential and comparative learning. Complementary tools such as Quizizz supported knowledge reinforcement, while Canva-facilitated concept mapping helped structure conceptual knowledge. These findings align with prior studies (Baki, 2022; Cıtaç, 2023; Köse et al., 2021) showing that Web 2.0-supported instruction enhances both achievement and attitudes toward technology, with Köse et al. (2021) further emphasizing its positive impact on conceptual understanding. Accordingly, the guide material's combination of visual, auditory, and experiential learning opportunities appears to have contributed significantly to students' improved comprehension of conductivity and insulation.

The learning outcome 6.7.1.2 ("Explains, with examples, the purposes for which the conductive and insulating properties of materials are used in daily life") aimed to assess not only students' recognition of these properties but also their ability to relate them to real-life contexts. Pre-test data indicated a low level of such contextual association: for Questions 4 and 5, the CU category rates were 43% and 29%, respectively, while for Question 6 this rate reached 95%. Following the intervention, the CU. rates for Questions 4, 5, and 6 increased to 76%, 90%, and 90%, respectively (see Table 6). This improvement is attributed to the use of interactive competition environments and visual content creation tools such as Quizizz and Canva, which enabled students to learn in an

enjoyable yet meaningful way. Indeed, student statements such as “I designed my own electrical device using Canva and understood the function of each part” (see Table 10) directly reflect this outcome. Similar findings have been reported in the literature. For example, Gürleroğlu and Yildirim (2022) demonstrated that students were more successful in transferring concepts to concrete contexts when working with Web 2.0–supported content, while Demirezer (2022) noted that these tools facilitate conceptual transfer through the enhancement of visual literacy skills.

The learning outcome 6.7.2.1 (“Predicts the variables affecting the brightness of a bulb in an electric circuit and tests these predictions through experimentation”) aimed to foster students’ understanding of the variables influencing bulb brightness and their ability to experimentally explore the relationships among these variables. Pre-test results revealed low levels of conceptual understanding: for Questions 7 and 8, the “Complete Understanding (CU)” rate was only 4.8%, and for Question 9, 23.8%. These low rates suggest that students struggled to distinguish variables such as resistance, current, and voltage, and to conceptualize their causal relationships. By the end of the intervention, post-test results showed substantial improvement: CU. rates for Questions 7 and 9 increased to 81% and 85.7%, respectively, indicating that Web 2.0 tools had a positive effect on learning by enabling visualization and experiential exploration of complex relationships (see Table 7). In particular, the use of PhET simulations allowed students to manipulate variables independently and observe the resulting effects. As one student noted, “I didn’t understand why the bulb’s brightness was changing, but when I set up the circuit, I realized” (Table 14), clearly reflecting the power of experiential learning. However, the fact that 57.1% of students remained at the “Partial Understanding with Misconception” (PUMC.) level for Question 8 indicates that some still confused resistance and voltage. This finding aligns with Demirezer’s (2022) observation that certain concepts require more extensive experimental practice and repetition. Similarly, Yildirim (2020) reported that Web 2.0–supported instruction enhances students’ self-directed learning with technology, which in turn supports the internalization of complex concepts. Alp (2019) emphasized that Scratch-based Web 2.0 applications improve conceptual understanding and critical thinking, particularly by concretizing abstract concepts through digital interactive tools. Likewise, Gürleroğlu (2019) found that learning environments in which students take active roles in experimental processes significantly improve their ability to grasp causal relationships—a finding consistent with the improvements observed in this study.

The learning outcome 6.7.2.2 (“Defines electrical resistance”) aimed to measure students’ understanding of the concept of electrical resistance. Pre-test results revealed that no students achieved “Complete Understanding” (CU.) in Questions 10, 11, or 12. In particular, 85.7% of students were in the “No Understanding” (NU.) category for Questions 10 and 12, while 28.6% fell into this category for Question 11, with the remainder distributed across the “Partial Understanding” categories (PU, PUMC, MC). These findings indicate that the concept of resistance was abstract and cognitively challenging for students. Post-test results, however, showed a marked improvement: CU. rates rose to 47.6% for Question 10, 42.9% for Question 11, and 52.4% for Question 12 (see Table 8). This progress can largely be attributed to the PhET simulations used in the guide material, which allowed students to manipulate resistance values in a circuit and directly observe the effects. This experiential approach helped them conceptualize resistance more meaningfully. As one student expressed, “Resistance is like an obstacle in the circuit; it slows down the current. I saw it that way in PhET” (see Table 10), clearly illustrating the contribution

of these tools to conceptual understanding. Similar findings are reported in the literature. Ekemen (2022) emphasized that Web 2.0–supported science instruction enhances digital literacy and critical thinking skills while fostering conceptual awareness. Likewise, Sarıkaya and Aydın (2021) found that EBA- and experiment-supported activities significantly improved achievement in topics related to electric circuits, demonstrating that supporting abstract concepts with concrete experiences strengthens learning.

The learning outcome 6.7.2.3 (“Recognizes that the filament inside a bulb has resistance”) aimed to assess students’ awareness of the resistance exhibited by a bulb’s filament and their ability to apply this knowledge in a functional context. Pre-test results showed that the proportion of students achieving “Complete Understanding” (CU.) was as low as 9.5% for Question 13 and 0% for Question 14, with 61.9% in the “No Understanding” (NU.) category for Question 14 (see Table 9). In the post-test, however, CU. rates rose markedly to 85.7% for Question 13 and 57.1% for Question 14, indicating that students had moved beyond merely recognizing the concept to understanding it in a functional context. Nonetheless, the fact that 57.1% of students remained in the “Partial Understanding with Misconception” (PUMC.) category for Question 15 suggests that, for some, the concept was only partially internalized. This may be attributed to the multifaceted nature of electrical resistance, which can be challenging to fully conceptualize, as well as to individual differences in learning pace and ability to process abstract concepts. The observed improvement can be largely attributed to the PhET simulations incorporated into the guide material, which enabled students to learn through direct experimentation. Additionally, tools such as Canva helped students visualize and articulate the concept, while game-based platforms like Quizizz reinforced their understanding. As one student reflected, “I used to wonder why the bulb was dim, but in the PhET circuit, I realized the filament has resistance” (see Table 10), clearly illustrating the impact of experiential learning. These findings are consistent with the literature. Gürleroğlu (2019) emphasized the importance of experimental contexts in concretizing abstract concepts related to resistance. Bolatlı and Korucu (2018) highlighted that learning environments supported by interactive simulations enhance students’ abilities to question scientific concepts and establish causal relationships. Similarly, Sarıkaya and Aydın (2021) reported that constructivist, experiment-based activities significantly improve achievement in topics related to electric circuits.

Overall, a significant progression was observed across all learning outcomes, with students moving from the “No Understanding” level toward “Complete Understanding.” It can be concluded that interactive, student-centered instructional practices supported by Web 2.0 tools effectively enhance conceptual understanding. However, the persistence of misconceptions in certain outcomes indicates the need for ongoing revision of this instructional model and the restructuring of content according to conceptual difficulties.

An analysis of students’ perspectives regarding the science course supported by Web 2.0 tools revealed that their responses clustered into eight principal themes (see Table 10): general attitudes and perceptions, contributions to learning, contributions to the instructional process, disadvantages, preferred tools, challenges encountered during usage, and application in other subject areas. Examination of Table 10 indicates that students’ overall experiences with the intervention were predominantly positive. Within the theme of “General Attitudes and Perceptions,” all participants reported that Web 2.0–enhanced lessons were engaging and enjoyable, characterizing this instructional approach as more motivating and captivating relative to traditional pedagogy (Participants S1, S2,

S4, S11, S15, S18). The statement, “The lessons were very enjoyable; I wish all classes were conducted in this manner,” (see Table 10) succinctly encapsulates the prevailing student sentiment. These findings suggest that the inherently interactive and learner-centered attributes of Web 2.0 technologies substantially augment learners’ engagement and interest in the educational process. Corroborating these findings, Yazıcıoğlu et al. (2023) observed that instruction incorporating Web 2.0 tools was perceived by students as enjoyable, memorable, and comprehensible, thereby fostering enhanced motivation and interest. Moreover, Akbaba (2019) demonstrated that Web 2.0–supported science instruction favorably influenced students’ attitudes toward the subject matter as well as their dispositions toward technology use. Collectively, these outcomes imply that the positive student perceptions are largely attributable to the interactive, participatory nature of the Web 2.0 tools employed.

Under the theme of “Contribution to Learning,” students reported that Web 2.0 tools supported conceptual understanding, enhanced the retention of knowledge, and facilitated comprehension. For instance, statements such as “After the lessons, I better understood and solved the tests” and “While solving tests, I recalled the lessons we covered” reflect students’ learning experiences. These findings indicate that Web 2.0 tools contribute positively to students’ cognitive processes, supporting durable learning. Similarly, Can (2021) reported that Web 2.0–supported conceptual cartoons positively impacted students’ achievement and conceptual understanding in science courses. Additionally, Yildirim and Şimşek (2023) noted that interactive digital content enhances students’ meaning-making processes.

One of the most salient aspects highlighted regarding the contributions of Web 2.0 tools to the instructional process is the enhancement of students’ digital competencies. Student testimonies, such as “I acquired proficiency in tools like WordArt and Canva, and now independently create my own designs,” (see Table 10) indicate not only an advancement in disciplinary knowledge but also a significant development in digital literacy skills. This outcome underscores the interdisciplinary skill-building potential inherent in Web 2.0–supported pedagogies. This assertion is corroborated by Yazıcıoğlu et al. (2023), whose findings reveal that students exhibited growth not only in academic knowledge but also in creative production and digital proficiency through engagement with Web 2.0 tools. Similarly, Sarıkaya and Aydın (2021) observed that such implementations contribute substantively to the cultivation of multifaceted competencies.

Conversely, participants identified several constraints associated with the use of Web 2.0 tools. Challenges related to “time management” and “inadequate technical infrastructure” emerged as significant impediments impacting the efficacy of instructional delivery. Illustrative student comments such as “We wished to engage with the games more extensively; however, the lesson duration was insufficient,” and “The time consumed in establishing an internet connection detracted from instructional time,” exemplify the detrimental influence of technical and temporal limitations on the learning experience. Moreover, a subset of students emphasized the necessity of preliminary training regarding the utilized tools, highlighting that effective technology integration extends beyond mere provision of resources to encompass comprehensive pedagogical guidance and technical support. These observations align with prior research; Uysal (2020) emphasized that factors such as time allocation, internet connectivity issues, and hardware inadequacies can adversely affect the effective deployment of Web 2.0 technologies within classroom environments. Correspondingly, Ekemen (2022) noted that preparatory training for

students significantly enhances the overall efficacy of technology-assisted learning interventions.

Another notable finding presented in Table 10 is students' explicit preferences for specific Web 2.0 tools. Platforms such as Canva, Quizizz, PhET, and Kahoot emerged prominently, with Canva's design-oriented interface and the competitive, interactive nature of Quizizz and Kahoot receiving particular acclaim. These tools not only facilitate content delivery but also actively engage students in the learning process. Expressions such as "Competing with the class was enjoyable" and "I can build my own circuit as I wish" illustrate how this interactivity directly contributes to learning. Ortakarsu and Sülün (2022) emphasized that students exhibit higher motivation and participation in competition-based learning environments. Additionally, Can (2021) reported that production-based tools like Canva enhance students' creativity and engagement with the lesson.

Furthermore, students articulated the view that Web 2.0 tools should be integrated into other subject areas as well. They suggested that these tools could be effectively utilized in mathematics, Turkish language, social studies, and English courses, contributing to making lessons more enjoyable. These perspectives underscore the flexibility and efficacy of Web 2.0 tools as integrative resources applicable across disciplines, not limited to science education alone. Correspondingly, Yazıcıoğlu et al. (2023) and Sarıkaya and Aydın (2021) highlighted the high interdisciplinary potential of Web 2.0 tools and their positive impact on achievement in various subject areas.

In summary, the student perspectives presented in Table 10 indicate that Web 2.0 tools contribute positively not only to academic achievement but also to students' attitudes toward learning, classroom engagement, digital competencies, and interdisciplinary skills. However, technical challenges, time constraints, and the need for preliminary training must also be considered. Accordingly, the planning of such innovative instructional models should incorporate appropriate infrastructure and time management strategies to ensure effective implementation.

## **Recommendations**

Within the scope of the present study, the quantitative and qualitative findings indicate that science education facilitated through Web 2.0 tools exerts a positive impact, particularly on students' conceptual understanding. Nevertheless, the study is constrained by its limited sample size and the examination of a single unit within the science curriculum. Accordingly, the generalizability of the findings could be enhanced by extending the research to encompass students from diverse socioeconomic backgrounds, different geographic regions, and varying age groups, thereby enabling a comparative analysis of the efficacy of Web 2.0 tools.

The Web 2.0 tools used in the guide material for the study are limited Canva, Quizizz, Kahoot, WordArt, and PhET. The investigation revealed that platforms such as Canva, Quizizz, Kahoot, WordArt, and PhET contribute effectively to the development of students' meaning-making, reinforcement, and application skills. These digital tools and the others can be systematically integrated into science education curricula through a constructivist pedagogical framework.

According to student perspectives, significant challenges associated with the implementation of Web 2.0 tools include time limitations and technical malfunctions. To mitigate these issues, it is recommended that example

lesson plans designed to optimize instructional time be developed and disseminated among educators, alongside initiatives aimed at addressing infrastructural deficiencies within educational institutions.

Furthermore, interviews with students highlighted a preference for the utilization of Web 2.0 tools beyond the confines of science instruction, extending to disciplines such as Turkish language, mathematics, English, and social studies. Restricting the deployment of these tools solely to science education may limit their pedagogical potential; therefore, their active application across multiple subject areas is likely to enhance the durability of learning outcomes. In this regard, fostering the interdisciplinary use of Web 2.0 tools is advisable.

## Notes

This study was taken from the first author's master thesis conducted under the supervision of the second author.

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## The Role of Mobile Technology in Language Learning: A Study on University Students

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### Abstract

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This study examines the influence of Mobile-Assisted Language Learning (MALL), a branch of mobile learning (M-learning), on language acquisition among university students in Azerbaijan. As technology becomes increasingly embedded in higher education, the research investigates the extent to which mobile applications and platforms enhance language skills, with a particular focus on student engagement and learning outcomes. Quantitative data were collected through online surveys completed by Azerbaijani university students, capturing both the benefits and limitations of using mobile learning tools. Positive feedback emphasized gains in listening skills, vocabulary expansion, and learning flexibility. Conversely, negative experiences highlighted issues such as limited content variety, insufficient opportunities for conversational practice, and distractions caused by advertisements and notifications. The results suggest that MALL can be highly effective in supporting language learning when combined with engaging, interactive, and well-structured content. Nonetheless, challenges related to repetitive tasks, technical errors, and content design must be addressed to optimize its educational potential and ensure a more sustainable and productive learning experience.

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## Introduction

With the rapid advancement of technology, Mobile learning, specifically Mobile-Assisted Language Learning (MALL), has emerged as a powerful tool for enhancing language learning experiences. The widespread use of smartphones and mobile applications has provided learners with flexible and accessible platforms to improve their language skills beyond traditional classroom settings. MALL allows learners to practice listening, speaking, vocabulary, and pronunciation skills through interactive and gamified applications (Kukulska-Hulme & Shield, 2008). In a meta-analysis of 20 years of MALL research, Burston (2015) discovered that although many projects showed promising learning effects, these studies' methodological rigor was frequently lacking. The results' generalizability was restricted by factors like small sample sizes, a lack of control groups, and brief study durations. Despite these difficulties, Burston emphasized that, if instructional design is in line with pedagogical objectives, MALL may be a useful tool for improving listening comprehension and vocabulary. Burston and Giannakou (2022) built on this work by performing a more thorough meta-analysis that covered 25 years of MALL research (1994–2019). Their results confirmed that MALL can improve language acquisition, especially in listening comprehension and vocabulary. They also emphasized the need for more research on how mobile learning promotes sustainable language development by pointing out that there are few studies on MALL's long-term retention and practical application. The study also pointed out the significance of learner autonomy and motivation, highlighting that the degree to which students actively use the technology determines how effective mobile learning is. However, despite its potential, the effectiveness of MALL remains influenced by various factors, including content quality, user engagement, and technical limitations.

This study explores mobile technology's role in language learning among Azerbaijani university students. By analyzing students' experiences and perceptions, the research identifies the key benefits and challenges associated with MALL. The study employs a quantitative research approach, utilizing a structured questionnaire with close-ended questions for statistical analysis, while two open-ended questions provide qualitative insights, combining quantitative data analysis with thematic coding to understand how mobile learning tools contribute to language development and engagement. Additionally, the research seeks to provide recommendations for integrating MALL more effectively into higher education language courses. The findings of this study will contribute to the growing body of literature on mobile learning in higher education and offer practical insights for educators and policymakers to enhance the learning experience through technology.

## Literature Review

### Mobile Learning

Mobile learning, also known as m-learning, is a modern educational approach that utilizes portable devices, including smartphones, tablets, and laptops, to facilitate learning anytime and anywhere. Unlike traditional classroom-based instruction, m-learning allows students to access educational resources, participate in interactive activities, and engage with content on demand. This flexibility makes it particularly valuable in higher education, where students often balance coursework with other commitments (Crompton, 2013). A key advantage of mobile learning is its accessibility, enabling students to continue their education beyond the physical classroom. Many

mobile learning applications and platforms incorporate multimedia elements, such as videos, podcasts, gamified exercises, and AI-driven chatbots, which cater to diverse learning styles (Al-Said, 2015).

In language learning, mobile devices have become constant companions, providing learners with authentic materials, real-time feedback, and opportunities for practice in various contexts (Godwin-Jones, 2017). According to Kukulska-Hulme (2009), mobile learning has the potential to transform language acquisition by supporting informal, contextual, and self-directed learning experiences. Furthermore, m-learning fosters collaborative learning, as students can communicate with peers and instructors through discussion forums, messaging apps, and virtual study groups, creating a dynamic and interactive learning environment that bridges formal and informal education.

### **Mobile-Assisted Language Learning (MALL)**

In the field of language education, mobile learning plays a crucial role in Mobile-Assisted Language Learning (MALL), a subcategory of m-learning that focuses on enhancing language acquisition through the use of mobile technology (Kukulska-Hulme & Shield, 2008). Language learners benefit from mobile apps that provide interactive vocabulary exercises, pronunciation practice, real-time feedback, and AI-powered language tutors. Due to its adaptive learning mechanisms, research suggests that m-learning can improve language retention, engagement, and motivation (Stockwell, 2013). Mobile learning applications offer several advantages for language learners. One key benefit is personalized learning, as many apps provide adaptive content tailored to the learner's proficiency level, ensuring a customized learning experience. Additionally, gamification and motivation play a significant role in engagement, with platforms like Duolingo and Memrise incorporating game-like elements such as rewards, streaks, and challenges to encourage consistent practice (Godwin-Jones, 2017). Furthermore, mobile learning enables continuous learning opportunities, allowing students to practice language skills anytime and anywhere, making education more flexible and accessible (Stockwell, 2013). Recent studies highlight the effectiveness of mobile apps in language education. One of the studies by Chen et al. (2020) found that mobile learning apps significantly improve vocabulary retention and listening skills. Research by Viberg and Grönlund (2017) indicates that students prefer mobile apps for informal learning rather than formal coursework. Studies also suggest that social media platforms like Instagram, YouTube, and TikTok play a growing role in language learning by providing authentic content and interactive engagement (Lee, 2022).

However, despite its advantages, mobile learning also presents challenges. These include digital distractions, internet dependency, lack of structured learning pathways, and varying levels of technological literacy among students (Loewen et al., 2019; McQuiggan et al., 2015). Additionally, while many mobile learning applications offer free content, premium features often require paid subscriptions, which may limit access for some students.

#### *Theories Support MALL*

Mobile learning is underpinned by several theoretical frameworks, one of which is connectivism. Connectivism, introduced by Siemens (2005), expands on traditional learning theories by focusing on the role of digital networks

and technology in modern education. According to this theory, learning occurs through connections with various information sources, including online communities, multimedia content, and social media interactions. In the context of mobile learning, students can access authentic language materials, such as podcasts, videos, and online discussions, and engage with native speakers or language learners worldwide, fostering a dynamic and immersive learning experience. The theory of Connectivism (Siemens, 2005) emphasizes that learning in the digital age is driven by networks and connections across platforms and communities. In the context of MALL, this theory is highly relevant as learners interact with authentic content, native speakers, and language learning communities through mobile apps and social media platforms. This supports the development of learner autonomy and collaborative learning environments, as Kukulska-Hulme (2012) suggested.

Additionally, self-regulated learning theory (Carneiro et al., 2007) highlights that mobile learning tools empower learners to take control of their learning process, track progress, and set personalized goals. Thus, mobile learning allows for autonomy, letting learners track progress, set goals, and customize their learning experiences through apps with personalized feedback. Studies have shown that gamified features in apps like Duolingo and Busuu enhance motivation and engagement (Krashen, 2014; Rosell-Aguilar, 2018), while progress-tracking tools boost learner accountability (Li, Fan & Wang, 2022).

Another relevant framework is Self-Directed Learning (SDL), developed by Knowles (1975), which highlights the importance of learner autonomy and self-regulation. Mobile learning supports SDL by allowing students to take control of their education, set their own learning goals, track their progress, and choose resources that match their needs and preferences. In technology-enhanced learning environments, self-regulated learning plays a crucial role in allowing students to take ownership of their learning process, set goals, and monitor their progress effectively (Carneiro et al., 2007). Unlike traditional classroom-based learning, where students follow a fixed curriculum, mobile learning offers the flexibility to practice language skills at their own pace, access diverse content, and tailor their learning experience based on individual strengths and weaknesses. By integrating these theories, mobile learning provides a student-centered, network-driven, and self-paced approach to language acquisition, making it a powerful tool for modern education.

#### *Mobile Learning in the Azerbaijani Context*

Although mobile learning has been widely explored in global research, studies focusing on Azerbaijan remain limited. Evidence suggests that Azerbaijani university students are increasingly turning to mobile devices for academic purposes, yet institutional support for integrating m-learning into higher education is still minimal (Hajiyev, 2018). This study addresses that gap by examining how students in Azerbaijan use mobile applications to enhance their language learning.

As the country's higher education system undergoes digital transformation, challenges such as outdated infrastructure, insufficient faculty training, and the absence of coherent digital policies persist (Aliyev & Aliyeva, 2024). These issues underscore the potential of mobile learning as an accessible, scalable solution. During the COVID-19 pandemic, the Ministry of Science and Education launched the "Virtual School" platform to maintain

continuity in education. By the end of the 2020–2021 academic year, it had registered over 1.4 million students, 128,186 teachers, and more than 1.1 million active users (Ministry of Science and Education of the Republic of Azerbaijan, 2022).

Research by Teymurova et al. (2020) shows that mobile learning can be adapted to the Azerbaijani context while respecting cultural values, such as respect for elders and practical, results-oriented instruction. Similarly, Hajiyev (2018) highlights both the promise and the barriers of m-learning adoption, emphasizing the need for user-friendly platforms and adequate institutional support. Together, these findings point to mobile-assisted language learning as a promising path for improving educational outcomes in Azerbaijan's higher education landscape.

## **Methodology**

### **Research Design**

This study employs a quantitative research approach to investigate the impact of mobile-assisted language learning (MALL) on the language development and engagement of university students. Using a purposive sample technique, the questionnaire was disseminated through university departments to reach language-learning students. The target group was chosen in accordance with the goals of the study, even though participation was entirely voluntary. The data was collected through a structured questionnaire consisting of 22 questions, which aimed to gather numerical data on students' usage patterns, preferences, and experiences with mobile learning apps. The online survey was distributed to 103 university students, and responses were analyzed to identify trends and patterns in mobile learning behavior. The majority of the questions were close-ended, allowing for statistical analysis, while two open-ended questions provided qualitative insights into students' positive and negative experiences with MALL. The quantitative data were analyzed using descriptive statistics (e.g., frequency and percentage analysis). At the same time, thematic coding was applied to the open-ended responses to identify recurring themes related to user experiences and challenges. The mixed-method approach allowed for a more comprehensive understanding of students' attitudes toward mobile learning, as the statistical data revealed general trends, while the qualitative data offered deeper insights into the effectiveness and limitations of mobile learning platforms.

### **Research Questions**

Which mobile apps do students use for language learning?

How do these apps impact their language skills?

What are the challenges and benefits of using mobile apps for language learning?

### **Participants**

The survey targeted undergraduate students in Azerbaijan. There were 110 responses. After editing, 103 responses (excluding incomplete and insincerely responded to 7 answers) were analyzed. The participants were from diverse academic disciplines, providing a broad perspective on mobile learning habits among university students.

## Data Collection

The survey was conducted online using Microsoft Forms and consisted of 22 questions, covering the following areas:

- Demographic Information: Age and academic background.
- Mobile Learning Practices: Frequency of mobile app usage for language learning.
- Types of Apps Used: Preferred platforms (e.g., Duolingo, Memrise, YouTube, podcasts, online dictionaries).
- Effectiveness of Mobile Learning: Students' perceptions of how mobile apps support language skill development.
- Challenges in Mobile Learning: Limitations or difficulties encountered while using mobile learning tools.

## Data Analysis

Responses were filtered to exclude incomplete entries that did not provide sufficient data for analysis. The final dataset was analyzed using descriptive statistics (percentages, frequencies) to identify trends in mobile learning usage. Open-ended responses were thematically coded to highlight qualitative insights.

## Results

### Q1: How old are you?

The majority of respondents (27.2%) are 20 years old, followed by 17-year-olds (23.3%). The smallest group is the 21-year-olds (9.7%) (see Table 1). The mean age of the respondents is 18.81 years, indicating that most participants are in the early stages of their university education. The majority of respondents are women (75%), while men constitute 25% of the sample. A significant portion of respondents (40%) are English Language Teaching (ELT) students, which aligns well with the study's focus on mobile-assisted language learning. Engineering students make up 20%, while the remaining 40% come from various disciplines such as Translation, Architecture, and Language & Literature. The diverse academic background of participants provides a broad perspective on how students from different fields engage with mobile learning tools.

Table 1. Age Distribution of Respondents

Age (years)	Number of Respondents	Percentage (%)
17	24	23.3%
18	20	19.4%
19	21	20.4%
20	28	27.2%
21	10	9.7%
<b>Total</b>	<b>103</b>	<b>100%</b>

**Q4: What year are you in?**

First-year students (42.7%) and third-year students (44.7%) make up the majority of the respondents. Second-year students (6.8%) and fourth-year students (5.8%) represent a much smaller portion of the participants.

**Q5: How often do you use mobile devices (smartphones, tablets) for language learning?**

The majority of respondents (62.1%) use mobile devices daily for language learning, indicating a strong dependence on mobile-assisted learning tools. Nearly a third (31.1%) use them a few times a week, which still shows regular engagement with mobile learning. Very few students (5.8%) use them only once a week, and just 1% reported using them rarely. None of the respondents reported "Never" using mobile devices, suggesting that mobile learning is widely adopted among university students in Azerbaijan.

**Q6: Which devices do you mainly use for language learning?**

Mobile phones are the dominant device (80.6%) used for language learning, reinforcing the central role of smartphones in mobile-assisted learning. Laptops (11.7%) are the second most commonly used, likely for more structured or academic-related tasks such as writing and research. Tablets (5.8%) are used by a small portion of students, which could be due to their lower availability compared to smartphones. A few respondents (1.9%) use other devices, which may include e-readers, smart speakers, or other digital tools.

**Q8: Which language learning apps or platforms have you used?**

YouTube (82.5%) is the most widely used platform, reflecting students' preference for free, easily accessible, and diverse content. Duolingo (69.9%) is the most popular dedicated language-learning app, showing a strong preference for gamified learning. BBC Learning English (41.7%) is another widely used resource, indicating that students rely on structured educational content from trusted institutions. Memrise (6.8%), Cambly (5.8%), and Busuu (4.9%) are much less common, likely due to subscription costs or less awareness among students. Other platforms (12.6%) suggest students explore additional apps or websites beyond the most well-known options – Telegram channels, Google Translate, ChatGPT, HalloTalk, Babbel, Tandem, Quizlet, Naver, Longman dictionary, Elsa Speak. Dillbill (0.9%) has almost no usage, which may indicate its limited availability or lesser reputation among learners.

**Q10: What features do you find most useful in language learning apps?**

Speaking and Pronunciation Practice (72.8%) is the most valued feature, indicating that students seek tools that help them improve oral fluency and pronunciation. Vocabulary-building exercises (70.9%) are nearly as popular, showing that students prioritize learning new words and phrases. Listening Exercises (66.0%) are also widely used, highlighting the importance of comprehension skills in language acquisition. Interactive Quizzes and Games (29.1%) appeal to a smaller group, suggesting that gamification is helpful but not the main priority for most

learners. Grammar Explanations (25.2%) are relatively low in preference, possibly because learners prefer more practical and engaging methods. AI-Based Chatbots or Tutors (19.4%) have the lowest preference among major categories, which could indicate that students either find them ineffective or have limited access to advanced AI-based learning tools. Only 2.9% of respondents mentioned "Other" features, showing that mainstream apps already cover the most common language-learning needs such as slang, and accents.

**Q12: Do you use social media platforms (e.g., Instagram, TikTok, YouTube) for language learning?**

A significant majority (86%) of students actively use social media for language learning, showing the growing influence of informal digital learning environments. 14% of respondents answered "Maybe," indicating that they might use social media for learning but not as their primary method. Only 3% stated they do not use social media for language learning, suggesting that nearly all students recognize the educational potential of platforms like Instagram, TikTok, and YouTube.

**Q13: If yes, which social media platforms do you use for language learning?**

YouTube is the most preferred platform (86 users), making it the dominant social media tool for language learning. This aligns with research on video-based learning, as YouTube offers free, structured courses, tutorials, and native-speaker interactions. Instagram is the second most used platform (53 users), likely due to educational reels, vocabulary posts, and grammar infographics. TikTok is also highly popular (45 users), showing the effectiveness of short-form, engaging content in learning (Peng et al., 2020). Facebook and WhatsApp are the least used platforms, possibly because they lack structured educational content. WhatsApp may still be useful for peer-to-peer language practice or group discussions. Other platforms (X, Reddit, Google, Character.AI, ChatGpt) are used by 7 respondents, suggesting that some students prefer discussion forums, AI-driven chatbots, or general search engines for learning.

**Q15: How effective do you find mobile apps for improving your language skills?**

A majority (96 respondents, 93%) find mobile apps effective for language learning. 46 respondents (45%) consider them "very effective," while 50 (49%) find them "somewhat effective." This highlights that mobile apps play a crucial role in students' language development, reinforcing previous research on MALL (Mobile-Assisted Language Learning). Only 3 respondents (3%) found mobile apps "not very effective", while no one rated them as "not effective at all". This suggests that while mobile apps are generally beneficial, they might not be equally effective for every learner.

**Q16: Which language skills have improved the most due to mobile learning?**

The findings of this study reveal that mobile-assisted language learning (MALL) plays a significant role in enhancing learners' language skills, particularly listening, speaking, and vocabulary development. The results align with previous research in the field, such as Soyooft et al. (2023) and Rosell-Aguilar (2018), which emphasize

the positive impact of mobile learning platforms on language acquisition. The most positively affected skill is listening (72 respondents), suggesting that mobile learning apps and platforms provide strong auditory input through podcasts, videos, and interactive listening exercises. This aligns with the popularity of YouTube (86 users) and BBC Learning English (43 users) as primary learning tools. 63 respondents reported improved vocabulary, reinforcing the effectiveness of apps like Duolingo (72 users) that focus on word retention through gamified exercises. This indicates that flashcards, word games, and contextual learning in mobile apps significantly contribute to vocabulary acquisition. Speaking (51 respondents) ranks third, suggesting that AI chatbots, pronunciation tools, and interactive speaking exercises play a vital role in enhancing verbal communication.

However, fewer students selected speaking compared to listening, possibly indicating a lack of real-time conversation opportunities in mobile learning apps. 46 respondents reported reading improvement, showing that mobile apps provide access to digital texts, articles, and comprehension exercises. This supports the use of social media (Instagram, TikTok, YouTube) for consuming educational content (Lin & Lin, 2019). Only 16 respondents reported improvement in writing, and 18 in grammar, making them the least impacted skills. This suggests that mobile learning tools are less effective at developing structured writing skills, as they focus more on interactive engagement rather than formal composition.

#### **Q17: What motivates you to use mobile apps for language learning?**

Accessibility is the most significant motivator (53 Responses, 51%). The majority of respondents (53 out of 103) stated that the ability to learn anytime and anywhere is their primary reason for using mobile apps. This highlights the flexibility and on-the-go learning advantage of mobile-assisted language learning (MALL). Interactivity and fun play a key role (28 Responses, 27%). Many students are motivated by engaging and entertaining content, which suggests that game-like features, quizzes, and interactive exercises make learning more appealing. This aligns with the popularity of apps like Duolingo, Memrise, and YouTube, which use engagement-driven learning approaches. The following most answered response is personalized Learning Experience (17 Responses, 16%). Some learners appreciate customized content based on their needs, indicating that adaptive learning paths and AI-driven recommendations play a role in motivation. Progress tracking and gamification have less impact (4 Responses, 4%). Surprisingly, only a few learners (4) mentioned progress tracking or gamification (badges, streaks, rewards) as their main motivation. This suggests that while gamified features exist, they may not be a strong driving force in long-term engagement. Only one respondent (1 Response, 1%) highlighted learning from native speakers as a motivation. This could indicate a lack of accessible real-time speaking practice with native speakers in mobile learning apps.

#### **Q19: What challenges do you face when using mobile learning apps for language learning?**

Ads and Distractions are the biggest challenge. More than half of the respondents (53 Responses, 51%) struggle with distractions from advertisements, notifications, or unrelated content. This suggests that ad-heavy apps may negatively impact learning engagement and that students may prefer ad-free or premium versions. The following challenge is limited free content, which is a major concern (43 Responses, 42%). Many mobile learning apps offer

only partial access to lessons, requiring payment for premium content. This financial barrier could limit students' ability to benefit from mobile learning resources fully. Furthermore, lack of motivation affects a large group (36 Responses, 35%). Some learners find it difficult to stay motivated and disciplined when using mobile apps for language learning. This aligns with the earlier finding that gamification and progress tracking were not strong motivators. Maintaining Regular Usage, which got 18 Responses (17%), is a challenge for some. While mobile learning offers flexibility, sticking to a routine can be difficult for some users. This suggests that apps could improve habit-building features, such as reminders, streaks, or social accountability features. There are other challenges mentioned by 2 respondents. They mentioned health-related issues (eye strain from screen time) and translation errors in mobile learning apps. This highlights the need for ergonomic app design and high-quality, contextually accurate translations.

### **Q21. Can you share a positive or negative experience you've had while using mobile learning apps for language learning?**

The open-ended responses from participants provided valuable qualitative insights into the perceived benefits and challenges of mobile-assisted language learning (MALL). A thematic analysis of the responses revealed key themes that align with this study's broader findings (see Table 2).

Table 2. Themes

Themes	Sub-categories	Supporting literature
Skill Development	Listening (72 quantitative responses); Vocabulary (63 quantitative responses); Pronunciation; Speaking; Engagement with native speakers; Learning slang & idioms (3 mentions)	These findings support previous research emphasizing the effectiveness of MALL in enhancing language competencies (Rosell-Aguilar, 2018).
User-Friendly Features	Flexibility (12 mentions); Accessibility (8 mentions), learning anytime, anywhere	This aligns with the principles of Situated Learning Theory (Li, Fan & Wang, 2022) which emphasizes the role of context and real-world application in learning. This theme reflects the convenience and accessibility of mobile learning apps, which are crucial for learners.
Social and Motivational Aspects	Gamification (daily reminders, awards) (3 mentions); Making friends (1 mention)	This is supported by Stockwell's (2013) discussion on technology-enhanced motivation in language learning.

Despite its advantages, several challenges emerged. Thematic analysis of the negative responses reveals three major themes: Content and Quality Issues, Technical and External Factors, and User Experience. The content and quality issues category received the highest number of mentions, indicating that users are dissatisfied with the quality and relevance of the content provided by mobile learning apps. Simple content, lack of free content, and limited access to common spoken language content were the most frequently mentioned issues, with 18 responses. This suggests that learners feel restricted in accessing authentic, real-life language materials. The result supports Krashen's (2014) argument that mobile apps often focus on structured input rather than authentic language use. Another key concern was the lack of conversational practice and commonly used vocabulary (8 mentions), reflecting gaps in the interactive capabilities of mobile learning tools. Lack of instructions, limited opportunities for conversational practice, and insufficient commonly used vocabulary highlight the gap between theoretical knowledge and practical usage. Memorization and repetitive learning methods were also pointed out by 3 respondents, showing that some apps rely heavily on rote learning, which can be demotivating for learners.

Technical challenges were another major concern for users. This theme highlights the importance of enhancing the functionality and accessibility of the apps while minimizing distractions and technical issues. Ads and distractions were mentioned 10 times, indicating that excessive advertisements disrupt the learning flow. AI errors and the need for an internet connection were cited 4 times, which shows that technical glitches and dependence on a stable internet connection hinder learning progress. Distracted notifications were also mentioned 4 times, reflecting the struggle of maintaining focus in a mobile learning environment. These findings highlight a common frustration with the user experience of mobile apps, which could hinder engagement. Similar concerns were raised in Kukulska-Hulme (2009, 2012, 2017), emphasizing that while mobile learning has advantages, usability and content quality remain critical areas for improvement. Although the user experience theme received fewer mentions, "waste of time" was reported by 1 respondent, which reflects individual dissatisfaction with the overall learning process and effectiveness of the app.

### **Comparison with Quantitative Findings**

The qualitative insights align with the survey results, where limited free content (43 responses) and distractions from ads (53 responses) were among the top challenges. Meanwhile, accessibility (53 responses) and skill improvement (particularly listening and vocabulary) were key motivators. These parallels between qualitative and quantitative data strengthen the argument that MALL is beneficial but requires improvements in content variety, interactive features, and user experience.

### **Q22. Do you think mobile learning should be integrated more into university language courses? Why or why not?**

Key themes in participant responses about the incorporation of mobile learning into university language courses were found using thematic coding analysis. Several recurrent viewpoints were identified by the investigation (see Table 3). The majority (71.8%) strongly support integrating mobile learning into university language courses. A smaller proportion (8.7%) supports it but with reservations. 5.8% are unsure, 13.6% oppose mobile learning

integration. The responses categorized under “Yes” were thematically coded to identify recurring patterns. According to the survey results, the most frequently mentioned theme is interactivity (62.7%), highlighting that students value engaging and interactive learning experiences in mobile-assisted language learning. Practicality (28.4%) is another key factor, indicating that learners appreciate real-life applications and efficiency. Accessibility (19.4%) and flexibility (17.9%) show that mobile learning is valued for its ease of access and adaptable nature. Technology Age (17.9%) suggests that students recognize the role of technological advancements in shaping modern learning.

Table 3. Responses on Integration

Response Category	Frequency (N)	Percentage (%)	Cumulative Percentage (%)
Yes (1)	74	71.8%	71.8%
Yes, but (2)	9	8.7%	80.5%
Maybe (3)	6	5.8%	86.4%
No (4)	14	13.6%	100.0%
<b>Total</b>	<b>103</b>	<b>100.0%</b>	—

The majority of participants who responded "Yes, but" said they preferred mobile learning as an adjunct to traditional training rather than as a substitute. Although they acknowledged its advantages, they emphasized the importance of teachers in the educational process. Potential over-reliance on technology, a decline in interpersonal interaction, and the idea that mobile learning should enhance in-person instruction rather than take its place were among the worries.

Uncertainty about integrating mobile learning was evident in the "Maybe" responses. Because mobile learning is self-directed and may not be suitable for all students, these participants had doubts regarding its efficacy. They also expressed worries about possible distractions in the classroom and the challenge of efficiently managing time when utilizing mobile devices. They were hesitant to completely support it because of these difficulties, even though they saw its potential benefits.

The majority of "No" replies opposed the use of mobile technology in the classroom. Many people thought that self-study was a better fit for mobile learning than organized classroom activities. One prevalent worry was that mobile devices can cause disruptions, resulting in diminished concentration and diversions. Furthermore, some respondents voiced the opinion that depending too much on mobile learning would make students lazy and less inclined to engage fully in class.

## Limitations

Even though this study offers insightful information about the function of mobile-assisted language learning (MALL) in academic settings, several limitations should be noted. The study first used a purposive sample technique, in which participants were chosen from university departments. Although this strategy made sure that the replies came from language-learning students, it might restrict how broadly the results can be applied because

the sample might not accurately reflect the wide range of college students with different degrees of experience with mobile learning.

Second, just two open-ended questions were included in the study, despite the fact that it contained both quantitative and qualitative data. Although these answers provide insightful information, a more thorough qualitative method, such as focus groups or interviews, could go deeper into the experiences, difficulties, and reasons why students use mobile learning resources.

## **Conclusion**

This study examined how mobile-assisted language learning (MALL) functions in university language classes and examined how students see its incorporation into the classroom. According to the results, most respondents had a generally favorable opinion of MALL and acknowledged its potential to improve language instruction's flexibility, accessibility, and engagement. Students emphasized how mobile learning can help with vocabulary growth, listening comprehension, and general language competency.

Concerns about its implementation are also raised by the results, though. Many participants stressed the value of striking a balance between technology and conventional teaching techniques, even though they favored the use of mobile learning as an additional tool. Concerning time management and distractions, a few students voiced skepticism regarding the self-directed nature of mobile learning. Others were adamantly against its inclusion, pointing to the dangers of fewer student participation, heightened reliance on technology, and possible disruptions in the classroom.

Overall, the study indicates that, with careful implementation, MALL might be a useful tool for language learning. The best method to take advantage of mobile learning's benefits while resolving issues may be to use a mixed learning strategy, in which it complements traditional instruction rather than takes its place. Future studies should examine certain approaches to incorporating mobile learning that optimize student involvement while reducing any potential negative effects.

## **Recommendation**

This study investigated the impact of Mobile-Assisted Language Learning (MALL) on university students' language learning experiences, focusing on the effectiveness, benefits, and challenges of mobile learning tools. The findings revealed that mobile learning is perceived as highly effective, particularly for enhancing listening, vocabulary, and pronunciation skills, which aligns with previous research (Rosell-Aguilar, 2018; Crompton, 2013). A significant number of participants highlighted the flexibility and accessibility of mobile apps, supporting Kukulska-Hulme and Shield's (2008) argument that mobile learning allows learners to engage with language content anytime and anywhere. However, limited free content, lack of conversational practice, and distractions from ads emerged as major challenges, consistent with the findings of Soyooof et al. (2023).

Moreover, almost 72 % of respondents supported integrating MALL into university courses, reflecting Kukulska-Hulme et al.'s (2017) view that mobile learning can enhance formal language education when combined with collaborative and interactive strategies. This study also confirms that mobile learning promotes learner autonomy, as highlighted by Kukulska-Hulme (2012), allowing students to self-regulate their learning and track progress through digital platforms.

Research suggests that integrating mobile learning tools into university language courses can enhance student engagement and learning outcomes. Carneiro et al. (2007) argue that blended learning environments that combine traditional classroom instruction with mobile learning tools lead to more effective learning experiences. In this study, 74 participants supported the idea of integrating mobile learning into university courses, which aligns with these findings.

Furthermore, the findings suggest that while MALL is widely used and considered effective, its implementation in formal education settings should address content limitations and engagement strategies (Shadiev, Liu, & Hwang, 2020). Future research could explore how mobile learning platforms can better integrate social and interactive elements to facilitate real-world language use, as suggested by Siemens' (2005) Connectivism Theory.

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## Critical Factors That Shape the Pedagogical Integration of ICT in Technology-Rich Senior High Schools

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### Abstract

The common belief is that providing technological tools and equipment leads to the pedagogical integration of ICT in schools. This study tested this idea by examining key factors and contextual barriers that influence how ICT is integrated pedagogically in technology-rich Senior High Schools in Ghana. Using a cross-sectional survey design, data were collected from 103 teachers in both public and private SHSs with modern ICT infrastructure. The study investigated important factors such as learning styles and needs, teacher motivation and incentives, teachers' perceived ease of use of technology, and ICT infrastructure. A multiple regression analysis revealed that teacher motivation/incentives and ICT infrastructure are significant predictors of the level of pedagogical ICT integration. These factors together explain 59.1% of the variation in ICT integration, while perceived ease of use and learning styles/needs were not significant predictors. Despite the availability of ICT resources, teachers highlighted contextual challenges, including a lack of technical skills, misalignment of technology with curriculum goals, difficulties in shifting to interactive learning methods, and promoting digital citizenship. These findings demonstrate that resources alone are insufficient; addressing pedagogical and systemic barriers is essential for meaningful ICT integration in SHSs. The implementation of sustainable technology integration in schools requires establishing policies which promote ICT-enhanced teaching methods, professional development and teacher motivation.

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## Introduction

The educational community maintains an ongoing interest in how Information and communication technologies (ICT) should be integrated into the teaching and learning process. The educational process requires modern technology alignment since ICT integration produces visible benefits for student learning and engagement (Arkorful et al., 2021). The integration of ICT in Senior High Schools (SHSs) creates possibilities to enhance students' technological and computer literacy skills, particularly through digital collaboration and internet-based research and information evaluation (Aremu et al., 2020). However, the implementation of ICT integration in teaching and learning encounters institutional and systemic obstacles which reduce its effectiveness despite its potential benefits for student learning, engagement and academic performance (Fernández-Gutiérrez et al., 2020). Most research about ICT integration in SHSs has investigated gender and region together with subject and infrastructure (e.g. Dei, 2021; Arkorful et al., 2021) but excluded essential elements such as learning styles/needs, teacher motivation/incentives and teachers' perceived ease of use of available infrastructure. This study investigates the factors driving ICT integration within private and public SHSs that possess modern technology resources to understand the current status of ICT integration in SHSs with technological infrastructure. The research explores essential variables to develop evidence-based approaches for improving ICT integration in instructional practices. The success of ICT pedagogical integration depends on supporting teachers in developing their technology skills and confidence rather than merely installing modern ICT infrastructure (Dede et al., 2019). Teachers need both administrative and technical support alongside ICT infrastructure provision to effectively integrate these technologies into their classroom instruction (Pernia-Espinoza et al., 2020). Teachers' technological competence and their ability to choose appropriate software for instruction directly affect student learning outcomes (Churchill et al., 2016). The effectiveness of technology integration depends on both teacher ICT training, stable electricity and internet services, along with continuous professional development programs (Bingimlas, 2021; Amemasor et al., 2025). These problems require combined action from policymakers together with school leaders and teachers (Kirkman, 2020; Rosenberg & Koehler, 2015)

## Statement of the Problem

The push to improve ICT infrastructure and digital tool access in Ghanaian SHSs has been significant. Initiatives like the Ministry of Education's connectivity project, which brought internet access to schools, the i-Box campus systems that offer digital content, and the OpenSTEM African virtual laboratories, among others (Ministry of Education, 2025), have really boosted access to modern ICT resources in schools. However, in many well-resourced SHSs, these advancements have not necessarily led to meaningful changes in teaching methods. The effective use of ICT in education remains random and often falls short of making a real impact. Teachers frequently rely on technology for basic tasks, such as looking up information and creating slides, instead of using it to foster student-centered activities, promote interactivity, engage students, and assess their learning (Asare & Okyere, 2020).

Teacher training programs need to match classroom requirements for successful technology integration in order to provide students with the required practical learning experiences (Gyamfi et al., 2025). Research shows that

the Ghanaian government's ICT for Accelerated Development (ICT4AD) policy failed to deliver promised classroom outcomes even though schools possess ICT infrastructure. The research conducted by Mintah et al. (2023) revealed that computers remained unused in instruction by 95.8% of teachers, while 83% of available computers lacked instructional software. The findings about ICT classroom success factors need further investigation to determine their actual influence on educational outcomes. Technology-rich schools face ongoing obstacles because they lack adequate technical assistance and teachers need ongoing professional development, and their institutions maintain traditional approaches to education and rigid curricula (Silva et al., 2023). The successful implementation of ICT integration in schools requires immediate solutions to these critical issues. This research aims to identify the elements and obstacles which determine successful ICT pedagogical integration in Ghanaian SHSs. The study will provide evidence-based recommendations for policy decisions and teacher support systems to improve technology-based education in Ghana.

### **Purpose of the Study**

The purpose of the study is to investigate the factors influencing the pedagogical integration of ICT in technology-rich SHSs, aiming to inform policymakers and educational leaders about the necessary contextual conditions for ICT adoption in teaching and learning. Specifically, the study seeks to assess the predictive effect of ICT infrastructure, student learning styles and needs, teachers' perceived ease of use of existing technologies, teacher motivation, and institutional support on the level of ICT use in instructional practice. Additionally, the study aims to contribute to the existing body of knowledge by providing insights into the current state of ICT integration in Ghanaian technology-rich schools, thereby supporting evidence-based decision-making for enhancing technology-driven education.

### **Research Questions**

1. To what extent do factors such as ICT infrastructure (ICTIF), Learning Styles and Learning Needs (LSLN), Teachers' Perceived Ease of Use (TPEU), and Incentives and Motivation for Teachers (IMT) and institutional support predict the level of ICT integration in teaching within technology-rich SHSs?
2. What contextual barriers hinder the effective integration of ICT in teaching despite the availability of ICT resources in SHSs?

## **Literature Review**

### **Status of ICT Integration in Ghanaian SHSs**

There has been mixed progress in the implementation of ICT policy regarding the integration of ICT in Ghanaian SHSs. Although there has been significant improvement in access to technology, challenges persist in integrating ICT in teaching and learning (Mensah & Adu, 2020). Over 70% of public secondary schools are equipped with ICT laboratories with computers and other digital equipment. Initiatives like the Ghana Online Learning Platform have also expanded access to digital educational resources (Arkorful et al., 2021). However, outdated software misaligned with the national curriculum, as well as limited professional development opportunities for teachers,

continue to hinder effective ICT integration (Mensah & Adu, 2020).

The lack of continuous professional development programs has reduced the overall impact of ICT on educational outcomes. The necessary knowledge and skills for technology integration in instructional practice are absent from practicing teachers (Asare & Okyere, 2020). The improvement in internet connectivity has not eliminated the ongoing resource distribution inequalities between rural and urban schools. More investments in modern ICT infrastructure, enhanced teacher professional development programs and the development of high-quality digital content tailored to the Ghana curriculum are needed to fully harness the potential of ICT in SHS education.

### **Factors That Influence Teachers' Integration of ICT in Their Instruction**

The implementation of ICT in educational practices depends on multiple contextual elements. The current research identifies essential variables which determine the integration of ICT in classroom teaching methods. Stockdill and Moreshouse (1992) established that four fundamental elements, including user characteristics and content considerations, together with organizational capacity and technological factors, form the foundation of effective ICT integration. The educational technology adoption process heavily depends on the presence of factors which exist at the teacher, school and system levels according to Balanskat et al. (2007). This means that, successful deployment of technology relies on elements at both the individual and institutional levels.

Teachers' attitude toward technology integration along with institutional backing and continuous professional development, determines the adoption of ICT in education (Lim and Chai, 2018). Ghavifekr and Rosdy (2015) found in their Malaysian study that proper ICT infrastructure, together with continuous teacher training, results in successful ICT integration. The research by Gil-Flores et al. (2017) in Spain proves that classroom ICT implementation effectiveness depends on teacher factors, including self-efficacy perceptions, ICT training, educational software access and collaborative practices.

The use of ICT for teaching and learning is determined by personal characteristics, including the educational background of teachers, gender and years of teaching experience (Schiller, 2003; Campbell, 2020). According to Jones (2020) technology integration depends more on teacher preparedness and personality characteristics than physical school technology availability. Teachers who maintain positive technology attitudes along with strong implementation intentions and basic computer competency tend to integrate ICT into their educational practices (Liaw & Huang, 2015; Teo, 2018; Drent & Meelissen, 2018; Tatnall, 2020). The way a teacher feels about technology implementation directly affects their ability to effectively use ICT. A teacher's assessment of technology usefulness for teaching purposes determines their willingness to adopt it (Wilson, 2020; Hew & Brush, 2017).

The classroom adoption of ICT also depends on teachers' self-efficacy, together with their competence and their individual learning preferences and requirements (van Braak et al., 2010; Peralta & Costa, 2007). Teachers need to learn multiple application tools to achieve effective teaching. Teachers who lack technical proficiency face doubts about their ability to choose suitable technologies for classroom integration (Peralta & Costa, 2007). The

amount of work demands placed on teaching professionals affects their readiness to accept new technology. The combination of excessive course management, skill development, and administrative work prevents teachers from using technology in their educational activities according to Iftikhar (2016) and Plomp et al. (2020). The successful implementation of technology integration depends heavily on institutional factors, which include teacher access to technology and structured teacher development programs and leadership support (Anderson & Dexter, 2011; Plair, 2018).

Research findings continue to demonstrate that ICT integration in education depends on both personal characteristics and contextual conditions. Teye and Duah's (2022) study in Ghana reveals that ICT adoption depends on four essential factors, which include attitude, perceived usefulness, access to ICT tools and training and technical support. The research established that motivation, together with incentives, proved to be the most influential factors among all studied variables. The level of ICT integration in primary and secondary education depends mainly on teachers' pedagogical beliefs, according to Almerich et al. (2024). The research shows that national ICT in education policies do not match the actual classroom practices as documented by Abedi (2024). The educational sector maintains traditional teaching methods even though policies promote technology-based student-centered learning. The educational sector needs immediate professional development to match teacher beliefs with policy recommendations.

The systematic review performed by Martin et al. (2025) revealed new insights about how contextual elements affect ICT integration. Martin et al. (2025) identified four categories of factors which affect ICT integration: school-related, student-related, teacher-related and technology-related factors. The school-related factors consist of support, culture, background and curriculum while student-related factors consist of demographic details, affective, cognitive and behavioral aspects. Teacher-related factors consist of teacher conditions, beliefs and their backgrounds, while technology-related factors consist of ease of access and usability. Student cognitive engagement proved to be the main factor that supports ICT integration, yet teacher technostress acted as a barrier to successful implementation. The study shows that ICT integration success depends on more than infrastructure. Teachers' perception of technology as easy to use, their learning style and needs, their motivation levels, institutional support and policy objectives that match educational content and classroom teaching methods are imperative.

## Methodology

A cross-sectional survey design, targeting teachers from technology-rich public and private schools, was used in the study. The target population was 230 teachers in both public and private schools. The public schools were Accra Academy (100) and St. Mary's SHS (70), while the private schools were Apostle Sarfo SHS (35) and Ideal College (25) (see Table 1). Using Yamane's (1967) formula with a 95% confidence interval, a sample size of 150 academic staff was determined as representative of the study population. However, out of 150 questionnaires distributed to the sample size, only 103 were retrieved successfully and used for the data analysis, representing a 68.67 % response rate.

Table 1. Sample Size Categories

Schools	Classification	Total population	Sample Size
Accra Academy SHS	Public	100	50
St. Marries SHS	Public	70	50
Apostle Sarfo SHS	Private	35	25
Ideal College	Private	25	25
<b>Total</b>		<b>230</b>	<b>150</b>

### Sampling Method

A convenience sampling method was used to select teachers from the chosen SHSs due to cost and time efficiency. Convenience sampling involves selecting participants based on their easy accessibility rather than random selection, making it suitable for exploratory research or studies with limited resources and tight timelines (Salkind, 2010). While not as rigorous as random sampling, it is often the most practical choice when other methods are not feasible due to resource or access constraints (Creswell & Creswell, 2017).

### Data Collection Instrument

The primary data collection instrument was a questionnaire. The questionnaire combined validated scales from different sources. Infrastructure and Support scales were adopted from Eze et al. (2021), Ease of Use and Self-Efficacy scales were adopted from Teo (2009), Motivation and Adapt learning-style scales were adopted from Al-Awidi and Aldhafeeri (2017). To establish validity, the instrument was reviewed by experts in ICT education research, followed by a pilot test with 20 teachers who shared characteristics with the study sample. Feedback from experts and the pilot test was incorporated to refine the instrument. Additionally, the reliability of the questionnaire was assessed using Cronbach's Alpha coefficient, which fell within the acceptable range of 0.70 to 0.90 (see Table 2), as suggested by Creswell and Creswell (2017).

Table 1. Reliability

Factors	Cronbach's Alpha	Cronbach's Alpha Based on Standardized items	N of Items
1	.811	.818	10
2	.728	.743	10
3	.723	.705	10
4	.731	.725	10
5	.911	.916	10

### Data Collection and Analysis

Data were collected through self-administered hard-copy questionnaires, accompanied by an introductory letter and an ethical consent form. The questionnaires were distributed over a week, and responses were received within three weeks, with a 25% delay due to bureaucratic procedures in schools. The final response rate was 68.6% (103

out of 150), which provided an adequate representation of the sample. Data analysis was done using Statistical Package for the Social Sciences (SPSS). Descriptive statistics and multiple linear regression were applied to answer the research questions.

## Results

### Demographics About Participants

From Table 3, Accra Academy was the most represented school in the survey, constituting 36.9% ( $n = 38$ ) of the participants. This was followed by Apostle Safo School of Arts and Science, comprising 24.3% ( $n = 25$ ) of the participants. Ideal College was next, making up 23.3% ( $n = 24$ ) of the participants. Then, finally, St. Mary's SHS, the least represented among the four, with 15.5% ( $n = 16$ ) of the participants.

Table 3. Various Schools of the Participants

	Frequency	Per cent	Cumulative Percent
Accra Academy	38	36.9	36.9
Apostle Safo School of Arts and Science	25	24.3	61.2
ideal college	24	23.3	84.5
St. Mary's SHS	16	15.5	100.0
Total	103	100.0	

The majority of the participants (70%,  $n = 72$ ) were males, and 30% ( $n = 31$ ) were females as shown in Figure 1.

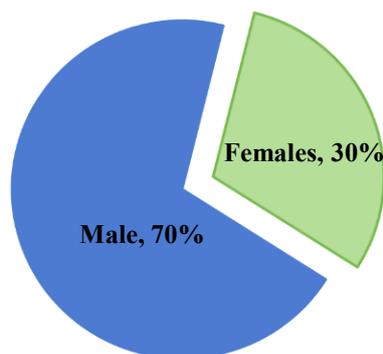


Figure 1 Gender Distribution

Data on the educational qualifications of participants were collected and are presented in Table 4. The results indicate that the majority of respondents (64.1%,  $n = 66$ ) hold a Bachelor's degree, followed by 25.2% ( $n = 26$ ) who possess a Diploma. A smaller proportion (3.9%,  $n = 4$ ) reported having a Master's degree, while 6.8% ( $n = 7$ ) were identified as untrained teachers. These findings suggest that the teaching workforce is predominantly composed of individuals with bachelors-level qualifications, indicating a foundation of formal pedagogical training. Conversely, participants with Master's degrees represent the smallest group, highlighting the limited representation of advanced academic preparation within the sample.

Table 4. Level of Education

	Frequency	Per cent	Cumulative Percent
Bachelors' degree	66	64.1	89.3
Diploma	26	25.2	25.2
Masters	4	3.9	93.2
Untrained teacher	7	6.8	100.0
<b>Total</b>	<b>103</b>	<b>100.0</b>	

As shown in Table 5, 25.2% (n = 26) of participants reported having less than two years of teaching experience, while 15.5% (n = 16) had between two and four years of experience. Additionally, 26.2% (n = 27) indicated having taught for four to seven years, and the largest proportion, 33.0% (n = 34), reported ten or more years of teaching experience. These results reflect a diverse range of teaching experience among participants, with a notable concentration of experienced educators who have been in the profession for a decade or more.

Table 5. Teaching Experience of Participants

	Frequency	Per cent	Valid Percent	Cumulative Percent
Below 2 years	26	25.2	25.2	25.2
2 – 4 years	16	15.5	15.5	40.8
4 - 7 years	27	26.2	26.2	67.0
10 years and above	34	33.0	33.0	100.0
Total	103	100.0	100.0	

## Findings

**Research question 1: To what extent do factors such as ICT infrastructure (ICTIF), Learning Styles and Learning Needs (LSLN), Teachers' Perceived Ease of Use (TPEU), and Incentives and Motivation for Teachers (IMT) and institutional support predict the level of ICT integration in teaching within technology-rich SHSs?**

A multiple linear regression analysis was conducted to examine how well ICT Infrastructure (ICTIF), Learning Styles and Learning Needs (LSLN), Teachers' Perceived Ease of Use (TPEU), and Incentives and Motivation for Teachers (IMT) predict the level of ICT integration in teaching within technology-rich SHSs. The required assumptions for multiple regression were carefully tested and met before the analysis.

### *Test of The Assumption of The Multiple Linear Regression Model*

Before the regression analysis, the necessary assumptions for the multiple linear regression were examined and met:

- *Measurement Level:* Both dependent and independent variables were treated as continuous variables through the transformation of Likert-scale responses into interval-level data.
- *Independence of Residuals:* The Durbin-Watson statistic was 2.189, suggesting that the residuals were

independent and free from autocorrelation (see Table 6).

- *Linearity*: Scatterplots revealed linear relationships between each predictor and the dependent variable (see Figure 2).

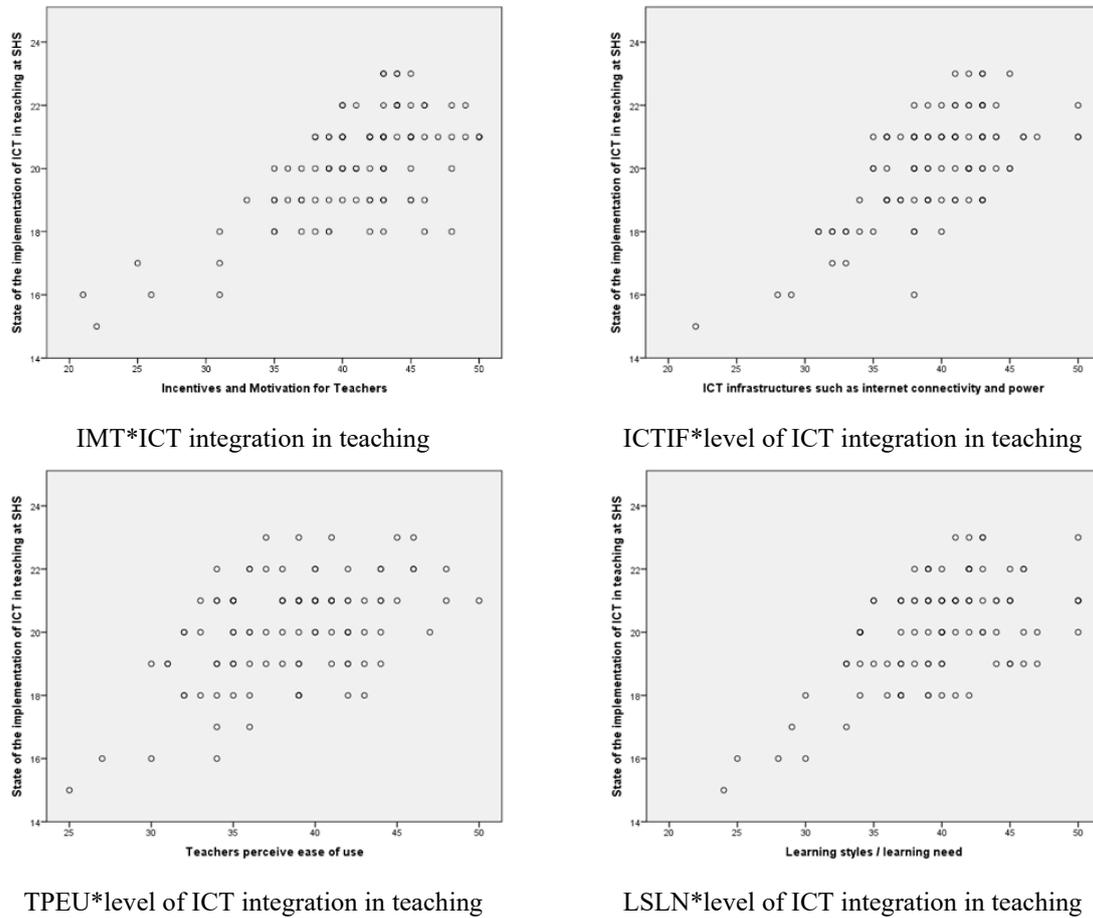


Figure 2. Scatterplot of Independent Variables and Dependent Variable

- *Homoscedasticity*: The scatterplot of standardized residuals versus predicted values indicated constant variance and no evidence of heteroscedasticity (see Figure 3).

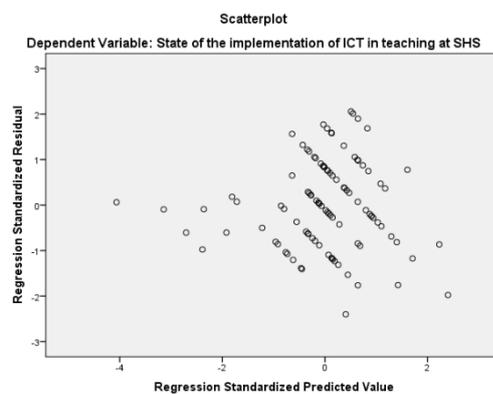


Figure 3. Scatterplot of Standardized Residuals Versus Standardized Predicted Values

- *Multicollinearity*: The tolerance values and Variance Inflation Factor (VIF) scores indicated no serious multicollinearity among predictors. The results showed that the tolerance values ranged from 0.358 to 0.599, which are above the critical threshold of 0.10, and the VIF scores ranged from 1.671 to 2.792, all well below the cut-off of 10 (see Table 8). These findings suggest that multicollinearity was not a concern in the model and that each predictor contributed uniquely to explaining the variation in ICT integration in teaching at the SHS level.
- *Influential Outliers*: Cook's Distance values were all below 1, indicating no influential data points were unduly affecting the model.
- *Normality of Residuals*: Histogram (see Figure 4) and Normal Q-Q plots of standardized residuals showed that the residuals were approximately normally distributed.

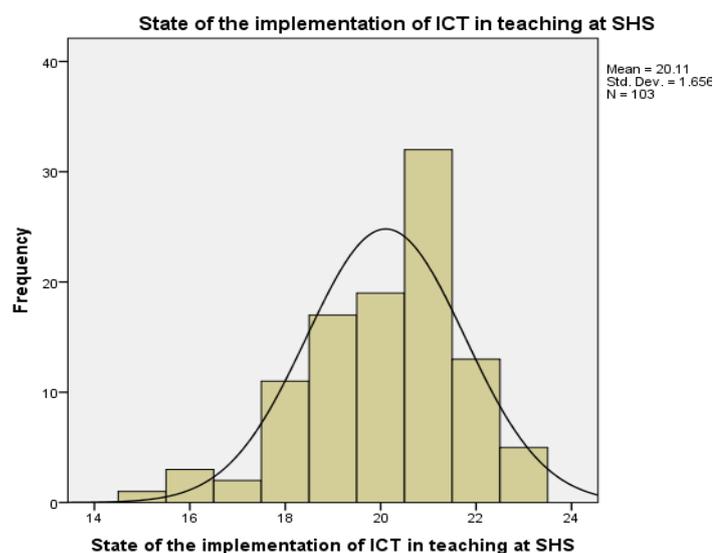


Figure 4. Histogram with the Normal Curve for the Dependent Variable

These checks confirmed that all key assumptions for regression were satisfactorily met, thereby validating the reliability of the model used for assessing ICT integration.

### *The Regression Model*

The regression model was found to be statistically significant,  $F(6, 96) = 23.103$ ,  $p < .001$  (see Table 7), suggesting that the combination of the predictors significantly explains variance in ICT integration level in technology-rich SHSs. The model accounted for approximately 59.1% ( $R^2 = .591$ ) of the variance, indicating a substantial level of explanatory power by the predictors combined (see Table 6). Among the independent variables, ICT Infrastructure (ICTIF) and Incentives/Motivation for Teachers (IMT) emerged as significant predictors. ICTIF had the strongest standardized effect ( $\beta = 0.387$ ,  $p < .001$ ), while IMT also contributed significantly ( $\beta = 0.303$ ,  $p = .003$ ) as shown in Table 8. These results highlight the critical roles of adequate infrastructure and motivational incentives in promoting ICT integration in teaching. These findings underscore the need for investments not only in infrastructure but also in teacher support systems to ensure the successful integration of ICT in instructional

practices.

Table 6. Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.769 <sup>a</sup>	.591	.565	1.092	2.189

Table 7. ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	165.328	6	27.555	23.103	.000 <sup>b</sup>
	Residual	114.497	96	1.193		
	Total	279.825	102			

a. Dependent Variable: Status of ICT integration in SHS

b. Predictors: (Constant), Learning styles/learning need (LSLN), ICT infrastructures such as internet connectivity and power (ICTIF), Teachers perceive ease of use (TPEU), Incentives and Motivation for Teachers (IMT)

Conversely, Teachers' Perceived Ease of Use (TPEU) and Learning Styles and Needs (LSLN) did not significantly contribute to the prediction of ICT integration status, with p-values of p=.605 and p=.264, respectively. While their coefficients were positive, the lack of statistical significance suggests that these variables did not have a strong influence on ICT integration levels. This suggests that while ease of use and alignment with student learning styles may be relevant in some contexts, they were not the primary drivers of ICT integration in technology-rich SHSs.

Table 8. Regression Model

Model	Unstandardized		Standardized		t	Sig.	Collinearity Statistics	
	B	Std. Error	Beta				Tolerance	VIF
(Constant)	8.520	1.111			7.666	.000		
IMT	.092	.034	.303		2.703	.003	.358	2.792
ICTIF	.139	.031	.387		4.461	.000	.599	1.671
TPEU	.017	.033	.049		.519	.605	.506	1.975
LSLN	.041	.037	.125		1.123	.264	.362	2.759

a. Dependent Variable: status of ICT integration in SHS

The regression model is as follows:

$$\text{Levels of ICT Integration in Technology-Rich SHSs} = 0.092(\text{IMT}) + 0.139(\text{ICTIF}) + 8.520$$

This indicates that an increase in either incentive/motivation of teachers (IMT) or ICT infrastructure (ICTIF) corresponds to a measurable increase in ICT integration, holding other factors constant. Overall, the findings emphasize that investment in robust ICT infrastructure and provision of incentives and motivational support for teachers are crucial for fostering effective ICT integration in SHS teaching practices.

## Research Question 2: What Contextual Barriers Hinder The Effective Integration of ICT in Teaching Despite the Availability of ICT Resources in SHSs?

This section explores the contextual challenges that hinder effective ICT integration in teaching, even in environments where ICT resources are available in SHSs. The findings, presented in Table 9, reflect teachers' responses to key barriers identified in the literature, with participants indicating their level of agreement with each item. Notably, none of the respondents disagreed with the listed challenges, suggesting widespread acknowledgement of these issues.

Table 9. Challenges in the Implementation Process of ICT Integration in Teaching at SHS

Challenges	Responses				
	SD	D	N	A	SA
1. Lack of skills and confidence to troubleshoot technical issues	0 (0)*	0 (0)	14 (13.6)	27 (26.2)	62 (60.2)
2. Shift in Teaching Approaches to Interactive learning	0 (0)	0 (0)	10 (9.7)	31 (30.1)	62 (60.2)
3. Nurturing digital citizenship and responsible use of technology	0 (0)	0 (0)	12 (11.7)	27 (26.2)	64 (62.1)
4. Alignment with curriculum and learning objectives	0 (0)	0 (0)	13 (12.6)	33 (32)	57 (55.4)

\* Percentage in parenthesis

A significant proportion of teachers (60.2%,  $n = 62$ ) strongly agreed that a lack of skills and confidence to troubleshoot technical issues is a major barrier to ICT integration. This was further supported by 26.2% ( $n = 27$ ) who agreed with the statement, while only 13.6% ( $n = 14$ ) remained neutral. Another widely recognized challenge was the shift in teaching approaches from traditional methods to more student-centered and interactive learning. Again, 60.2% ( $n = 62$ ) of respondents strongly agreed that this shift presents difficulties, with 30.1% ( $n = 31$ ) agreeing and just 9.7% ( $n = 10$ ) reporting neutrality. In terms of nurturing digital citizenship and encouraging responsible use of technology, 62.1% ( $n = 64$ ) of participants strongly agreed that this is a significant implementation challenge. An additional 26.2% ( $n = 27$ ) also agreed, while 11.7% ( $n = 12$ ) were neutral on the matter. Finally, 55.4% ( $n = 57$ ) of the respondents strongly agreed that aligning ICT use with curriculum goals and learning objectives is a challenge. This view was shared by 32% ( $n = 33$ ) who agreed, whereas 12.6% ( $n = 13$ ) neither agreed nor disagreed. Overall, the data indicate a strong consensus among teachers that technical skills, pedagogical shifts, digital citizenship, and curriculum alignment are contextual barriers. These barriers significantly impact their ability to integrate ICT effectively, despite the availability of digital resources.

## Discussion and Conclusion

The research shows that ICT integration in technology-rich SHSs mainly depends on two key factors: ICT infrastructure (ICTIF) and teacher incentives or motivation (IMT). While proper ICT infrastructure is essential,

the actual crucial element for integrating ICT into teaching and learning is teacher motivation and incentives. Teachers are more likely to use ICT resources if school management acknowledges their ICT efforts and offers financial incentives and training opportunities. The findings align with existing studies indicating that technology adoption in classrooms relies on both ICT infrastructure and teacher motivation (Ghavifekr & Rosdy, 2015; Teye & Duah, 2022; Amemasor et al., 2025). The perceived ease of use (TPEU) and learning styles or needs (LSLN) of teachers did not influence the level of ICT integration in technology-rich schools, despite earlier research highlighting their importance (van Braak et al, 2010; Peralta & Coasta, 2007; Apeanti, 2016). This may be because access to technology becomes less problematic in schools where availability is not an issue, shifting focus from tool functionality and learning compatibility to providing adequate support for effective ICT integration in classrooms. The key factor for sustainable ICT implementation becomes institutional characteristics and leadership support (Anderson & Dexter, 2011).

Having ICT resources alone does not overcome contextual challenges that hinder the full integration of these tools. Teachers report feeling they lack sufficient skills and confidence, alongside difficulties in adopting student-centered methods, teaching digital citizenship, and aligning ICT with educational goals. Other studies reinforce these findings, showing how policies and classroom practices vary (Mensah & Adu, 2020; Asare & Okyere, 2020). School administrators must realize that merely providing infrastructure is inadequate for meaningful ICT integration, as teachers face multiple skill gaps and practice barriers. Ongoing professional development should focus on teaching methods that combine technological support with learner-centered approaches. Continuous training on technology integration for learner-centered environments can prevent teachers from sticking to traditional methods that limit ICT's transformative potential (Hew & Brush, 2017; Abedi, 2024). The difficulties teachers encounter in aligning ICT with curriculum standards reveal deep structural issues in Ghana. ICT integration becomes ineffective when outdated software and content that do not align with the national curriculum pose major barriers (Mensah & Adu, 2020). The problem is compounded by the absence of structured professional development programs that link technology to curriculum needs. The challenges teachers face when teaching digital citizenship are consistent with Martin et al. (2025), who found that teachers experience technostress due to a lack of sufficient technology responsibility skills. The study shows that SHS ICT integration success depends on ICT resources, motivated teachers, sustained professional development and curriculum alignment. The research shows that investing in ICT resources by itself is not enough because institutions must also prepare their teachers and establish strong internal support mechanisms (Lim & Chai, 2018; Plomp et al., 2020).

The research shows that specific factors determine how ICT integrates into technology-rich SHSs. Teachers' motivation and incentives are crucial in influencing their use of technology in teaching and learning within these environments. Merely having ICT infrastructure available does not ensure successful outcomes. Effective integration of ICT in teaching methods requires recognizing teachers' efforts, along with tangible rewards and professional development opportunities, to motivate them. Schools with ICT resources should focus on establishing institutional support, developing teachers' skills, and creating sustainable motivation strategies.

The provision of ICT resources in schools does not eliminate all contextual barriers that teachers face. Teachers encounter three main obstacles, which include insufficient skills and confidence issues and difficulties in adopting

student-centered teaching approaches. There seems to be a mismatch between technology use, national curriculum goals and the need to develop digital citizenship skills. The existing problems reveal the difference between educational policy targets and real classroom practices. The implementation of ICT infrastructure alone does not solve the problem. The implementation of ICT infrastructure requires simultaneous professional development and teacher motivation programs. A sustainable ICT integration in Ghanaian SHSs requires a complete strategy which combines ICT infrastructure investment with capacity development and institutional backing.

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## Online Learning Community: University English Teachers' Engagement in Using Facebook Page

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### Abstract

In addition to providing a wide range of information, Facebook has also been used as a significant learning platform in various educational contexts. This article examines the experiences of University English Teachers (UETs) in Nepal who engaged in a Facebook page as an Online Learning Community (OLC). A four-week intervention was conducted among 19 UETs, who shared professional development content and related activities on the page. Qualitative data were collected through online semi-structured interviews with 11 UETs and were analyzed thematically based on interpretative phenomenological analysis. The findings revealed that teachers initially had limited awareness of the concept of OLC; they gradually identified it as a valuable space for sharing experiences, solving professional challenges, and developing collaborative skills. Their engagement increased on the page through activities such as following shared content, commenting, and uploading their learning materials. UETs shared mixed experiences on the Facebook page's effectiveness for academic discussion and professional development. Moreover, they also expressed challenges related to technical devices and skills for active engagement in the OLC. The study suggests that professional online social communities can enhance English teachers' professional knowledge and collaborative skills.

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## Introduction

Facebook, one of the most popular social networking websites, was developed by Mark Elliot Zuckerberg in 2004 and initially targeted at college students, although it eventually became inclusive to allow all age groups (Hart & Steinbrecher, 2011). It rapidly became popular across the world for sharing personal information, events, and ideas, and has been a platform for different professional, business, and educational activities (Manca & Ranieri, 2013). Moreover, social media like Facebook, Twitter, and Instagram are extensively used to promote business (Hutchings, 2012) and socialize in diverse communities by university students (Madge et al., 2009). These social sites have been widely used by teachers to share content, experiences, and ideas relevant to their curriculum. Students also use these social sites to communicate with their friends and teachers to discuss their learning issues. However, there is limited literature about how university English teachers use Facebook pages in their professional activities. Facebook is a productive means of communication for university students to discuss their problems, share ideas, and collaborate with each other (Gray et al., 2010). The use of computer-mediated communication in teaching and learning helps both teachers and students build collaborative relationships and make their teaching and learning productive (Mazer et.al, 2007). Moreover, students can use Facebook and other similar social media to discuss their homework and project work, and teachers use it to contact their students and support them (Hew, 2011). Likewise, university students use Facebook to narrate their experience in their university with their friends, communicate about practical and academic information with colleagues, and create humor with colleagues (Selwyn, 2009). However, when students spend excessive time on Facebook chatting unnecessarily beyond academic purposes with their friends and read unnecessary content shared on Facebook, they cannot complete their academic tasks on time. (Janković et al., 2016). Therefore, students need to be aware of the consequences of excessive use of Facebook. (Busalim et al., 2019).

Facebook allows an individual to create a page and a group of many members who share the same interest and goal. Many teachers and students have developed their online groups of friends where they communicate personal ideas and professional activities by seeking and sharing ideas. In the past, the concept of community was relevant to a unit of several households residing in a place (Rovai, 2001). However, the development of internet facilities has provided a new virtual platform for people to develop their online groups of people, to share ideas with each other, and to conduct teaching and learning activities in an online learning community (Liu et al., 2010). McMillan (1996) views that the community has a spirit of belongingness to each other, a feeling of trust in an authoritative structure, and the advantage of mutual relationships. Members of Facebook use various user-friendly tools like wall, private message, group, page, event, news feed, and live streaming to communicate with each other (Pemppek et al., 2009). Particularly, a Facebook group, a forum for interaction, allows members to communicate with each other and share ideas (Dalsgaard, 2016).

In Nepal, it is estimated that about 35% of the total population, which comprises 59.9% males and 40.1% females, uses Facebook (Khabarhub, 2019). Jha et al. (2016) reported that many students specifically use Facebook to communicate with their family and friends, although they have limited practice of the site for learning purposes. Some students often use Facebook to discuss personal issues, share information, and make plans, like a picnic program during the holiday (Sharma, 2012). Moreover, Ayu and Abrizah (2011) argue that Facebook is supportive

for non-profit groups to promote their career by gaining popularity. Facebook users create a Facebook page and post photos, videos, and other materials on its wall, invite comments, and escalate discussions among many Facebook page members (Sokoloff, 2009). In this context, this paper reports how the Facebook page, an online learning community, helps UETs in their academic activities.

### Study Questions

- How is the university's English teachers' experience of using the Facebook page, an online learning community for sharing educational ideas?
- In what ways have they reflected the experiences they shared on the Facebook page, an online learning community?

### Online Learning Community for Educational Practices

Many studies have reported that various Social Media apps, such as Facebook, Twitter, Skype, Viber, Snapchat, WhatsApp, and Instagram, are used for educational practices through creating groups. In this regard, a qualitative study in the USA by Trust et al. (2016) reported that social networking sites helped experts communicate and support teachers when needed. Likewise, an earlier survey by Carpenter & Krutka (2014) reported that Twitter became supportive to educators for professional development because of its affordance, accessibility, and flexible nature. Similarly, Al-Bahrani and Patel (2015) suggested that teachers incorporate social media like Facebook, Instagram, and Twitter in teaching by making some rules to use them properly and argued that teachers might face privacy problems, whereas students might misuse ICT devices. Similarly, in a survey in Australia, Duncan-Howell (2010) reported that online communities facilitated teachers to solve their problems by participating in learning and debating in their scheduled time, but they experienced difficulties in managing time and making a clear understanding among participants. Forte et al. (2012) reported that a large number of teachers followed Twits of other than their colleagues and were followed by them more than their colleagues. In a survey in Turkey, Cetinkaya (2017) reported that WhatsApp was popular for sharing academic resources, works, and immediate solutions to problems.

Popular apps like Skype and ooVoo, which are useful for teaching and learning, allow users to share screens and files for collaborative learning from a distance (Hashemi & Azizinezhad, 2011). A study in Turkey, Erarslan (2019) reported that Instagram became a supportive tool to develop language skills. A qualitative study in the USA, Bloch (2002) reported that teachers used email for socialization and improving students' learning. Likewise, a qualitative study of Qi and Wang (2018) highlighted that Australian teachers used WeChat to exchange experiences, update students' progress, build rapport, and share audios. However, a survey in Hong Kong, Chik (2011) found that some teachers were suspicious of the potential and value of new social apps in teaching and learning practices because teachers lacked the technical skills to integrate them into educational practice. In a similar study, Allam and Elyas (2016) revealed that Saudi Arabian teachers did not adopt social media in teaching because of their fear of its misuse and distraction, and advised that not to incorporating social media in the curriculum. Similarly, in Malaysian setting, a qualitative study of Yunus et al. (2012) highlighted that social networking sites distracted teacher-trainees' attention, destroyed their writing, and made them passive. Likewise,

in a quantitative study of Soomro et al. (2014) in the USA, it was reported that some teachers rejected Facebook and social networking application in teaching and learning as they doubted if students would engage in non-academic activities.

### **Teachers' Strategies for Using Social Media**

Many studies reported that teachers could integrate online communities in teaching and learning activities, professional development, rapport building with students, and constructive learning. For instance, Staudt et al. (2013) in a qualitative study in the USA reported that experts and trainers used Facebook to develop novice teachers' professionalism. Likewise, DeWitt et al. (2013) in Malaysia found that YouTube could be a beneficial ICT tool for teachers to motivate and improve students' performance and deliver information in acting arts. Ellefsen (2016), in a qualitative study in the UK, stated that university teachers used Facebook to have better educational interaction with students. However, Manca and Ranieri (2016) argued that the use of social media would complicate the issues of confidentiality and gradually add stress of secrecy in educational activities. In an ethnographic study, Bosch (2009) argued that some South African lecturers used Facebook to deal with students' problems, enhance students' collaborative learning, and disseminate teaching and learning materials prior to the beginning of real classes to develop confidence in teaching. In a case study in Israel, Blonder and Rap (2017) found that the majority of the teachers used Facebook groups proficiently to facilitate their students' teaching and learning, although some of them in the beginning experienced technical problems. However, Asterhan et al. (2014) reported that Facebook disturbed teachers' private lives and freedom, and developed students' dependency on teachers to solve their problems.

Carpenter et al. (2020) in their survey in USA reported that the majority of educationists used Instagram to cooperate, share ideas, study, support fellows, and make their community. Similarly, Goktalay (2015) identified that trainers in Turkey used Facebook to share knowledge, send messages, and give feedback to the students. Similarly, Said et al. (2014) in cross-case analysis showed that Malaysian teachers could engage students by posting and sharing information on the Facebook wall, and shift existing teaching and learning activities into new, suitable ones and teach accordingly, although a few students reported some technical problems of using Facebook for learning. Similarly, Saini and Abraham (2019) in an empirical investigation in India reported that pre-service teachers used Facebook to improve their studies. However, Kirschner and Karpinski (2010) in their earlier study in the Netherlands found that students who spent maximum time on Facebook obtained a lower Grade Point Average (GPA) than those who did not use it. In their study in Turkey, Çam and Işman (2013) revealed that Turkish junior teacher candidates used Facebook to communicate, cooperate, and share materials, while seniors used it to discuss subject matter with teachers and colleagues, share content of study, and form an academic group on the basis of academic commonality. However, Hew and Cheung (2012) reported that students in Singapore used Facebook for socialization, communication, and entertainment instead of educational activities.

### **Teachers' Experiences of Using Social Networking Websites**

In the American setting, Davis's (2015) study revealed that Twitter became an effective learning community and an appropriate platform for teachers to access and share materials for professional development, and establish a

worldwide link. In a Turkish context, Çakır and Atmaca (2015) found that the application of Facebook in teaching and learning helped teachers enhance their linguistic skills, encouraged and supported students to develop their vocabulary power, and made students feel comfortable in learning. Similarly, Bicen and Uzunboylu (2013) reported that Facebook supported teachers to improve teaching strategies by creating a collaborative learning environment. However, Grosseck et al. (2011) reported that teachers experiences of difficulties in providing feedback on students' regular work in Romanian schools. A qualitative study of Lin et al. (2016) mentioned that in Taiwan, teachers used Facebook as an important tool to help students in learning. However, Sirivedin et al. (2018) argued that the use of Facebook in Thai schools mechanized communication and limited interaction between students and teachers, and complicated the task of assignments. In a mixed-method study in Spain, Sánchez et al. (2014) found that the use of Facebook enabled teachers to create collaborative teaching and learning. There is limited literature about the experience of using social network sites in teaching and learning activities in Nepal (Rana et al., 2020). A few studies have reported that social networking sites have helped students to cooperate and learning (Sharma, 2012). For example, in a survey, Jha et al. (2016) reported that in Nepal, a limited number of health students used Facebook to receive study-related information, whereas most students used Facebook to gain knowledge. Likewise, Sijali and Laksamba (2020) in an experimental study in Nepal reported that Facebook improved students' performance. The National Curriculum Framework 2007 has recommended incorporating ICT in teaching and learning and improving the quality of education (Ministry of Education and Sports, 2007). However, Rana et al. (2018) reported the limited access to ICT, particularly in rural areas, the lack of ICT infrastructure in schools, expensive mobile data, and people's lack of affordability of expensive technologies to implement ICT in schools in Nepal. In a case study in Nepal, Rana and Rana (2020) revealed that ICT tools helped teachers in their planning and delivery of lessons and provided immediate feedback on students' work. However, Rana et al. (2020) argued that although the government emphasizes the implementation of ICT in education to transform traditional pedagogies to modern learning, increase the access to quality education for all, produce skillful graduates and integrate Nepal into global society, the government without allocating budget for the project of ICT has involved NGOs to equip schools with ICT infrastructure and teachers with ICT knowledge and skills. Despite worldwide research on the educational use of social media, particularly Facebook, there is a lack of empirical research in the context of Nepal examining UETs' experiences using Facebook-based online learning communities for engaging and discussion within their specific Nepali socio-cultural context. Therefore, it is worthwhile to conduct the study to examine the UETs' experiences in this field.

## Methods

### Participatory Action Research (PAR)

This study explored UETs' experience of using a Facebook page for sharing and discussion in learning materials for professional enhancement. It is participatory action research employing observation of a Facebook page (Nørskov & Rask, 2011) and interviews to collect qualitative information. The intervention design consisted of creating a Facebook page as planning, disseminating content as action, and conducting follow-up activity as observation and reflection, as described in detail.

**Planning:** To begin the online learning community, we created a Facebook page named *University English*

*Professionals' Community, Surkhet (UEPCS).* We sent invitations to over 30 UETs from different districts and colleges of Nepal in their Messenger to like the page and be engaged by making comments about the uploaded materials. Among them, 19 accepted and joined the page. We included them as participants in the study.

**Action:** We systematically shared on the page a wide range of materials related to teaching and learning, motivation, English language learning, academic writing, poetry recitation, and current political issues to stimulate engagement and foster academic exchange. Our shared thought-provoking captions encouraged UETs for their interactive engagement on the page. To ensure active involvement of UETs, we directly sent the link of the uploaded materials to their messenger, reminding their engagement with the contents shared on the page.

**Observation:** We closely observed UETs' interactions, such as comments, responses, and sharing, by taking screenshots to maintain a verifiable record. Based on the nature of participants' feedback, motivation levels, and thematic interests, additional materials were posted. This iterative process of observation and content adaptation continued in cycles over more than three weeks.

**Reflection:** The Facebook page emerged as an effective platform for collaborative learning and professional exchange among UETs. They shared and explored a wide range of relevant information, enriching the collective knowledge base. The Facebook page facilitated the exchange of ideas, discussion of academic issues, and exploration of new perspectives. It appeared to be a practical and accessible medium for fostering professional learning communities in the context of higher education in Nepal. The PAR cycle used in the study is given in Figure 1:

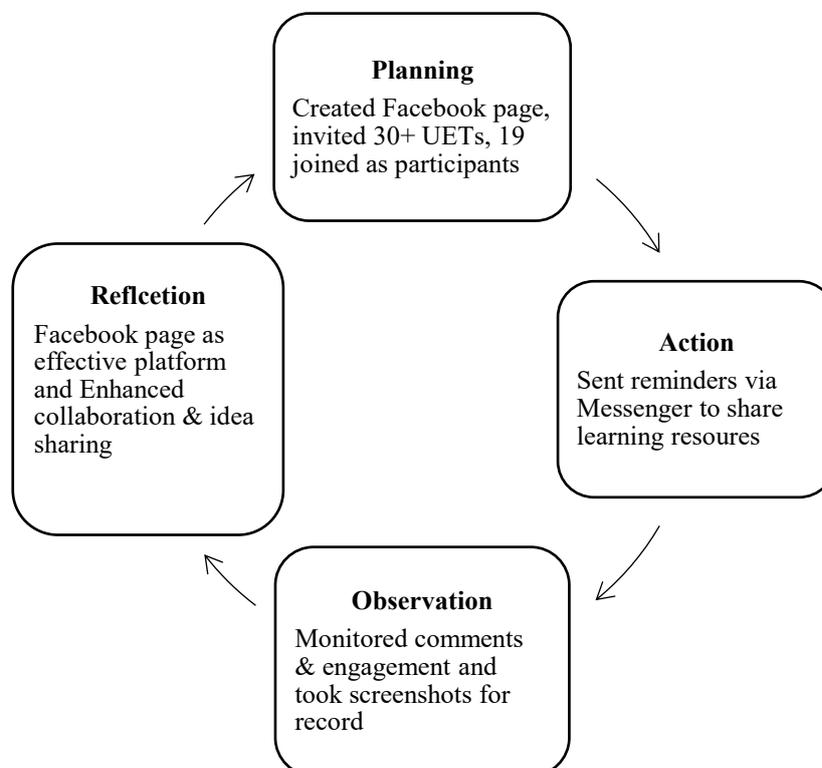


Figure 1. PAR Cycle

## Data Collection Procedures

Continuous observation of UETs' activities on the UEPCS Facebook page was used as a key tool for data collection. UETs' interactions, comments, and engagement with the UETs' shared content were documented to identify their perceptions related to online learning. Additionally, we conducted online interviews with 11 UETs via Zoom, which were guided by the framework of Longhurst (2003) for addressing the core research questions. We purposively selected them based on the ideas of Patton (2007). The interview was conducted on Zoom, a freely available videoconferencing tool, which was recorded on a laptop. The UETs' participation was based on their willingness to engage in the online learning activities. For ethical considerations, the names of all participants and their affiliated colleges used in this study are pseudonyms.

## Thematic Analysis

Data collected through observations and interviews were thematically analyzed following Gavin's (2008) framework. The interviews were transcribed, categorized into specific themes, and critically interpreted. Interpretative Phenomenological Analysis (IPA) was employed to gain deeper insights into the qualitative data. Additionally, various sources such as books, articles, journals, theses, newspapers, and online materials, were reviewed in relation to the interview and observation findings.

## Results

This section offers an analysis of the findings into three themes developed from the observation of nineteen UETs' engagement on the UEPCS Facebook page and the interviews with nine selected members of the community. These three themes elicited from the overall study are: Facebook page as a learning tool, teachers' participation on Facebook page, and perceived value of Facebook page in learning.

### Facebook Page as a Learning Tool

The interviews with the participants and the observation of their involvement in UEPCS revealed that the majority of the participants did not participate in the discussion on the uploaded materials in the beginning. Although a few participants constantly remained inactive during the observation period, the majority of them developed their interest in the course of time. Their interest and participation increased in terms of watching the uploaded videos and commenting on the posts. However, none of them were involved in scholarly debates with other participants on new videos and pictures posted on the Facebook page. They initially took this page similar to other normal Facebook pages. However, they gradually increased their participation upon the request to comment on the posts and follow others' comments. When they found shared posts that were academic and relevant to their interest, they actively participated. In our interviews, participants shared their diverse experiences about how the content on the page encouraged them to engage with it. For example, Tilak, an English teacher at Karnali Model College, stated:

*In the beginning, I was not much careful about the page because so many people post many useless things on the Facebook wall and Facebook pages. They upload their pictures, videos, and other materials which are not academic.*

Tilak's comment reflected the initial perception of the Facebook page that the majority of the participants had. They were more suspicious about whether or not it could be useful to share learning materials. Their expression reflected why teachers developed negativity against the use of Facebook. Teachers' responses indicated their limited knowledge of how social media like Facebook pages can be utilized as an OLC to develop their professionalism, share problems with members of the community, and help solve problems. Following the provocative questions shared on the page, the majority of the participants watched the videos and made comments on the page. They were probably aware of non-academic pages created for engaging people to disseminate political propaganda and fun, which they did not consider useful for them.

*In the beginning, I was not much fascinated by the page because most of the pages are just created to deliver bogus things and they are really not important and not useful. So, that they only consume people's time and make people fool. (Reshami, an English teacher at Karnali Model College)*

*Especially, in the initial phase I was unknown about this kind of page because I was not familiar with this kind of page. I felt that this kind of page may not support the teachers and students. (Dharma, an English teacher at Khalanga Multiple Campus)*

These comments provided a picture of how teachers developed their awareness of the affordance of the Facebook page for their professional development. Continuous observation of the page identified that teachers proactively liked posts and explored other professional OLC to grow their knowledge and share skills and experiences with their teaching fellows, rather than wasting time on non-academic and fake information. It was observed that teachers following the UEPCS Facebook page increased the engagement on professional content and discussion. For instance, Chaitanya, an English teacher at Nepalgunj Management College, shared:

*Later on, I noticed that it is very useful platform for us to professional development. It is a platform to share ideas and conduct scholarly discussions with each other. Not only sharing the ideas, but sometimes we can also invite people for an important discussion.*

However, a few teachers still had doubt whether or not they could utilize such online learning communities to communicate problems and get help from other professionals to solve them. On the other hand, the proactive participation of many other teachers suggests how teachers can benefit from professional community pages.

*I involved more in discussion with the creator or admin of the page. I loved the way he put next question instantly after my replies. At first, those questions seemed irritating but later I really enjoyed them as they expanded my horizon of looking at things. (Suren, an English teacher at Kathmandu Multiple Campus)*

Suren's expression reflected how teachers can be motivated to engage in professional activities. Probably, schools and colleges can involve their teachers in such online communities to encourage them to engage in academic activities.

### **Teachers' Participation on the Facebook Page**

The majority of the participants were engaged on the page by watching uploaded videos and making comments on the shared content. It was observed that a few members made just superficial comments like "good video", "good job", and "related to children," as well as sticker comments. Participants perceived that social networking sites like Facebook page, Twitter, and Instagram are powerful tools to create scholarly discussion on various content, including education. For example, Tilak, an English teacher from Karnali Model College, shared:

*Before writing comments, generally, I watch their comments and videos and comment on them. I forward my view after observing the materials in detail.*

Continuous engagement on the UEPCS Facebook page developed teachers' awareness of how they could communicate on the social site, comment on uploaded materials, and share issues and ideas. Moreover, the page increased its responsibility and honesty to engage in professional activities. Participants' increasing engagement on the page indicated that they gradually developed their interest, curiosity, and awareness of the online community. Their academic interactions on the page provided a clear picture of how such online learning communities can be integrated in educational practices and promoted to help teachers solve learning problems. For instance, Dirgha, an English teacher at Narayan Multiple Campus, highlighted:

*I was interested in this kind of activity. I repeatedly watch materials and analyse them. I read comments.*

His comment revealed that he was aware of using social networking sites for educational purposes.

*I try to understand the materials profoundly, try to see the same thing from different perspectives and deliver my thoughts on the page. Regarding other members' comments, I have selected a few participants from the first day whose thoughts and standpoints really entice me. (Suren, an English teacher at Kathmandu Multiple Campus)*

The majority of the participants emphasized that they utilized Facebook for academic discussion. However, observation identified that a participant only watched videos but was never involved in the discussion. It was much clearer from interviews that they were very aware of how public debate on personal character would get them involved in social conflicts.

*I watch most of the videos but do not make any comments on the materials and do not comment over other members' comments because they are their views. I do not comment concerning personal privacy. (Lal, an English teacher at Narayan Multiple Campus)*

*I watch most videos but I comment on only some of them. I do not respond to all materials uploaded on social media. I do not have sufficient time. My device also does not work properly. (Reshami, an English teacher at Karnali Model College)*

The use of such professional online learning communities can be extended to various fields and promote the professionalism of people. It can reduce the misuse of social networking sites and help many professionals increase their entrepreneurship. Although many participants ignored the UEPCS Facebook page at the early stage, they significantly utilized it for getting ideas about crisis, online learning strategies, and the use of the internet for learning.

### **Perceived Value of the Facebook Page in Learning**

Observations found that teachers' perception of Facebook significantly changed following the continuous use of it, and that they accepted Facebook page as an online learning tool. For example, Tilak shared his changed perception that: "Because of those pictures, I deeply thought about shifting of teaching and learning activities". It was observed that the Facebook page could be integrated in educational practices.

*Materials are well selected for university professionals. Very few materials are not related to university level but match the secondary and lower secondary level. (Dirgha, an English teacher at Narayan Multiple Campus)*

The UEPCS Facebook page has received a high level of value in educational practices and professional development. Teachers probably were able to utilize the materials shared on the page in their teaching and learning activities.

*Materials are interesting, relevant, and useful for teaching and learning activities as well as developing knowledge. They are really beneficial for personal as well as professional development for teachers. (Gobinda, an English teacher at Narayan Multiple Campus)*

Although it was difficult to encourage teachers to participate in discussions on the page at the early stage of using the UEPCS Facebook page, they proactively engaged on the page to comment and react to the materials and others' comments, and utilized the ideas generated from the discussions. A Facebook page can be a platform to acquire knowledge and share professional skills with colleagues, which helps members of the community to improve pedagogical skills and knowledge.

*The materials on the page are very applicable for teaching and learning. They are very authentic and worth incorporating in teaching and learning. (Sabin, an English teacher at Lumbini Multiple Campus)*  
*The materials uploaded are not so detailed. I do not comment on those materials. Some of them are effective. (Lal, an English teacher at Narayan Multiple Campus)*

However, each member of the UEPCS Facebook page was not satisfied with the content shared on the page. Lal, for example, did not find the page very productive for his professional activities. His expression provided a lesson to improve intervention ideas ahead. Following his comments, several diverse materials were shared on the page to encourage all the members to participate in professional interactions.

## Discussion

This study has identified UETs' experience of using a Facebook page for online teaching and learning. They initially doubted whether or not the UEPCS Facebook page would be productive for developing students' educational knowledge, sharing educational ideas, and engaging in academic discussions. They gradually increased their engagement on shared materials on the page, which motivated them to have a higher level of interaction with friends. Following their active engagement on the UEPCS page, they identified that it is a suitable platform for academic interactions, intellectual discourses, and professional development. Participants appreciated the uploaded materials because of their relevance in teaching and learning activities, and they increasingly watched and commented on the uploaded materials during the intervention. They developed their interest, curiosity, and awareness about the online learning community. They found it useful for sharing profession-related and other useful materials. Teachers used a Facebook page to share professional knowledge, skills, experiences, and educational materials among their colleagues. This finding corroborates the study of Dalsgaard (2016), Ellefsen (2016), and Qi & Wang (2018), who also suggested that online learning communities promote teachers' teaching abilities, enable their problem-solving skills, and develop their professionalism, often by sharing useful, authentic academic materials.

Some of the teachers were found to be less active in watching shared materials and commenting on them on the page because they were worried about their personal privacy and freedom. While many members watched most of the videos but were never involved in the academic discourses. They just engaged on the page with superficial

comments such as 'good matter', 'motivational video', 'suitable for children', and just sticker comments without writing anything, ignoring its educational use and value in the initial days. Studies (Al-Bahrani & Patel, 2015; Asterhan et al., 2014; Manca & Ranieri, 2016) have also demonstrated that teachers are aware of how social media goes to a wider community of all kinds of people beyond professional users. Moreover, the study revealed that some members faced technical problems, such as problems with the keyboards of laptops and mobile devices, and thus made comments on the limited uploaded materials. This finding resonates with the finding of Blonder & Rap (2017), who revealed that technological issues and limited ICT skills prevent teachers from utilizing available features on Facebook.

It was identified that after engaging on the UEPCS Facebook page, teachers proactively searched other professional online learning communities to enhance their professional knowledge and share skills and experiences with their colleagues, rather than wasting time on non-academic and fake information. This finding aligned the study of Jaffar (2014), who highlighted that the Facebook page helped increase their responsibility and honesty in their professional development. Similarly, participants' active engagement on the UEPCS Facebook page showed that social networking sites like Facebook, Twitter, and Instagram are useful platforms to create scholarly discussion about educational content, issues, and other various content. They are affordable to utilize in education. The efficient use of such freely available mobile apps in educational activities save both time and money, and ease teachers' teaching activities (Charteris et.al, 2018). Schools, colleges, and universities can encourage their teachers to use such facilities to create online learning communities and enhance their professional development activities.

Observation found that participants developed awareness of OLC from their consistent engagement on the UEPCS Facebook page by commenting on shared materials. It was observed that the majority of members' limited participation in scholarly discussions by commenting on provoked questions indicated either their lack of previous experience in using OLC or lack of interest in participating in such open discussions (Cuesta et al., 2016). A few members of the UEPCS Facebook page remained inactive during the whole observation period. For their active participation, they were frequently requested to send a request message in Messenger. However, such messages did not work much to increase their participation in discussions. Their behavior indicated their limited knowledge of how social media, such as a Facebook page, can be utilized as an online community to enhance their professionalism and share their professional problems.

The UEPCS became a platform to share various teaching and learning materials covering multiple content and other materials relevant to social awareness. This finding suggest that teachers utilize OLC to acquire knowledge and share professional skills to improve their pedagogical skills. It supported university teachers to discuss various academic issues and solve their professional-related problems. Various teaching and learning materials and other materials were shared on the page to develop their professional skills necessary for their profession. However, international studies (Hew & Cheung, 2012; Janković et al., 2016; Soomro et al., 2014) reported that teachers' rejection of using Facebook as a teaching and learning tool because they found students wasting their study time by engaging in non-academic activities on Facebook. It suggests that school students who are too young to understand much about the potential of Facebook for educational activities might not be able to utilize it in the

same way as teachers use it for professional activities. This study suggests that university teachers appreciated the Facebook page as a platform to bring additional motivation and enthusiasm to the existing teaching and learning practices. Teachers were able to utilize the shared materials on UEPCS in their teaching and learning activities and develop their pedagogical skills. However, it was very difficult to meet all participants' needs and satisfy them fully.

## Conclusion and Limitation

The Facebook page, an OLC, helped university teachers of Nepal have academic discussions, share teaching and learning materials, and improve their pedagogical skills. Despite initial suspicion about the potential of the page in terms of professional development, the university English teachers increased their participation in interactive activities such as watching and commenting on materials shared on the page during the intervention. Their increasing interest, growing participation, and comments on how they used shared materials in their teaching and learning practices indicated the benefits of the Facebook page for professional enhancement. However, technical problems, such as device-related problems and limited ICT skills of English teachers, have become barriers to the effective use of the page for professional discussions.

The findings of this study are based on the experiences of a limited number of UETs who participated in sharing, uploading, commenting, and reacting to the learning materials on a Facebook page. Therefore, the results cannot be generalized to all university English teachers in Nepal. Nevertheless, the evidence presented provides valuable insights and suggests new directions for future research. The study highlights that, although the government and educational institutions have promoted online learning communities as a replacement for traditional methods of sharing and discussing academic activities, further research is needed.

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## Analysis of the Influence of Utilizing STEM-Based Physics Learning Media: A Systematic Literature Review

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### Abstract

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21st-century education offers numerous benefits to society across various sectors, including the field of education itself. The STEM (Science, Technology, Engineering, and Mathematics) approach is designed to support teachers in realizing effective education in the 21st century. This study examines 40 articles published between 2018 and 2024, which have undergone a filtering stage based on inclusion criteria. The method used in this research is a literature review. The main objective of this study is to identify the variables that influence the use of STEM-based physics learning media. The most frequent publication years for the articles were 2021 and 2022. The academic level with the most prevalent use of STEM-based learning media is the high school level. The most dominant research method used in the analyzed articles is the quasi-experiment, as this method tends to be easier in evaluating student learning outcomes. The material most frequently taught using the STEM approach is electrical circuits. The most widely used learning media with the STEM approach is prototypes, as prototypes are easily accessible and can utilize existing school facilities. The most frequently used instrument in the research is tests, as the dominant focus of measurement is on students' conceptual understanding.

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## Introduction

21st-century education has entered an era of rapid change and advancement in science and technology. This era offers numerous benefits to society across various sectors, notably in the field of education (Oktay et al., 2023). The Fourth Industrial Revolution (Industry 4.0) is also a hallmark of this century, bringing about significant shifts in societal life, including how we work and interact with one another. Its impact extends beyond the realms of economics and the arts, profoundly influencing the field of education (Sulaiman et al., 2023; Sunarti & Rusilowati, 2021; Zidatunnur & Rusilowati, 2021). In this age of rapid transformation, individuals are expected to equip themselves with the knowledge and skills that must be possessed in order to achieve learning in the 21st century. These essential skills include scientific process skills, critical thinking, design thinking, and production skills. By developing these competencies, individuals can effectively find solutions, generate innovative ideas, and address challenges using scientific concepts and approaches (Tekbiyık & Çakmakçı, 2018; Yulianti et al., 2019; Zollman, 2012; Sulaiman et al., 2023). One such approach that is grounded in science and aligns with the demands of 21st-century education is the STEM approach.

The benefits of the STEM approach, if implemented in learning, will encourage students to acquire new things or innovations in the form of knowledge (Permanasari, 2016; Sari & Kholiq, 2022). Advances in technology have provided opportunities for the STEM approach. In learning using the STEM approach, students will need computational skills, understanding and analyzing data, critical analysis, and scientific understanding based on mathematical principles (Sagala et al., 2019). The STEM approach is designed to support teachers in achieving successful 21st-century education (Sunarti & Rusilowati, 2021). Teachers who have the ability to apply the STEM approach in learning activities are included in an indicator that is very decisive in achieving the learning objectives of students in producing new ideas or innovations when overcoming a problem (Milaurrahmah et al., 2017; Yusuf & Widyaningsih, 2019). STEM-based learning has many benefits in the world of education, including helping students build character in understanding a concept and knowledge (Zidatunnur & Rusilowati, 2021; Tanel, 2019). The STEM approach also has several objectives, including providing students with the skills to work together interdisciplinarily, think systematically, communicate openly, have ethical values, be creative, and have problem-solving skills, especially in physics learning (Tanel, 2019).

One of the subjects in the Merdeka curriculum is physics. Physics is a science-based subject that explores physical matter, facts, and concepts (Sunarti & Rusilowati, 2021). Physics is also a part of natural science which is the basis for the development of technology and studies concepts related to nature and human life (Sapitri et al., 2016; Pahrudin et al., 2021). Research conducted by Nurhayati et al. (2019) states that physics is a subject that seems difficult because the concepts taught in it are very abstract. This is also supported by research conducted by Tanel (2019) which states that students often experience difficulties in understanding physics lessons and consider physics to be challenging. Therefore, students tend to be more passive when participating in physics learning. Students even consider physics to be one of the problems that cause low grades, motivation, and a negative attitude towards learning (Guido, 2013; Prima, Putri, & Rustaman, 2018; Yasin et al., 2018). The reasons why students tend to have difficulty understanding physics concepts include learning models, learning approaches, and conventional learning media that do not yet support students' learning styles today.

The selection of appropriate approaches and learning media during learning will help students understand a material and concept in physics learning. The use of learning media will encourage students to prepare themselves with the skills needed to face the advancement of technology-based education (Hanif et al., 2019; Yusuf et al., 2018). Based on literature studies in the article, many kinds of learning media have been developed, both in the form of e-learning, digital teaching materials, simulation software, and even using practicum tools (prototypes) found in school facilities. By presenting learning media during the learning process, students will play a more active role in learning. This is supported by research conducted by Taufiqy et al. (2016) in Zidatunnur and Rusilowati (2021) that the existence of digital-based learning media can increase students' understanding of the material provided and increase students' interest in learning physics. This will certainly affect the improvement of student learning outcomes. However, there are no articles that analyze the effect of physics learning media based on STEM as a whole based on the variables that affect physics learning.

The purpose of this literature review research is to identify and analyze the effect of STEM-based learning media on students' physics learning. Therefore, this study has several questions as follows:

- Q1: What are the moderating variables that influence the use of STEM-based learning media in students' physics learning?
- Q2: Do moderating variables influence the use of STEM-based learning media in students' physics learning?

## Method

The research design used is a qualitative study with a systematic literature review method. Systematic literature review is a research method with content analysis. This method focuses on findings made by various other researchers published in the form of articles. The articles analyzed are both national and international articles. The articles analyzed will be carried out in several stages, the research stages will be carried out using the Prisma-P form. The stages of Prisma-P research are identification, screening, and inclusion (Heo et al., 2022). The stages of this research can be seen in Figure 1.

As seen in Figure 1, the identification stage involves searching for articles to be analyzed. The article search uses databases indexed by Scopus, Google Scholar, and Eric. The article search on the Scopus site was conducted using the keywords "STEM based AND physics AND learning AND media" with 11 articles obtained. The article search on the Google Scholar site was conducted using the keywords "STEM-based physics AND learning media", in this search 131 articles were obtained. While the last site search on Eric used the keywords "STEM-based physics learning media", this obtained 552 articles. So the total search results for articles with keywords for STEM-based physics learning media were 694 articles with a publication year range of 2018-2024.

After the identification stage, the screening stage is carried out. This stage involves filtering the articles to be analyzed based on the inclusion criteria set by the researcher. The first inclusion criterion is open access articles. A total of 241 open access articles were obtained, while 453 articles were eliminated that were not categorized as open access. Next, filtering will be carried out based on inclusion criteria such as the media used in physics learning, academic level, and other variables. This resulted in 64 articles based on the inclusion criteria and 177

articles that were eliminated. Further screening was carried out based on quality, which was done through a review process, resulting in 40 articles and 24 articles being eliminated based on quality. The third stage is inclusion. This stage involves the articles that will be analyzed. There are 40 articles to be analyzed. The variables that will be analyzed from these 40 articles include the country of publication, year of publication, academic level, research method, physics learning material, learning media, research instruments used, abilities measured from cognitive, psychomotor and affective aspects, and the most frequent publication journals in the findings of this research article.

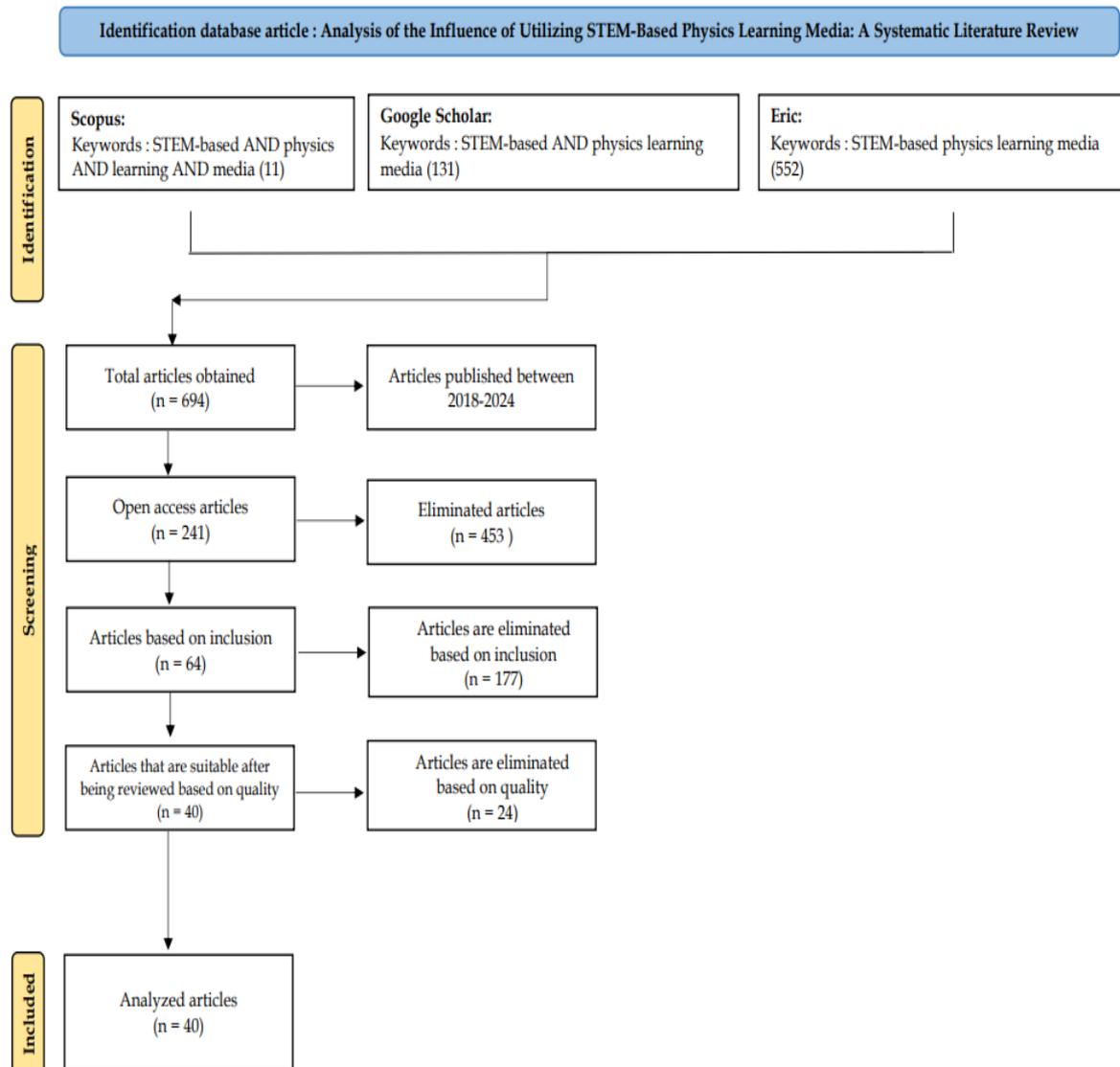


Figure 1. Prisma-P Research Stages

## Results

Based on the results of the inclusion stage, 40 articles were obtained for analysis. The articles that have been analyzed will be synthesized. The synthesis of 10 articles can be seen in the following Table 1.

Table 1. Synthesis of 10 Articles

No	Author, years	Method	Sample	Findings
1.	Ashidiq et al., 2024	Quasi experimental	SMP	The use of a STEM Project-based learning model was able to improve students' critical thinking skills with an N-gain value of 0.718.
2.	Badmus & Jita, 2022	Quantitative	SMA	With the use of video-assisted STEM, students' spatial visualization abilities experience an increase in physics learning in terms of score level, gender and school of type
3.	Martaningsih et al., 2022	R & D	SD	There are differences in students' problem solving ability scores based on the results of the pretest and posttest using the STEM-PBL module.
4.	Uygun, 2022	Quasi experimental	SD	With the use of prototype-STEM based there is a significant difference in increasing students' STEM attitudes and students' attitudes towards science
5.	Kartini et al., 2021	Quantitative	SMP	Physics learning by applying the STEM Project Based learning model is highly recommended in improving students' Problem Solving Skills
6.	Kırıcı & Bakırcı, 2021	Quasi experimental	SMP	There is a significant difference in the results of students' scientific creativity tests with the application of STEM-based LKPD media in learning
7.	Pahrudin et al., 2021	Quasi experimental	SMA	Students' critical thinking abilities have increased with the implementation of STEM-based videos using inquiry models.
8.	Tanel, 2019	Semi- experimental	University students	The findings of this research are that there are significant differences in the experimental group in the learning outcomes of prospective teachers
9.	Sagala et al., 2019	Quasi experimental	SMA	The results of this research show that STEM-based ESciT learning with the help of LKPD is very supportive as a medium for increasing understanding of concepts
10.	Yusuf et al., 2018	Quasi experimental	University students	Students' HOTS ability in learning quantum physics obtained significant results using STEM-based e-learning with an N-gain value (0.7) in the high category

### Country of Publication

Based on the analysis of 40 articles obtained from 2018-2024, several publishing countries were identified that conducted research using STEM-based learning media in physics education. This can be seen in Figure 2.

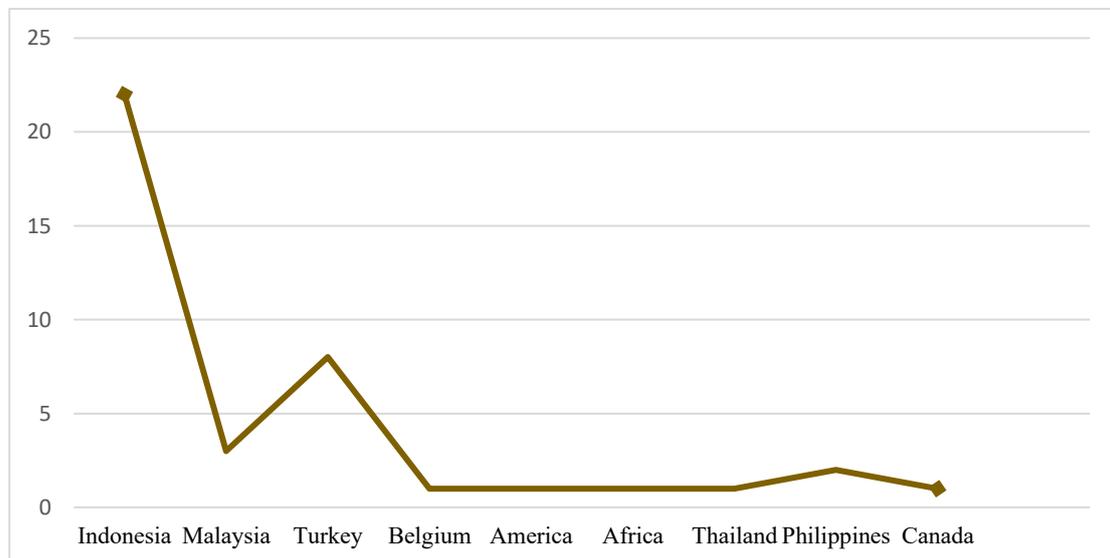


Figure 2. Country of Publication

Figure 2 shows that there are 9 countries that have published articles on STEM-based learning media, including Indonesia with 22 articles (Jannati et al., 2020; Fitria & Asrizal, 2021; Badaruddin et al., 2024), Malaysia with 3 articles (Sulaiman et al., 2023; Othman, 2022), Turkey with 8 articles, Belgium with 1 article, the United States with 1 article, Africa with 1 article, Thailand with 1 article, the Philippines with 2 articles, and Canada with 1 article. Based on this analysis, the country that publishes the most on STEM-based learning media in physics education is Indonesia. This is likely due to the surge of Coronavirus Disease-2019 (COVID-19) cases in Indonesia, which led to a temporary change in the implementation of learning systems until the disaster subsides and the learning system returns to normal. This change occurred not only at the elementary and junior high school levels but also across all academic levels from elementary school to university.

Due to the ongoing disaster, the learning system has been shifted online. Therefore, the learning used is learning that uses media with an integrated STEM approach (Sunarti & Rusilowati, 2021; Zidatunnur & Rusilowati, 2021). However, this shows that the country of publication does not influence the use of STEM-based learning media in physics education because all countries from various continents are conducting research and development regarding STEM-based learning media in physics education.

### Year of Publication

Based on the inclusion criteria, the 40 articles to be analyzed were those published between 2018 and 2024. This resulted in the grouping of articles for each year, as shown in Figure 3.

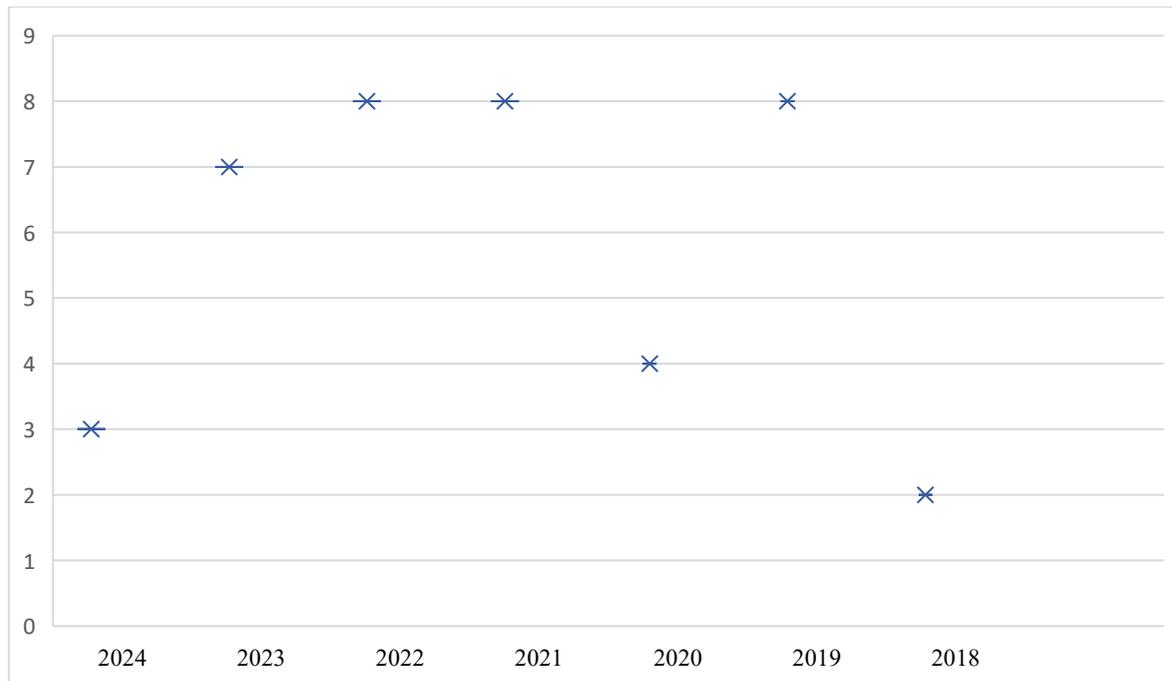


Figure 3. Year of Publication

The years with the most publications on STEM-based learning media in physics education are 2021 and 2022, with 8 publications each (Sanjaya et al., 2021; Kırıcı & Bakırcı, 2021; Bazelais et al., 2022; Badmus & Jita, 2022). 2021 and 2022 were marked by advancements in science and technology, and the end of the Covid-19 pandemic. As a result, there was a need for new and innovative learning approaches to support students in understanding learning concepts. This is supported by research conducted by Fitria and Asrizal (2021), who conducted observations at SMA Negeri 1 Gunung Omeh. Their findings are based on the results of observations and interviews conducted with physics teachers, it turns out that the learning media that is still used is textbooks. This is an obstacle because students think that physics subjects are still difficult to understand concepts and formulas so that students are more likely to get bored, which will hinder their creative development. Creativity is one of the essential skills needed in 21st-century education. Therefore, one approach that can help students develop scientific creativity is the STEM approach. By possessing scientific creativity skills, students will be able to produce new products (Bakirci et al., 2022; Hu & Adey, 2002).

### Academic Level

The analysis of the articles revealed four academic levels that were the subjects of these studies: elementary school, junior high school, high school, and university students. The grouping can be seen in Figure 4. The academic level with the highest number of publications on STEM-based learning media in physics education is high school, with 19 articles representing 39% of the total. Elementary school had 8% (4 articles), junior high school had 22% (11 articles), and university level had 31% (15 articles).

At the high school level, students are more prepared to face the era of globalization. Therefore, human resources in this era are encouraged to be literate and technologically skilled (Suwarma et al., 2019). Students are required

to be able to understand global issues related to STEM and also understand scientific and non-scientific explanations with evidence (Beybee, 2013).

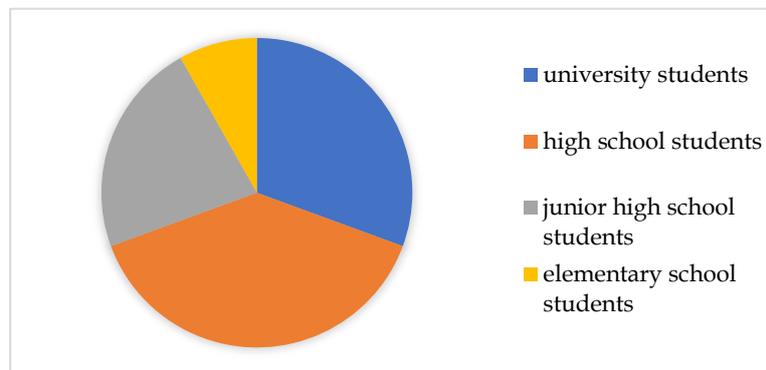


Figure 4. Academic Level

### Research Method

The research methods analyzed in the data of this article yielded several method groupings. This can be seen in Figure 5.

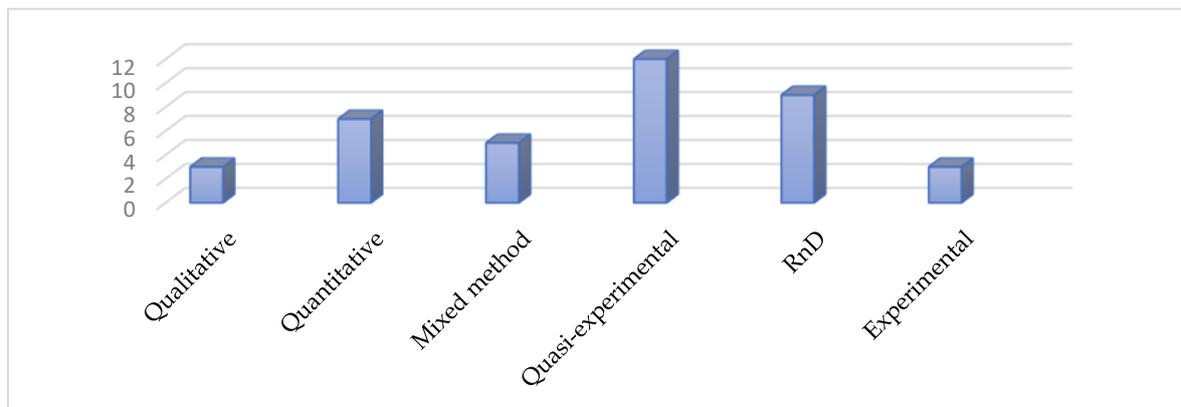


Figure 5. Research Method

The most widely used research method with the use of STEM-based learning media is the quasi-experimental research method, with 12 articles obtained. This is because the quasi-experimental method makes it easier for researchers to determine the effect of using STEM-based learning media in physics learning on the variables to be measured. This is supported by research conducted (Yulianti et al., 2019; Bazelais et al., 2022; Uygur, 2022) which used a quasi-experimental method by measuring students' critical thinking skills and conceptual understanding in physics learning.

### Learning Material

The articles analyzed are articles that are relevant to physics learning material. In this analysis, various physics

materials were obtained which were carried out in research using STEM-based learning media. These will be grouped in Figure 6.

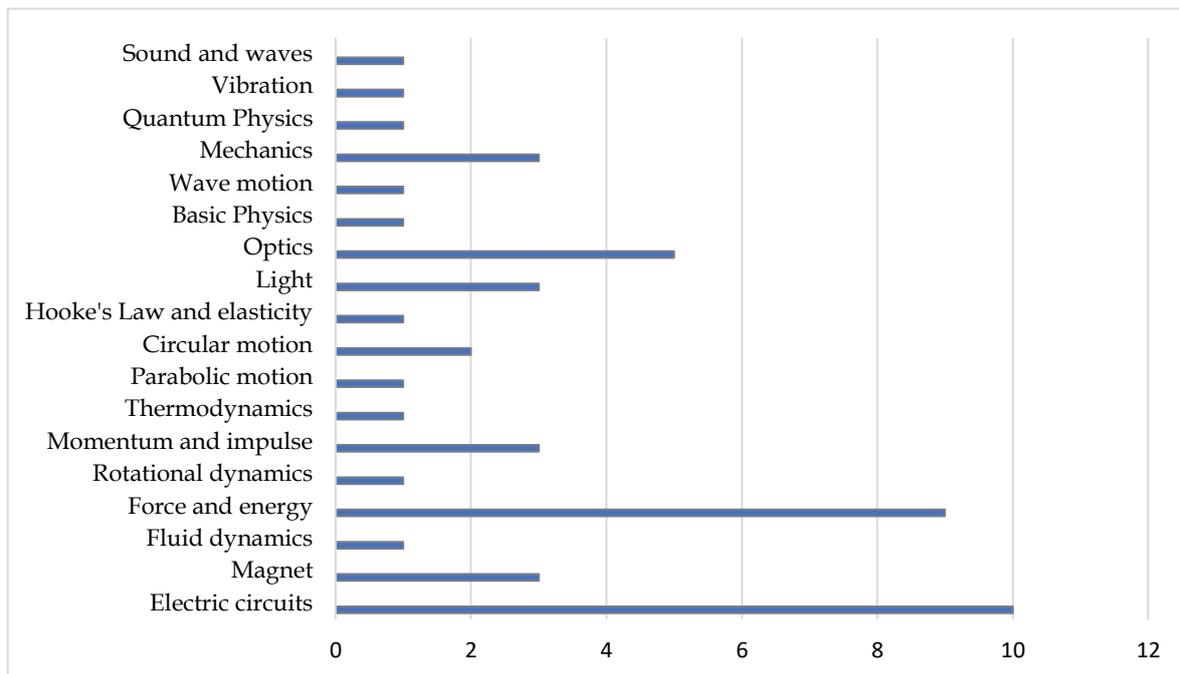


Figure 6. Learning Material

Based on the analysis results, 18 physics subjects were studied from elementary school to university levels. From the grouping in the figure above, the most researched topic is electrical circuits, with 10 articles obtained. Difficulties were found for students in the topic of electrical circuits. This is supported by research conducted by Yasin et al. in 2018, which states that electrical circuits are one of the physics topics whose problems involve very complex and abstract concepts. Students also have difficulty explaining the role of electric fields when conducting electrical circuit experiments (Cao & Brizuela, 2016; Yasin et al., 2018). Electrical circuits also require concepts related to circuit diagrams, graphs, and vectors, thus requiring spatial visualization skills (McCunn & Cilli-Turner, 2020; Lowrie et al., 2019; Badmus & Jita, 2022). Thus, learning using the STEM approach in electrical circuit material can increase students' interest in learning science, which will be able to provide a deep understanding and be able to interpret learning and improve students' skills (Anwari et al., 2015; Yasin et al., 2018).

### Learning Media

Based on the analysis of the article data, various learning media were used in physics learning using the STEM approach, including worksheets, e-modules or modules, simulations/software, student worksheets, prototypes, e-books, e-learning, and videos. This can be seen in Figure 7. The most widely used STEM-based learning media is the prototype, with 13 articles obtained (Akkoyun et al., 2023; Yakob et al., 2021; Samsudin et al., 2020; Hanif et al., 2019; Apriyani et al., 2019). Prototyping is the development of a new product or design with the aim of testing a concept or material to be studied. Prototypes can be created using experimental tools found in school laboratories.

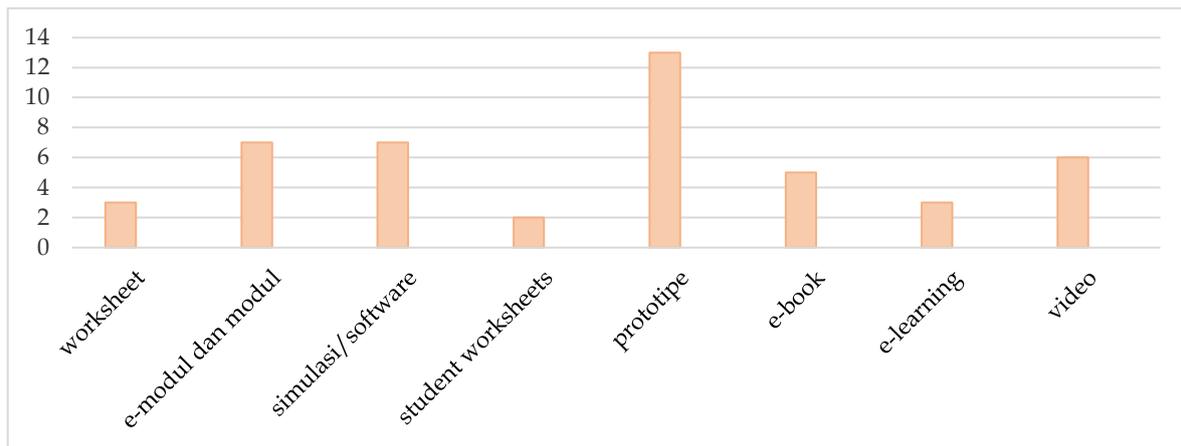


Figure 7. Learning Media

### Research Instrument

The research instruments obtained based on the analysis results include tests, questionnaires, observation, interviews, perception, and some that were not mentioned. The grouping can be seen in Figure 8.

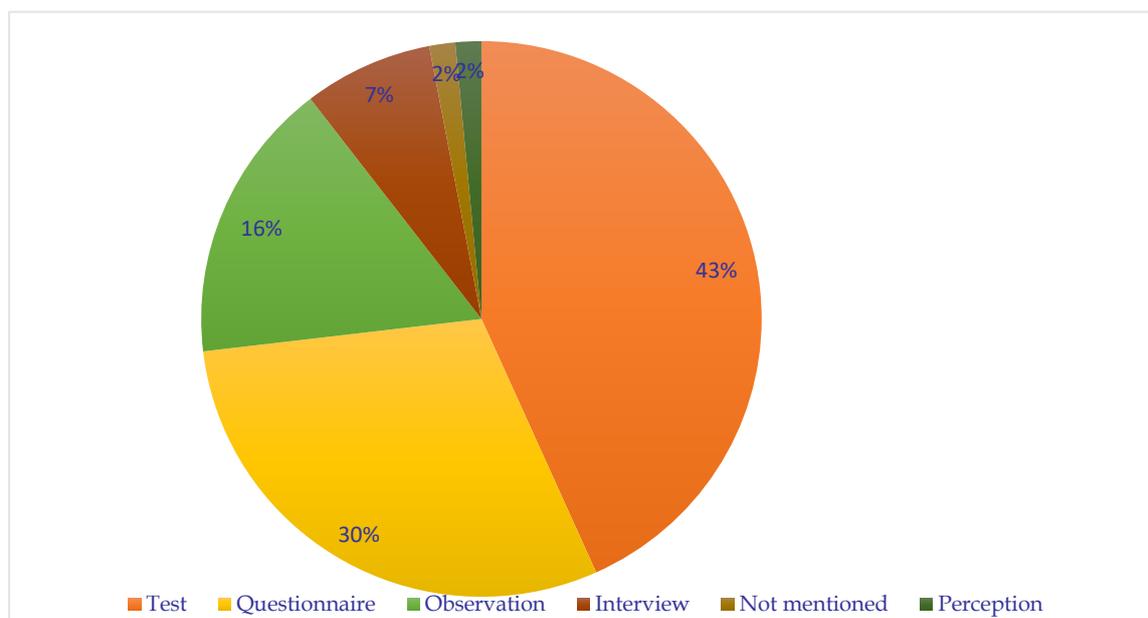


Figure 8. Research Instrument

The most widely used instrument in this research article is the test, with a percentage of 43%. Thus, it can be concluded that tests are instruments that can make it easier for researchers to obtain results or scores when measuring students' abilities. This is supported by research conducted by Bahtaji (2023) using the Force Concept Inventory (FCI), an instrument developed not only to measure students' conceptual understanding of Newtonian mechanics but also to help students overcome misconceptions in Newtonian mechanics. The developed instrument will undergo feasibility and reliability testing. The tested instrument shows good reliability.

## Student Abilities

Based on the analysis of 40 articles, various abilities were measured using STEM-based learning media in physics learning. These abilities consist of cognitive, psychomotor, and affective aspects of the students. This grouping can be seen in Figure 9.

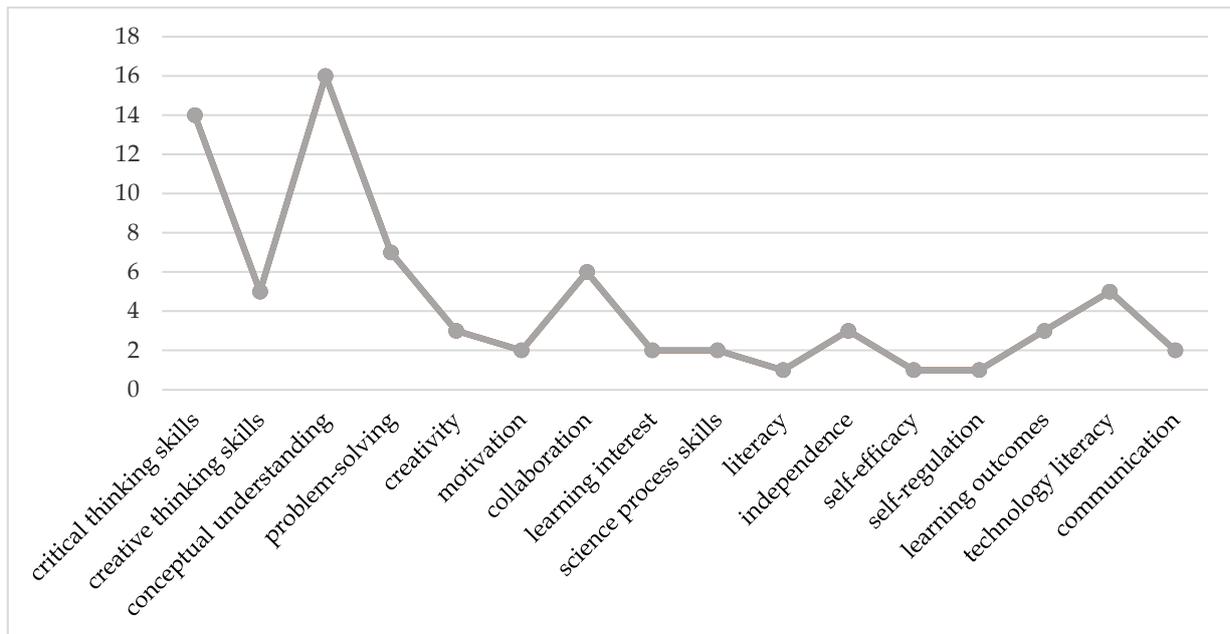


Figure 9. Student Abilities

The learning abilities of students in Figure 9 represent abilities relevant to the 21st century. However, the most researched ability in STEM-based learning, particularly in physics education, is conceptual understanding, with 16 articles acquired (Uzun & Şen, 2023; Serevina & Hamidah, 2022; Ladachart et al., 2022; Sanjaya et al., 2021; Modesto, 2018). The second most frequent ability is critical thinking, with 14 articles (Ashidiq et al., 2024; Akkoyun et al., 2023; Othman, 2022; Pahrudin et al., 2021). Problem-solving ability was addressed in 7 articles (Dignam, 2024; Martaningsih et al., 2022; Kartini et al., 2021). From the psychomotor domain, creativity was found in 3 articles (Kırıcı & Bakırcı, 2021; Hanif et al., 2019).

Meanwhile, from the affective domain, self-efficacy was found in 1 article (Samsudin et al., 2020). It can be concluded that the most frequently measured ability in this research is conceptual understanding. It is important to acknowledge that conceptual understanding in physics is crucial for students, as successful physics learning is indicated by a good understanding of concepts (Rose Amanda Puri & Riki Perdana, 2023). This research was conducted to determine whether there were significant differences in conceptual understanding abilities between the experimental and control groups in the pretest and posttest (Bakirci et al. (2022) conducted research implementing an inquiry-based STEM approach in learning physics, specifically on Work and Energy. The media used in this research was a worksheet. The results showed a significant difference in pretest and posttest results between the experimental and control classes, with a result of ( $F_{1; 61} = 33.235$ ;  $p < 0.05$ ).

## Most Frequent Publications

Based on the analysis of 40 articles, the top 5 articles with the most publications were identified. This can be seen in Table 2.

Table 2. Most Frequent Publications

No	Journal Name	N	Percentage
1.	Journal of Physics: Conference Series	6	15%
2.	Journal of Science Learning	6	15%
3.	Journal of Turkish Science Education	4	10%
4.	European Journal of Educational Research	3	7.5%
5.	Journal of Baltic Science Education	3	7.5%

Table 2 shows the top 5 publications with the most articles published, including the Journal of Physics: Conference Series (Jannati et al., 2020; Yusuf & Widyaningsih, 2019; Yulianti et al., 2019) and the Journal of Science Learning (Oktay et al., 2023; Kartini et al., 2021) with a percentage of 15% (N = 6). The publication ranked third is the Journal of Turkish Science Education with a percentage of 10% (N = 4) (Badmus & Jita, 2022; Yusuf et al., 2018). Publications ranked fourth and fifth are the European Journal of Educational Research (Pahrudin et al., 2021; Goovaerts et al., 2019) and the Journal of Baltic Science Education (Sulaiman et al., 2023; Tanel, 2019) with a percentage of 7.5% (N = 3). Thus, the most popular publications with the theme of STEM-based learning media are the Journal of Physics: Conference Series and the Journal of Science Learning.

## Conclusion

This research utilizes data from 40 articles (2018-2024) that have undergone a screening process based on inclusion criteria. The research method employed is a systematic literature review. The objective of this research is to identify the variables influencing the use of STEM-based physics learning media. After conducting the analysis, several influencing variables were identified. In this study, the country of publication did not influence the research, as article publications were widely distributed across various countries experiencing changes in their learning curricula, thus necessitating STEM-based learning media. The years with the most published articles were 2021 and 2022, marking the resumption of full face-to-face schooling after the COVID-19 pandemic. This period also saw a slight decline in students' understanding of physics due to the reduced effectiveness of online learning during the pandemic. The academic level with the most prevalent use of STEM-based learning media is high school. The most dominant research method used, due to its relative ease in assessing student learning outcomes, is the quasi-experimental method. The most dominant subject matter is electrical circuits, as this topic is considered abstract and challenging to comprehend. The most widely used learning media with a STEM approach is the prototype, due to its ease of acquisition by utilizing school facilities. The most frequently used instrument is the test, as the most commonly measured ability in the analyzed articles is conceptual understanding. The most popular publications are the Journal of Physics: Conference Series and the Journal of Science Learning, with a representation of 15%, comprising 6 articles.

## Statements and Declarations

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## AI vs Human Writers: A Comparative Analysis of Story Rewriting through Readability Metrics

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### Abstract

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This study examines how generative artificial intelligence (GenAI) might be used to rewrite narratives in comparison to texts written by humans, with an emphasis on writing style, readability, and verbosity. GenAI's performance is evaluated by means of quantitative analysis and readability metrics. The results indicate that GenAI often generates writings with higher verbosity and readability scores than stories written by humans. Furthermore, the examination of lexical density and diversity reveals subtle variations in writing styles between human, ChatGPT, and Gemini; GenAI exhibits competitive performance in these metrics. Although the results point to potential applications of GenAI in narrative, more research is needed to determine how effective the technology is when compared to human authors.

#### Keywords

HCI  
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Verbosity  
Lexical density  
Lexical diversity

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## Introduction

Significant interest has been garnered by the rise of generative artificial intelligence (GenAI) and its potential to revolutionize the creative industries, especially storytelling (Cheung & Shi, 2025). The intriguing subject of whether GenAI can efficiently rewrite stories to a standard that is on par with or better than that of human specialists is researched in this study and also reported by Habib and El Tarabishi (2024). The research specifically aims on comparing AI-generated texts to texts written by professional authors in order to analyze important metrics like verbosity, readability, and writing skill. The discipline of story writing has been profoundly impacted by the new era of automated content generation which was brought about by the substantial development of generative artificial intelligence (GenAI) (Fang et al., 2023b). This paper dives into investigating the use of GenAI technology to rewrite stories, critically assessing the differences between human-written and AI-generated texts in terms of verbosity, readability, and literary style. The scholarship explores stylistic subtleties, lexical diversity, and the overall communication efficiency of texts created by human writers and sophisticated GenAI models like ChatGPT and Gemini using quantitative analysis and recognized readability criteria. Given the increasing use of AI in the creative and educational sectors, it is critical to comprehend these differences in order to evaluate the usefulness, advantages, and constraints of GenAI in story writing.

The way we write includes different language and style elements that shape stories, like the choice of words, how sentences are put together, the use of figurative language, and the overall voice of the narrative (Al-Alami, 2025). Generative AI systems have been getting better at creating text that fits well with different styles and makes sense in context, changing tone and structure to match various storytelling needs. GenAI works by looking at large sets of existing texts, figuring out the connections between words and phrases so it can create smooth writing that often mimics human styles (Mariani & Dwivedi, 2024). This method based on data allows the AI to mimic stylistic patterns while also sticking to known writing rules, which limits true originality or major creative breakthroughs.

Comparative analyses show that AI-generated narratives are consistent and logically coherent, but they usually don't have the figurative richness and descriptive novelty that human-written texts do (Sardinha, 2023). Human writing frequently incorporates metaphors, idiomatic expressions, and emotional subtleties that are closely tied to personal and cultural backgrounds elements that Generative AI struggles to genuinely replicate because it lacks consciousness and real-life experiences as per the note of Beguš (2024). Additionally, GenAI's reliance on learned patterns might result in outputs that seem formulaic or overly generic, unlike human authors who can bring in their unique voice and creative nuances.

Lexical density and diversity serve as measurable indicators of stylistic complexity. Studies show that earlier GenAI models usually have a smaller vocabulary and a more restricted range of language compared to humans, leading to a tendency for repetitive and formulaic expressions (Durak et al., 2025). Wu and Xu (2025) found that recent GenAI systems, like Gemini, show improved vocabulary and varied phrasing, making them capable of matching human writing in some situations. The progress shows that GenAI is still improving its language skills, but there are still some subtle differences in how deeply it can express ideas.

Readability is a critical factor in narrative writing, as it directly affects reader engagement and comprehension. In order to quantify textual accessibility, readability metrics, including the Flesch-Kincaid Grade Level and Reading Ease scores, assess features such as sentence length, word complexity, and syntactic structure. A consistent finding in quantitative research comparing GenAI-generated narratives and human writing is that AI outputs score higher on readability measures due to their generally clearer sentence structures and more unambiguous diction (Zhao, 2024). The improved readability of AI-generated texts can render them particularly appropriate for audiences who are interested in content that is readily digestible or for preliminary manuscripts that require further enrichment.

On the other hand, the increased intelligibility is frequently accompanied by verbosity, as GenAI texts are more intricate and wordy than those written by humans. This level of verbosity encompasses longer sentences, a higher word count, and occasionally redundant or repetitive expressions that may impede narrative rhythm and conciseness. Excessive elaboration can overshadow narrative momentum, which is a skill that experienced human writers typically calibrate more adeptly to maintain reader interest and story flow, despite the fact that such verbosity can enhance detail and clarity. The polish of AI-generated text in terms of grammar, spelling, and punctuation is typically impressive, largely due to the AI's algorithmic precision in sentence construction and its training on vast corpora with high linguistic standards. However, Yang et al. (2024) says that AI-generated prose frequently fails to incorporate the nuanced stylistic embellishments or emotionally resonant phrasing that human editors and authors intentionally employ to enhance the reader's experience.

Verbosity is the degree of depth and elaboration shown in a story. GenAI's tendency for verbosity may be related to its design, which creates text token-by-token depending on learning probabilities rather than deliberate intents about narrative economy. Using repeated words and phrases more often than usual human writing, this produces material that may be complex yet occasionally repetitive. For example, in AI-generated sections, repeated theme terms like "mystery" or "fear" stand out, which might compromise the authenticity of the text and the reader's immersion.

Furthermore, the AI's lack of thorough memory across long narrative spans causes plot discrepancies and narrative logic holes, problems that human writers usually solve by deliberate storytelling technique. Highlighting the constraints of modern AI creativity and contextual awareness, AI-generated narratives might include plot gaps or character behavior discrepancies that shatter reader suspension of disbelief. Notwithstanding their flaws, GenAI tools provide great value as helpers in idea generating, writing, and breaking writer's block, hence acting as cooperative partners rather than solo creators. GenAI may increase output by quickly generating coherent material that people can hone and modify when directed by knowledgeable human writers who grasp narrative goals and story structure. This symbiosis fits the developing perspective of GenAI as "intelligent assistance" complementing rather than replacing human creative effort.

## **Method**

### **Research Design**

For our research design, we have hired a professional story writer with a background in English literature to write

a subjective story. We then instructed ChatGPT and Gemini (the freely available version) to rewrite the story with no specific instruction was given as to summarizing within certain words, for certain levels, or for specific genres.

## Data Analysis

A combination of Python (Van Rossum, 2007), MS Excel, and SPSS(Hinton et al., 2014) was used to analyze the texts generated by these three parties. Descriptive statistics(George & Mallery, 2018) pertaining to usage or parts of speech, word and sentence count, complex word count, word lengths, and sentence lengths were measured. A readability analysis was performed for several readability matrices based on phrase and word level, such as Linsear Write (LW) (Wang et al., 2022), SMOG Index (SMOG) (McLaughlin, 1969), The Coleman-Liau Index (CLI) (Coleman & Liau, 1975), The Flesch-Kincaid Grade Level (FKGL) (Kincaid et al., n.d.), The Gunning Fog Index (GFI) (Gunning, 1968). Furthermore, we analyzed the writing style of three prompts using the concept of Lexical Density and Lexical Diversity.

## Linsear Write

Linsear Write is an approach to determine how hard it is to read English text. The U.S. Air Force originally developed it to evaluate the clarity of their technical manuals (Wang et al., 2022). The Linsear Write formula determines the U.S. grade level of a text by analyzing the length of sentences and counting the words that have three or more syllables.

To apply the formula, we need to count all the words that contain more than two syllables while avoiding the usage of specific names, general technical language, or words that combine multiple concepts. Next, we start to tally the words that have one or two syllables, which are referred to as "easy words," and include this count in the overall total weight. Finally, we divide the total number of words by the number.

The formula can be written as:

$$Score(LW) = (ASL + (2 * HDW)) / SL$$

Here,

Score (LW) = Linsear Write readability score

ASL = Average sentence length (the total number of words divided by the number of sentences)

HDW = Number of "hard words" (words with more than two syllables)

SL = Number of sentences in the text

The Linsear Write formula assists in determining the ease or difficulty of reading an English text. This straightforward scoring system assists writers in determining whether their text is appropriate for the intended audience. It provides a general indication of the grade level at which the writing would be comprehensible to the reader. This formula is particularly beneficial for the evaluation of technical or scientific materials.

The Linsear Write score is determined by the U.S. school grade system. A score of 1 indicates that the text is

comprehensible to a first-grade student, a score of 2 is indicative of a second-grade student, and so forth for subsequent grades. For instance, A score of 8 indicates that the text is comprehensible to an eighth-grade pupil, who is approximately 13–14 years old. A score of 12 indicates that the text is appropriate for a high school senior. Texts that receive a score of 16 are considered to be at the reading level of a university senior.

### The SMOG Index

The SMOG Index, an acronym for "Simple Measure of Gobbledygook," is a useful instrument for evaluating the complexity of text, particularly in terms of legibility and comprehension (McLaughlin, 1969). It allows writers and editors to ensure that their content is compatible with the literacy level of their intended audience. To be more precise, the SMOG Index offers an estimate of the educational level necessary to completely understand a specific piece of writing. This index is particularly dependable for the assessment of extended texts, including books, reports, and articles. Its credibility is derived from its emphasis on the frequency of polysyllabic words, which are words that contain three or more syllables. These words are known to exacerbate sentence complexity and impede comprehension.

In order to determine the SMOG Index Readability Score of a text, it is necessary to select a sample that includes a minimum of 30 sentences from the document. Next, we must determine the total number of polysyllabic words in the sentences. The square root of the total number of polysyllabic words must be calculated after this measure has been obtained. Finally, the SMOG Index score is obtained by adding 3 to the square root value:

$$\text{The formula for the SMOG Index: } \sqrt{\text{Number of Polysyllabic Words}} + 3$$

The final number called the SMOG Index Readability Score, tells how easy or difficult the text is to understand. This score is based on two main things; the first one being the average number of syllables in the words and the second factor is the total number of long words in the sample we have chosen. The SMOG Index serves as a way to measure how complex a text is and gives a rough idea of how many years of schooling someone usually needs to understand a certain piece of writing easily. This is really useful for making sure that written materials match the reading levels of different audiences.

A SMOG Index score ranging from 6 to 7 shows that the text is pretty straightforward and easy to understand, typically for those who have gone through about six to seven years of school. This relates to the higher grades of elementary school, where students have basic reading skills that allow them to understand simple sentences and common words. If the score is between 8 and 9, it means the text is kind of easy to read. This is usually appropriate for individuals who have completed around eight to nine years of schooling, which is about the middle school level. At this point, readers can handle a bit more complex sentences and a wider variety of words, but they still need a text that is clear and straightforward. A score ranging from 10 to 12 indicates that the text has a moderate level of difficulty, making it most appropriate for those who have finished ten to twelve years of formal education, which aligns with the high school level. These texts usually have more complex vocabulary and sentence structures, which require a greater level of reading skills to understand completely. Texts that score 13 or higher on the SMOG Index are seen as difficult and are usually meant for readers who have a college-level education or

more. These texts have a lot of complicated academic language, specific terms, and intricate sentence structures. Because of this, they need strong reading and writing skills, along with an understanding of complex ideas and the specific language used in different fields to be easily understood. The SMOG Index offers a structured way for writers and editors to assess and improve the readability of their writing, making sure it aligns well with the educational level of the audience they are targeting.

### **The Coleman-Liau Index**

The Coleman-Liau Index is a well-known readability formula that measures how easy or hard it is to understand and read a piece of English writing (Coleman & Liau, 1975). It gives a rough idea of the grade level in the U.S. school system that a typical reader would need to reach in order to understand the text well. The Coleman-Liau Index is different from many other standard reading measures because it doesn't count syllables or look for words with more than one syllable. Instead, it is based on looking at two things that can be measured: the number of letters and the number of words in the text. Based on the idea that longer words (which usually have more letters) and longer sentences make reading harder, this design was made.

There are two easy averages that are used to figure out the Coleman-Liau Index readability number. The first is the average amount of letters in 100 words, which shows how long things are and how hard they are to read. The second number shows the average number of sentences per 100 words and shows how long and complicated the sentences are. Since the Coleman-Liau Index looks at characters and phrases instead of sounds, it is a simpler and more computer-friendly way to judge how easy something is to read. This makes it perfect for automatically analyzing digital texts.

By using numbers to show how hard a book is, the index helps writers, teachers, and editors make sure their work is appropriate for the reading level of the people they want to read it. It is especially useful in school settings, where matching the level of difficulty of the text to the reading level of the students is important for helping them understand and learn.

The formula is:

$$Score = 0.0588 * L - 0.296 * S - 15.8$$

Here,

L = Average number of characters per 100 words

S = Average number of sentences per 100 words

The Coleman-Liau Index is a well-known readability formula that measures how easy or hard it is to understand and read a bit of English writing. It gives a rough idea of the grade level in the U.S. school system that a typical reader would need to reach in order to understand the book well. The Coleman-Liau Index is different from many other standard reading measures because it doesn't count syllables or look for words with more than one syllable. Instead, it is based on looking at two things that can be measured: the number of letters and the number of words in the text. Based on the idea that longer words (which usually have more letters) and longer lines make reading

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### **The Flesch-Kincaid Grade Level**

The Flesch-Kincaid Grade Level is a widely utilized readability formula designed to assess the relative difficulty of English-language texts (Kincaid et al., n.d.). It provides an estimate of the U.S. school grade level necessary for a reader to comprehend the material comfortably, making it a valuable tool for educators, publishers, and writers who seek to align their content with the reading abilities of specific audiences.

This formula evaluates text complexity by analyzing two primary linguistic features: sentence length and word difficulty. Specifically, it considers the average number of words per sentence as an indicator of syntactic complexity and the average number of syllables per word as a measure of lexical difficulty. The underlying assumption is that longer sentences often require greater cognitive effort to process, while words containing more syllables tend to be more advanced and less familiar to readers, thereby increasing the overall reading challenge.

Originally developed as part of efforts to improve the accessibility of U.S. Navy technical manuals in the 1970s, the Flesch-Kincaid Grade Level has since become a standard tool in educational settings, government communications, and the publishing industry. It is particularly useful in evaluating whether textbooks, instructional materials, and general publications are appropriately tailored to the intended reader's educational level. By providing a score that directly corresponds to a U.S. grade level, the Flesch-Kincaid Grade Level offers an intuitive and practical means of readability assessment. A lower score indicates simpler, more accessible text suitable for younger readers, while a higher score reflects increased complexity, requiring more advanced reading skills. This capacity to translate linguistic features into educational benchmarks has made the formula an enduring and essential component of readability evaluation across a wide range of fields.

The specific mathematical formula looks like this:

$$FKRA = (0.39 * ASL) + (11.8 * ASW) - 15.59$$

Here,

FKRA is the Flesch-Kincaid Reading Age\newline

ASL is the Average Sentence Length (calculated by dividing the total number of words by the number of sentences)

ASW is the Average number of Syllable per Word (calculated by dividing the total number of syllables by the number of words)

The flowchart and step by step process for calculating FKGL is given in Figure 1.

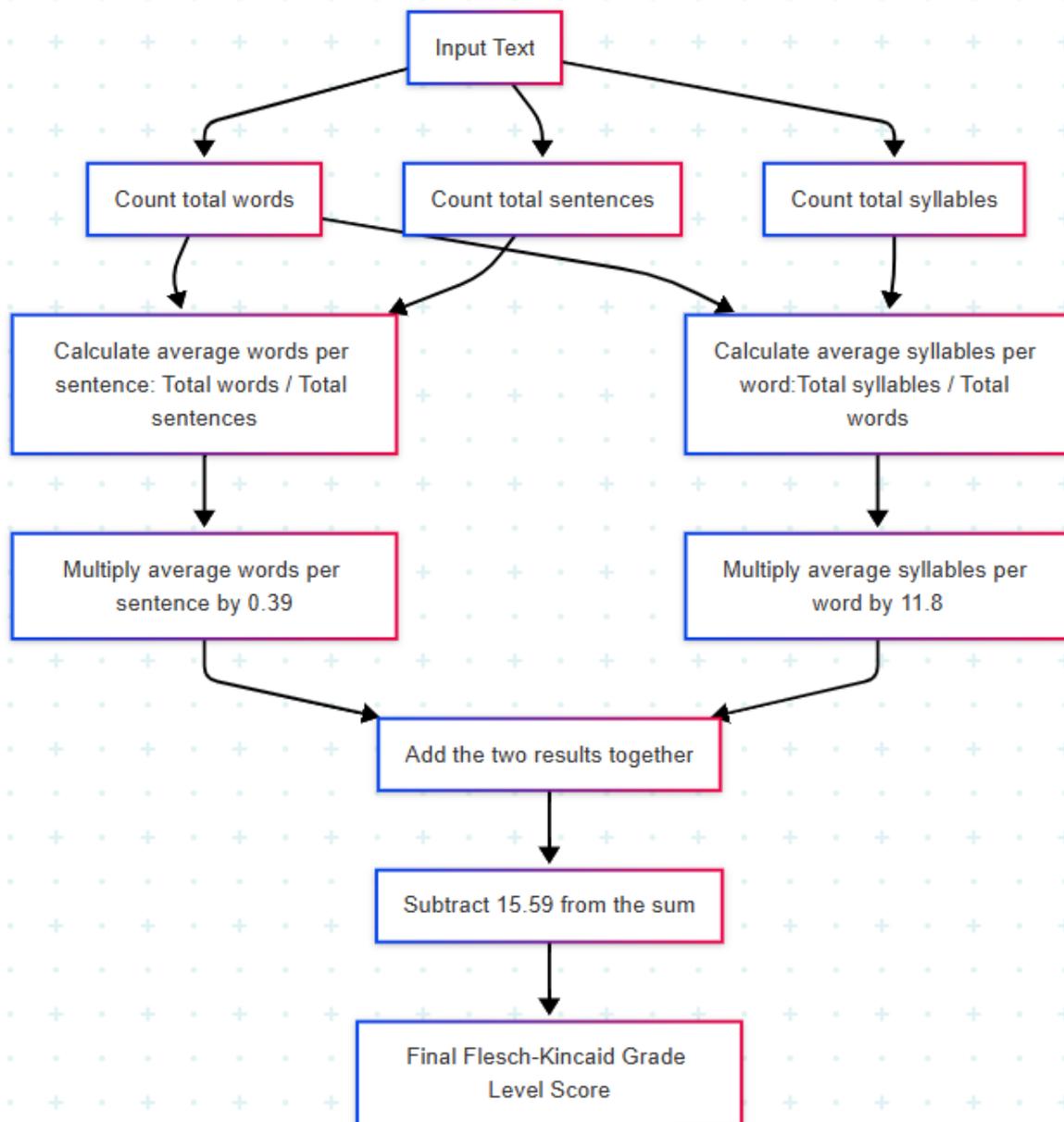


Figure 1. Flowchart of Working Principle of FKGL

The Flesch-Kincaid Grade Level gives a number score that is in line with standards for schooling. For instance, an 8.2 score means that the text is appropriate for users at or above the eighth-grade level, while a 12.5 score means that the material is appropriate for people at the twelfth-grade level or in their first year of college. The method works well to make sure that written materials are easy to read, understand, and right for the level of understanding of the people they are meant for by turning linguistic features into clear, grade-level measurements.

The formula evaluates text difficulty by analyzing two key linguistic features: the length of sentences and the complexity of words. Specifically, it calculates the average number of words per sentence as an indicator of syntactic complexity, alongside the average number of syllables per word as a measure of lexical difficulty. The underlying principle is that longer sentences tend to impose greater cognitive demands on readers, while words with multiple syllables are often more advanced and less familiar, thereby raising the overall reading challenge. This formula can be used in many real-world situations, not just in school. For example, the United States Army uses the Flesch-Kincaid Grade Level to check how easy it is to read its technical manuals, making sure that important operational and instructional texts are understandable for people with different education backgrounds. In Pennsylvania, the law says that car insurance policies have to be written using this formula, making sure they are easy enough for someone at a ninth-grade reading level to understand. This policy is designed to help people understand financial matters better by making sure that key financial documents are available to everyone. Some other states have also started using the formula to assess how easy legal documents are to read, like business policies, financial disclosures, and consumer contracts, showing a wider trend in public communication.

### **The Gunning Fog Index**

The Gunning Fog Index is a recognized readability formula intended to assess the difficulty of English texts and to estimate the educational level necessary for a reader to easily understand the content (Gunning, 1968). Created by Robert Gunning in the 1970s, this index serves as a crucial instrument for writers, educators, and publishers seeking to match their writings with the reading capabilities of their target audience. The Gunning Fog Index, similar to other readability metrics, produces a numerical score indicative of a U.S. school grade level, providing a definitive and practical standard for evaluating text complexity.

The Gunning Fog Index is calculated using two main linguistic factors: the average sentence length and the ratio of complicated terms in the text. The algorithm specifically evaluates the average number of words per sentence as a measure of syntactic difficulty and designates words with three or more syllables as challenging. The index posits that lengthier sentences and polysyllabic words elevate cognitive load, rendering a text more difficult to read and comprehend.

The Gunning Fog Index algorithm integrates several characteristics into a singular score. It calculates a grade-level estimate by multiplying the sum of the average sentence length and the percentage of complicated words by a fixed factor. This technique facilitates a direct and efficient assessment of readability, rendering it especially valuable in circumstances where clear and accessible information is paramount.

The Gunning Fog Index is frequently utilized for various written products, including digital content, news stories, corporate reports, and instructional publications. In the age of digital media, it has emerged as a mechanism for guaranteeing that online material is available to a diverse audience, including those with differing reading skills. Furthermore, in academic and professional contexts, the index functions as a reference for creating writings that harmonize precision with clarity, thereby improving understanding and engagement.

The Gunning Fog Index, emphasizing sentence structure and lexical complexity, provides a realistic and dependable metric for readability, facilitating successful communication across all domains and audiences:

$$\text{Fog Index} = 0.4 * ((\text{words/sentences}) + (\text{percentage of (complex words/ words)}))$$

Calculating the Gunning Fog Index requires two critical components of information. The average sentence length is determined by dividing the total number of words by the total number of sentences, providing a measure of syntactic complexity. The proportion of complex or polysyllabic words is assessed. In this index, complex words are defined as those with three or more syllables, excluding common suffixes like -ed, -es, and -ing, as well as proper nouns and well-known compound words. Furthermore, the use of highly technical or specialized terminology can elevate the perceived complexity of the text, as these terms may create comprehension challenges for general audiences.

The Gunning Fog Index formula quantitatively assesses a text's readability by incorporating sentence length and word complexity to generate an overall score. This score reflects the years of formal education generally necessary for a reader to understand the material upon initial reading. It is generally advised that public communication texts target a Fog Index score of 7 to 8 to maintain accessibility for most adult readers. A score above 12 indicates that the material likely poses considerable difficulties for numerous readers and may necessitate advanced literacy skills for effective comprehension.

Classic children's literature, exemplified by Charlotte's Web by E.B. White, typically attains a Fog Index of approximately 6, signifying its accessibility to middle-grade readers. In contrast, prominent publications like The Economist or Scientific American often produce Fog Index scores between 12 and 14, indicating a more complex and intellectually rigorous style aimed at educated readers. A Fog Index of 12 indicates that the text is appropriate for readers with a proficiency level comparable to that of a U.S. high school senior, generally aged 17 to 18 years. The Gunning Fog Index provides a standardized metric that emphasizes both sentence structure and lexical complexity. This tool is beneficial for writers, educators, and policymakers aiming to achieve a balance between precision and clarity, ensuring effective and accessible written communication for the intended audience.

### **The Flesch Reading Ease Formula**

The Flesch Reading Ease Formula provides a simple method for assessing the reading level of a text. This tool is highly reliable, providing accurate results with minimal need for detailed verification. Initially developed for educational purposes, it has evolved into a widely utilized resource among various U.S. government agencies, organizations, and businesses. This formula assesses the readability of a piece of English writing (Flesch, 1948). To apply the formula, one must first quantify the number of words, sentences, and syllables present in the text. Subsequently, the following formula can be utilized to compute the Flesch Reading Ease score:

$$\text{Reading Ease} = (206.835 - (1.015 * (\text{words/sentences})) - (84.6 * (\text{syllables/words})))$$

The Flesch Reading Ease score is a popular tool used to evaluate how easy it is to read English texts. Created in 1948 by Rudolf Flesch, who was a key figure in readability research, this formula offers a structured method to

assess how easily a text can be comprehended by its target readers (Flesch, 1948). The Flesch Reading Ease score is determined by looking at two key elements of language: the average syllables in each word and the average number of words in each sentence. By concentrating on these aspects, the formula reflects both the vocabulary and sentence structure of a text, providing a useful way to gauge how easy it is to understand.

The score is shown as a number between 0 and 100, where higher numbers mean it's easier to read. Texts that get better scores usually use shorter words and simpler sentences, which makes them easier for everyone to read. A score between 60 and 70 is usually seen as acceptable for most types of public communication because it balances clarity and sophistication pretty well.

Scores that fall between 90 and 100 are considered very easy to read and are usually appropriate for materials aimed at younger readers or those with basic literacy skills. Texts that score between 80 and 89 are seen as easy and suitable for a wide general audience. A score between 70 and 79 shows that the text is pretty easy to read, while scores from 60 to 69 are considered standard and suitable for high school readers.

As scores go down, the difficulty goes up: texts that score between 50 and 59 are pretty tough, those between 30 and 49 are seen as difficult, and materials scoring between 0 and 29 are considered really confusing and hard for most readers to understand without some extra knowledge or reading them multiple times. So, the Flesch Reading Ease score is not just a number; it's also a helpful guide for writers, editors, and teachers who want to adjust their texts to fit the reading skills of their audience. By choosing the right words and organizing sentences well, writers can make their work easier to read and communicate their ideas clearly.

### **The Automated Readability Index**

A well-known way to figure out how easy or hard it is to read English writing is to use the Automated Readability Index (ARI) (Smith & Senter, 1967). Researchers from the U.S. Air Force made it in the 1960s to help figure out how easy it is to read scientific papers and other kinds of learning materials. The ARI uses two factors to determine the level of difficulty of a piece of writing: the average number of characters in each word and the average number of words in each sentence. This grade level score tells you what grade level the work is at.

The ARI looks at two things to see how easy a text is to read: the average number of characters in a word and the average number of words in a sentence. To find the ARI, use this formula:

$$ARI = (4.71 * (\text{characters/words})) + (0.5 * (\text{words/sentences})) - 21.43$$

To calculate the ARI, initially tally the total amount of characters, words, and sentences in the text. Subsequently, insert these values into the formula to compute the ARI score. This score indicates the grade level required to comprehend the material. The ARI quantifies text complexity and indicates its readability level. Dr. Rudolf Flesch, who previously devised the Flesch Reading Ease formula, established the Automated Readability Index (ARI) in the 1960s as an alternative. Currently, the ARI is widely employed by educators, academics, and professionals to assess diverse written content.

The ARI score indicates the corresponding grade level of the text, ranging from grade 1 to grade 14 or above. If the ARI score is 6.0, the text corresponds to a 6th-grade reading level. The scale aligns with the U.S. education system, wherein grade 1 represents the inaugural year of elementary school and grade 14 signifies the concluding year of college.

### Writing Style Analysis

Two ways to look at how people write are lexical density and lexical diversity. These ways help us figure out how hard someone's writing is and how many different words they use. This test checks how much information is packed into each word, and this test checks how many different words are used in the text. You can use these tools to learn more about how people write or to compare different types of writing. But they don't say how good the writing style is or how easy the text is to read (Halliday, 1995; Johnson, 1944).

The number of words in a piece of writing is called its lexical density. Among the words in the text, it figures out how many "content words" (like names, verbs, adjectives, and adverbs) are used. Words that are used a lot in a writing generally mean that it is formal or full of facts and ideas. Most of the time, writing that is less dense in words means it is more relaxed and chatty. Most of the time, writing that is less dense in words means it is more relaxed and chatty (Halliday, 1995).

Lexical variety is the number of unique words a piece of writing uses. To find it, divide the number of unique words by the total number of words. A lot of different words used shows that the writer has a big language and doesn't use the same words over and over. A low vocabulary variety, on the other hand, could mean that the text repeats words a lot, only uses certain terms for a certain topic, or doesn't have many words to choose from. The overall research design process for readability is illustrated in Figure 2 and Figure 3 illustrates the design process for writing style.

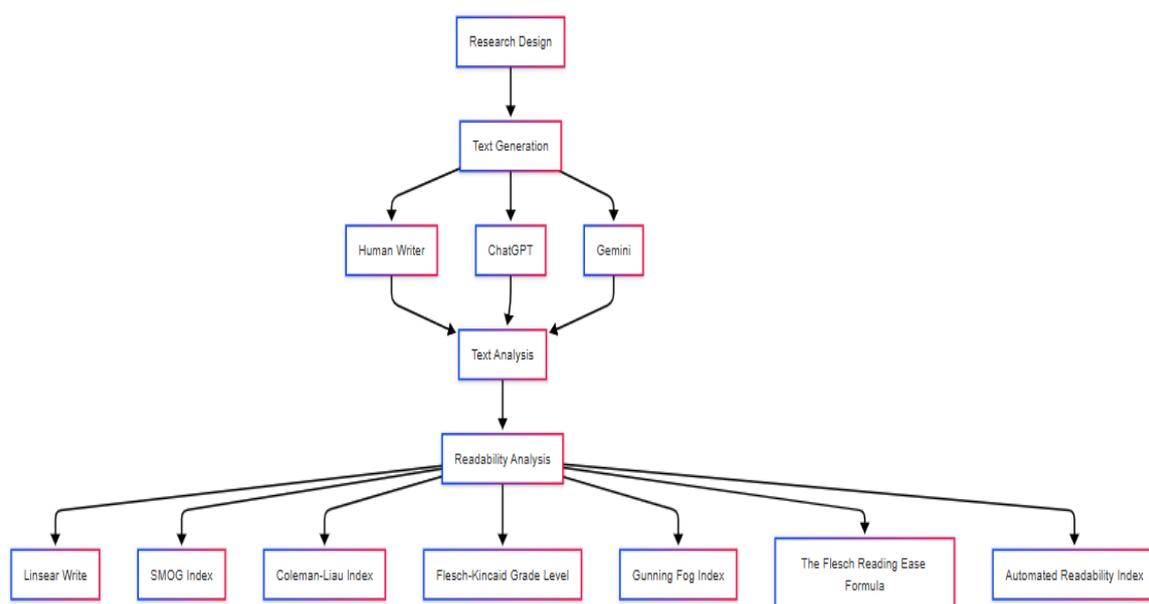


Figure 2. Research Design for Measuring Readability

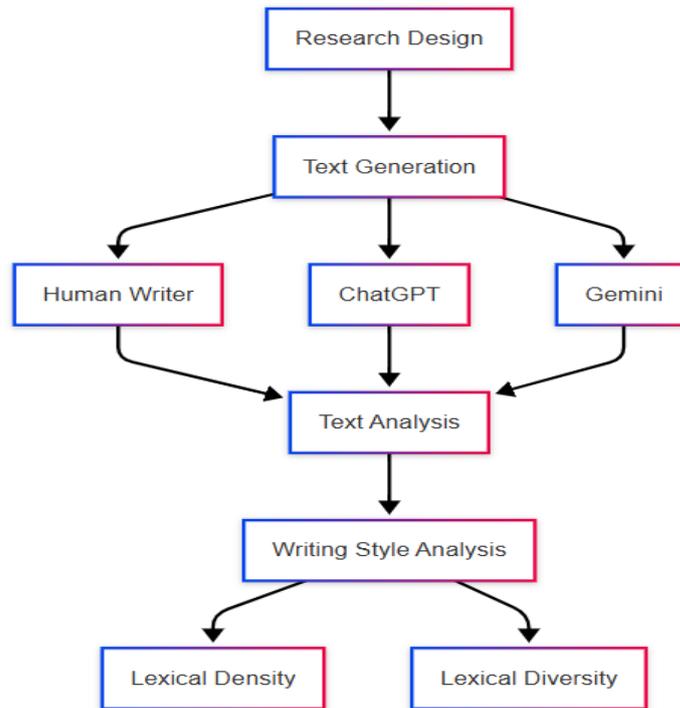


Figure 3. Research Design for Writing Style Analysis

## Results

We observe a decreasing word count while analyzing the text's descriptions while shifting from human to GenAI. This instance points towards the enrichment of the verbosity of the texts as the text shifts from human to GenAI. We note for human, at the peak of the graph, 25.85% of words in the text comprised of at least 3 letters while 0.62% of words in the text had 12 letters as the highest lettered word length. As per sentence length, 9 sentences in the text had 16 words on one spectrum and on the other spectrum, 1 sentence had 54 words. For ChatGPT, 23.39% of words in the text comprised of at least 3 letters while 0.4% of words in the text had 13 letters as the highest lettered word length. As far as sentence length is concerned, 8 sentences in the text had 16 words on one spectrum, and on the other spectrum, 1 sentence had 30 words. The details are reported in Table 1.

Table 1. Descriptive Statistics of Story Texts Generated by Human, ChatGPT and Gemini

Descriptive Analysis	Human	ChatGPT	Gemini
Word Count	975	868	795
Sentence Count	69	59	52
Complex Word Count	88	106	137
Syllable Count	1358	1297	1305
Avg. Word Length	4.41	4.72	5.08
SD of Word Length	2.38	2.6	2.9
Avg. Sentence Length	14.13	14.68	15.1
SD of Sentence Length	7.47	5.28	6.91

We have reported the data on several readability measures along with scores, difficulty level, grade level, and age range in Table 2.

Table 2. Readability Analysis of Story Texts Generated by Human, ChatGPT and Gemini

Readability	Writer	Score	Reading Difficulty	Grade Level	Age Range
LW	Human	7.43	Average	7 <sup>th</sup>	12 – 13
	ChatGPT	8.4	Average-Slightly Difficult	8 <sup>th</sup>	13 – 14
	Gemini	10.5	Fairly Difficult	11 <sup>th</sup>	16 – 17
SMOG	Human	6.99	Average	7 <sup>th</sup>	12 – 13
	ChatGPT	8.42	Average-Slightly Difficult	8 <sup>th</sup>	13 – 14
	Gemini	9.81	Somewhat Difficult	10 <sup>th</sup>	15 – 16
CLI	Human	7.95	Average-Slightly Difficult	8 <sup>th</sup>	13 – 14
	ChatGPT	9.86	Somewhat Difficult	10 <sup>th</sup>	15 – 16
	Gemini	12	Difficult	12 <sup>th</sup>	17 – 18
FKGL	Human	6.36	Fairly Easy	6 <sup>th</sup>	11 – 12
	ChatGPT	8.04	Average-Slightly Difficult	8 <sup>th</sup>	13 – 14
	Gemini	10.02	Somewhat Difficult	10 <sup>th</sup>	15 – 16
GFI	Human	9.3	Slightly Difficult	9 <sup>th</sup>	14 – 15
	ChatGPT	11	Fairly Difficult	11 <sup>th</sup>	16 – 17
	Gemini	12.8	Very Difficult	College	18 – 20
FREF	Human	75	Fairly Easy	7 <sup>th</sup>	12 – 13
	ChatGPT	64	Standard	8 <sup>th</sup> – 9 <sup>th</sup>	13 – 15
	Gemini	51	Fairly Difficult	10 <sup>th</sup> – 12 <sup>th</sup>	15 – 18
ARI	Human	7.04	Average	7 <sup>th</sup>	12 – 13
	ChatGPT	8.79	Slightly Difficult	9 <sup>th</sup>	14 – 15
	Gemini	10.93	Fairly Difficult	11 <sup>th</sup>	16 – 17

It's interesting to note that, in all formulae across the spectrum discussed in our research, GenAI's score on readability has a higher performance than that of a story written by Human, thus making the writeup a bit difficult from the preceding human-based writeup.

Table 3. Writing Style Analysis of Story Texts Generated by Human, ChatGPT and Gemini

Writing Style	Style Analysis Metrics	Human	ChatGPT	Gemini
Lexical Density	Test Score	58.2%	60%	64.3%
	Density Range	50% - 59%	60% - 69%	60% - 69%
	Scale (Density)	Above Average	Moderately High	Moderately High
Lexical Diversity	Test Score	41.1%	46.6%	53.2%
	Density Range	40% - 49%	40% - 49%	50% - 59%
	Scale (Density)	Average	Average	Above Average

We observe the story written by Human had a density range within 50%-59% which has a balance on accessibility and detail. The write-up caters to wider audience, and it provides a substantial content but skips overwhelming readers with unknown and specialized type of language. As per diversity, this writing style uses a wide range of words. This type of writing often finds a way to balance the introduction of new terms with the reinforcement of already-established ones. This can suggest that the writer is avoiding repetition by utilizing a variety of words and idioms. The results are reported in Table 3.

## Discussion

The comparison between stories written by humans and those generated by GenAI shows clear differences in how wordy they are, how easy they are to read, and their writing styles. This helps us understand how AI writing models are improving and where they still have limitations. This part goes over the results in detail, focusing on the main metrics like word and sentence analysis, readability scores, and writing style indices.

### Text Length and Verbosity

We noticed that the word count consistently decreases when comparing human-written text, which has 975 words, to the text generated by ChatGPT at 868 words, and then to the text generated by Gemini, which has 795 words. This pattern shows that while GenAI models are good at summarizing stories, they also tend to use more complicated sentences and words. The average sentence length goes up across the three versions: 14.13 words in human writing, 14.68 in ChatGPT, and 15.1 words in Gemini. This gradual increase shows that even though GenAI lowers the overall word count, it creates longer sentences, which might influence the flow and tempo of the story. The standard deviation of sentence lengths shows some interesting differences, with human-written text having more variety (7.47) compared to ChatGPT (5.28) and Gemini (6.91). This suggests that human writers have a more flexible narrative style, while AI tends to stick to a more regular structure.

The length of words tends to follow a similar pattern. The average word length increases from 4.41 characters in human text to 4.72 in ChatGPT, reaching a high of 5.08 in Gemini. Also, the standard deviation in word length goes up, which suggests that GenAI systems, especially Gemini, tend to use longer and more diverse words. The way words are stretched out adds to the complexity of AI outputs, which is shown in the readability metrics.

### Readability Metrics

The readability assessment, which uses several well-known formulas like Linsear Write, SMOG Index, Coleman-Liau Index, Flesch-Kincaid Grade Level, and Gunning Fog Index, consistently indicates that AI-generated texts have higher scores, suggesting they are more difficult to read. This might seem a bit surprising at first, especially since AI focuses on being clear. However, it highlights how these models tend to create text that, even though it's grammatically correct, ends up being more wordy and complex in structure. For instance, when applying the Linsear Write formula, text written by humans scores 7.43, which is appropriate for 7th-grade readers aged 12 to 13. In comparison, ChatGPT scores 8.4, and Gemini scores 10.5, indicating that the latter is suitable for 11th-

grade students aged 16 to 17. This upward trend is regularly shown in other equations. The SMOG Index goes from 6.99 for humans to 9.81 for Gemini, and the Coleman-Liau Index ranges from 7.95 to 12, indicating that Gemini's output is around college-level difficulty.

The Flesch-Kincaid Grade Level shows a similar trend, increasing from 6.36 for human writing to 10.02 for Gemini. This suggests that human writing is still easy for middle school readers, while AI-generated texts are more suited for high school juniors and seniors or early college students. The Gunning Fog Index highlights the difference in complexity between human writing and AI-generated text. Human writing scores a 9.3, which is at a 9th-grade level, while ChatGPT and Gemini score 11 and 12.8, respectively. Interestingly, Gemini's score is getting close to the level of difficulty usually found in academic papers meant for young adults between 18 and 20 years old.

The trends indicate that GenAI models frequently produce narratives that are more challenging to comprehend and denser, despite seeming fluent and grammatically accurate on the surface. The intricacy may enhance the content's appeal to older audiences, however also poses issues for ordinary readers, particularly in educational or public communications. This heightened density frequently arises from extended sentences and a greater ratio of intricate vocabulary, hence augmenting the cognitive burden necessary for understanding. Although this may augment the narrative's depth, it can also impede the speed and accessibility crucial for captivating a wide audience. Moreover, the propensity for verbosity and redundancy in GenAI outputs might undermine clarity, hindering users' ability to seamlessly grasp essential concepts. Resolving these challenges is essential for GenAI systems to function well in educational, journalistic, or public service settings where readability is crucial.

### **Writing Style: Lexical Density and Diversity**

Exploring the aspects of writing style, particularly focusing on lexical density and diversity, is essential for enhancing the richness and complexity of text. By analyzing the variety of vocabulary and the frequency of word usage, one can better understand how these elements contribute to effective communication and engagement in writing. The analysis of writing style through metrics like lexical density and diversity helps to highlight the differences in quality between narratives created by humans and those generated by AI. The lexical density, which looks at the ratio of content-carrying words like nouns, verbs, adjectives, and adverbs, shows a steady increase across the samples: 58.2% in human text, 60% in ChatGPT, and 64.3% in Gemini. Based on what I've learned, human writing typically sits in the "above average" density range (50%–59%), which means it strikes a good balance between being informative and easy to read. On the other hand, both AI models show "moderately high" density, which could improve the amount of information but might also overwhelm readers.

Lexical diversity measures how rich a vocabulary is by looking at the ratio of unique words to the total number of words, which helps to further distinguish the samples. The human text scored 41.1%, which falls into the "average" range. This indicates a good mix of repetition and variety, a quality seen in skilled narrative writing that helps to reinforce themes without being repetitive. ChatGPT has a score of 46.6%, which is still considered average but shows some potential for more variety. On the other hand, Gemini scored 53.2%, placing it in the

"above average" category and suggesting it has a wider vocabulary. Having more diversity in writing can make it better, but too many different words can confuse things, especially in stories where sticking to a theme is important.

### **Implications for AI Storytelling**

The results highlight the potential and the existing limitations of GenAI systems when it comes to creative writing tasks. On one hand, texts generated by AI show strong performance in terms of lexical density and diversity, getting close to or even exceeding human standards. This shows how the models are getting better at copying the complex style that comes with professional writing. However, the high readability scores point out a continuing issue: GenAI systems tend to prefer complex syntax and lengthy structures instead of clear and straightforward writing. The longer sentences, more complex words, and increased word lengths make the text harder to read, even though it stays grammatically correct and stylistically fluent.

Additionally, even though GenAI's increased use of complex vocabulary and varied language indicates a level of sophistication, it might unintentionally make the story harder to follow and understand, especially for general audiences or younger readers. This tension between richness and readability shows the basic trade-offs in AI writing: the push for detailed content versus the necessity for clarity and engagement. The story written by humans shows a good mix of complexity and variety, something that AI models still haven't quite mastered. Writers, using their own experiences and careful style choices, effectively handle wordiness, rhythm, and theme to create stories that connect with readers on both emotional and intellectual levels. On the other hand, GenAI models work by making predictions based on probabilities and recognizing patterns. They are good at sounding fluent on the surface, but they have a hard time with creating deeper connections in narratives and making things easier to understand.

Still, the advancements shown by tools such as ChatGPT and Gemini indicate that AI narrative skills are improving. As large language models keep developing, it will be really important to improve how they balance complexity and clarity. Future development should aim to help AI systems change their writing styles based on what the audience needs. This could involve adding features that adjust readability or allow users to set their preferred difficulty levels.

### **Conclusion**

In comparison to texts created by human writers, the study shows that GenAI, as represented by ChatGPT and Gemini models, typically produces information with a higher verbosity. Additionally, across a range of reading metrics, including Linsear Write, SMOG Index, and Flesch-Kincaid Grade Level, the AI-generated stories have consistently higher readability scores than those authored by humans. Nuanced variations can be seen when writing style is analyzed using metrics like lexical diversity and density. In summary, GenAI demonstrates encouraging potential in rewriting stories with improved verbosity and competitive readability metrics, its efficacy in storytelling still needs investigation and improvement. Subsequent investigations may explore user satisfaction

and user experience studies alongside optimizing LLMs related to narrative creativity while preserving human-like characteristics that appeal to a wide range of viewers.

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## Apprehensions of Integrating Artificial Intelligence into Higher Learning: A Systematic Review

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### Abstract

The integration of artificial intelligence in higher learning has been studied and commented upon by several researchers. One thing that is obvious is that there are several authors who are hopeful that artificial intelligence has positive prospects for higher learning. On the other hand, there are also several authors who think that artificial intelligence is negatively affecting higher learning. While some authors report on hopes only and others on fears only, some others report both fears and hopes. This systematic review engages a total of 61 reports, including journal articles and grey literature, to address three issues. The first is about the extent to which researchers admit to the existence of negatives of AI in higher education. The second is about the factors that these researchers associate with the fears they admit. The third is a summarized identification of sources of this fear. Literature for this review was collected from various online sources, and the PRISMA 2020 flowchart was used for screening. Finally, content analysis was conducted using NVIVO computer software. Results show that, to a large extent, authors admit to the existence of various kinds of disadvantages in using AI in higher learning. These disadvantages lead to fears related to ethics and compromise established standards of higher education. Higher education policy makers and managers are, therefore, called upon to take necessary precautions in designing AI-supported systems and put in place reliable and effective guidelines for their use.

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## Introduction

The use of artificial intelligence in learning, particularly learning in higher education, has become a reality that can no longer be overlooked or ignored. Specifically, the use of generative AI in learning has become very common all over the world (Zentner, 2023; Mahbub et al., 2024). Bala et al., (2025) have reported that artificial intelligence is used to improve the learning environment and that in recent years, higher education has progressively been implementing modern technology, presenting a clear transformative power to higher education practices (Kavitha and Joshith, 2024; Yang, 2024). These authors continue to show that, although technology has so much transformed many aspects of education, with substantial impact in areas of language translation, speech recognition, and game simulation, there are questions over how AI can influence higher education. Some authors have gone as far as stating that AI has ‘revolutionized’ higher learning (Rahiman & Kodikal, 2024).

In the same vein, O'Dea and O'Dea (2023) have added that artificial intelligence in higher education (AIED) is becoming a more important research area with increasing developments and applications of AI within the wider society. The need for more research in AI in higher education finds its rationale from the fact that, as time goes on, more and more universities and colleges will need it as part of their competitive advantage. Just as Hanna and Liu (2021) have argued, amidst various faces of competition for excellence, forward-thinking universities can integrate artificial intelligence (AI) into their operations to set themselves apart from the competition and brace up for long-term growth.

Notwithstanding the perceived positive role of artificial intelligence in higher education, the pace of academic research in the area of artificial intelligence in higher education has increased only recently. In 2019, for example, it was argued that despite the fact that artificial intelligence is a reality, academic research on its application in higher education was still lacking (Hinojo-Lucena et al., 2019). A few years later, though, particularly after the introduction of AI chatbot ChatGPT by Open AI in late 2022, a new wave of instantaneous and widespread discussions on the use of AI in higher education came in (Jensen et al., 2015). This new wave brought in polarized perceptions or positions on the use of technology in higher education. In one extreme are the “doomsters” who present apprehensions that technology will ruin what is already present in the status quo of teaching and learning in higher education. In the other extreme are the “boosters” who believe that the technology will positively revolutionize teaching, learning, and educational management practices in higher education (Selwyn, 2014; Shimpi, 2024). In addition, while Santos and Serpa (2023) argued that AI offers an opportunity to support students by offering personalized learning processes and intelligent tutoring systems that improve performance, the adoption of AI is reported to have introduced challenges to traditional education frameworks (Fitriani et al., 2023). In a nutshell, AI in higher learning presents benefits, hurdles, and controversies (DeBello, 2024). Some have even termed the negative side of AI in higher education as the ‘dark side’ (Ivanov, 2023).

It is equally important to note that recent years have witnessed a significant increase in research output reporting on various aspects and issues related to artificial intelligence in higher learning, including views from both extremes of the perception spectrum. For example, Crompton and Burke report that in 2021 and 2022, there was a rapid change as publications on artificial intelligence in higher education rose to nearly two to three times the

number of previous years. Sabado (2025) presents a bibliometric study identifying trends and gaps crucial for policy development, higher education management, and future research initiatives. Sabado's two-decade bibliometric analysis provides an overview of the increasing trajectory of research publications concerning artificial intelligence in higher education. A similar study is also presented by Oguntona and Emere (2025). These studies attest to the fact that literature on the use of AI in higher learning has increased significantly in recent years. It is worthwhile, therefore, to review these emerging studies and learn what authors are suggesting about the use of AI in higher education, specifically the sources of concern directed at the possibility that AI comes with disadvantages.

## **An Overview of Literature**

The decision by universities and colleges whether to adopt or not to adopt AI-powered educational programs depends on a forecast of costs and benefits of using AI in higher education. Studies have reported on several issues related to the adoption and use of AI in teaching, learning, and information or data management. For example, Nagy et al. (2024) conducted an exploratory study with the aim of determining the relationship between risk policies, implementation assumptions, and effort assumptions with social expectations regarding the acceptance of computer-based intelligence innovations in advanced educational organizations in North Sulawesi, Indonesia. The results of the study showed that risk perception, performance expectations, and effort expectations had a large influence on behavioural intentions to adopt artificial intelligence (AI) in higher education. It is important to note that the most dominant factor affecting the decision to adopt AI use in higher education, according to this study, is related to risk perception. Risk in this case has several faces and manifests in several different ways, including the fear that AI could compromise rather than improve cognitive learning.

Additionally, issues to do with artificial intelligence in higher learning are extremely varied. They span from economic considerations, through matters related to skills, to matters of risks related to ethics. Vorontsova et al. (2025) focused on identifying the key trends, knowledge gaps, and opportunities for further research in the use of AI in higher learning with emphasis on the economic effects of using artificial intelligence and ChatGPT tools in higher education. The study concluded that the main areas of economic effects of artificial intelligence and ChatGPT tools in higher education included reducing administrative costs, saving time for teachers and students, and improving the quality and accessibility of educational processes.

Another issue that has been studied and discussed in recent literature is that of initial experiences with the new technology. Azmir and Atikuzzaman (2025) explored attitudes toward using ChatGPT based on academic and demographic variables. This study also explored the difficulties the students faced while using ChatGPT in education. This study revealed that ChatGPT and Grammarly were the most used AI tools. It also revealed that most students trust ChatGPT as a useful tool for coursework, saving time and improving learning. However, attitudes towards the use of AI in higher learning significantly varied with geographical location, internet competency, academic discipline, and previous ChatGPT experience or training. These kinds of studies help researchers, users, and policymakers to realize the need for improved access to AI technologies, focused training programs, and AI literacy in the curricula.

In summary, most of the recent studies on AI in higher education could fit into a matrix of the following subjects:

### **Students' and Teachers' Perceptions of Using AI in Learning**

These authors include perceptions, perspectives, and attitudes of teachers and students as they discuss their expectations in using AI in teaching and learning. These kinds of studies are mostly qualitative, and they only collect, interpret, and report on the views of the respondents in evaluating the new technology. Under this category are such authors as DeBello et al. (2023); McGrath et al. (2023); Galindo-Domínguez et al. (2024); Frutos et al. (2024); Johnston et al. (2024); Sharma et al. (2024); and Novozhilova et al. (2024). These studies are key and foundational, as they help to build a platform for further research into lived experiences of users of AI in higher education. Using findings from these studies, further research can focus on the actual impact of AI in higher learning, identification of challenges and opportunities, and even comparing magnitudes of challenges and opportunities of using AI in higher learning.

### **Impact of AI in Higher Education in General**

In this category are found all the authors who identify the way AI changes the teaching and learning processes in higher learning institutions. While some authors discuss positive impact and negative impact, some discuss other cross-cutting issues, including people's behaviour change, new ways of managing things, etc. Under this category are such authors as Bates et al. (2020); Crompton and Song (2021); Slimi (2023); Talan and Kalinkara (2023); Zhang (2023); Aithal and Aithal (2023); Marengo et al. (2024); Begum (2024), Danish et al. (2024); Vieriu and Petrea (2025); and Anderha (2025). These authors show that the situation before and after the introduction of AI in higher learning is not the same. The introduction of AI in higher learning has caused notable changes in higher learning practices and processes. As noted earlier, these authors may or may not have directly pinpointed the existing identifiable contrasts between what is desirable and what is not desirable while using AI in higher learning. What they have in common is that they alert the reader that the inclusion of AI in higher learning may have negative impacts.

### **Opportunities and Challenges of Introducing AI to Higher Learning**

These are authors who narrow their research to clearly focus on a comparative analysis of positive and negative impacts of AI in higher learning. Their reported findings are important, as they make the reader aware that AI is not only impactful in general terms but that it has created two different realities of pros and cons. They help the reader to be able to start a comparative process of deciding whether or not to include AI in higher learning and why. They also help researchers to identify areas of study that need attention as research endeavours to inform education policies that intend or plan to include AI in higher learning. Under this category are such authors as Akinwalere and Ivanov (2022); Michel-Villarreal et al. (2023); Pisica et al. (2023); Yeralan and Lee (2023); Zeb et al. (2024); Arowosegbe et al. (2024); Hoernig et al. (2024); Abulibdeh (2024); Jafari and Keykha (2023), Contreras et al. (2024); Jomezai et al. (2025); Udeh (2025), Foroughi et al. (2024); and Ali (2025). It is noteworthy that most of these studies are qualitative, and they do not engage in comparing the magnitudes of opportunities

brought in by AI in higher learning against the challenges. Rather, most of these studies identify and mention the existing challenges and opportunities. Further research could focus on identifying and even quantifying the negative impacts (challenges) in order to highlight the necessary precautions for policymakers and managers of higher learning. This leads to the next category of literature.

### Negative Impacts of AI in Higher Education

In this category are researchers who devote their studies to pointing out the identifiable sources of apprehension in deciding to include AI in higher learning. The focus of studies under this category is on how AI could actually compromise teaching and learning in institutions of higher learning if the necessary precautions are not taken. Under this category are such authors as Walczak and Cellary (2023); Sweeney (2023); Lowe (2024); Moya et al. (2024); Rodzi et al. (2024); Bond et al. (2024); Airaj (2024); Cotton et al. (2024), Adewojo (2025); Buele and Llerena-Aguirre (2025); AL-Qadri and Al-Khreshah (2025); and Itani et al. (2025). These authors point out the ‘fear’ facing the decision makers who intend to integrate AI into higher learning. This identification of sources of fear is important for this study because the study intends to present the identified sources of apprehension of using AI in higher education.

### Methodology

This review employed the content analysis technique to identify the sources of apprehension related to the use of AI in higher learning. The analysis involved the use of NVIVO qualitative data analysis software. The research questions, search protocol, inclusion and exclusion criteria, and analysis process were as follows:

### Research Questions

The systematic review aimed at answering three research question (RQs). The questions are arranged below in their cascading order in the analysis process.

RQ1: To what extent do authors admit to the fact that there are disadvantages in using AI in higher learning?

RQ2: To which issues do authors relate the fear of using AI in higher learning?

RQ3: What are the identifiable sources of apprehension related to using AI in higher learning?

Table 1. Literature Sources

Name of search tool	Documents accessed	Relevant and included	Screened out
ResearchGate	72	12	60
Google Scholar	117	24	93
ERIC	86	9	77
Emerald	39	9	30
Refseek*	22	7	15

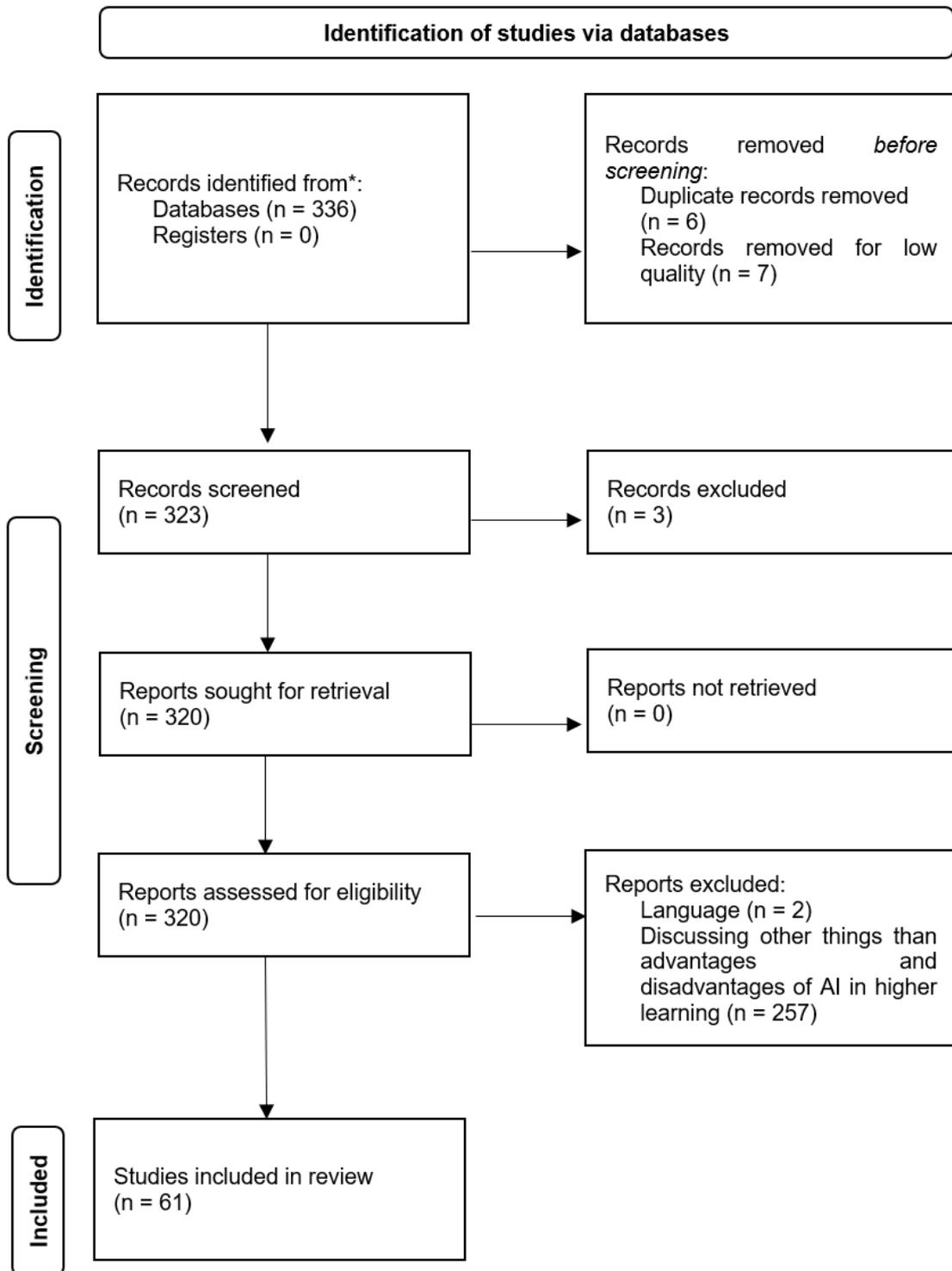


Figure 1. PRISMA Flow Chart Showing the Screening Process

A total of 61 files were imported into Zotero reference manager software to prepare them for analysis in NVIVO 12. Then, the 61 files were exported in RIS file format into NVIVO. The files were then classified as cases in order to come up with file attributes for each file. Text search queries were run in order to identify the dominance of themes and words within the 61 documents through a process of content analysis. Text search query outputs such as ‘reference’ and ‘word tree’ were used to visualize and present the findings of the content analysis process.

Table 2. Inclusion/exclusion Criteria

<u>Aspect</u>	<u>Inclusion</u>	<u>Exclusion</u>
<b>Publication date</b>	From 2020 to date	Before 2020
<b>Genre/type</b>	Journal Articles and Research Reports	Other genres
<b>Theme/Subject matter</b>	Not only the use/application of AI in higher education but discussing advantages/shortcomings	Other themes
<b>Geography</b>	From anywhere in the world	N/A
<b>Level of education</b>	Articles on higher education (college and university)	Other levels of education
<b>Functional usage</b>	Teaching/learning	Other uses like library or administration etc
<b>Language</b>	English	Non-English
<b>Quality</b>	Good quality based on depth of analysis and publisher reputation	Low quality

### Findings

The first step was to explore the use of the term ‘disadvantage’ in all the documents. This was done using the text search query in NVIVO. The search was expanded from ‘exact matches’ to ‘with generalizations’ in order to include all related terms. The query results produced a very complex word tree, which centralized the term ‘limitation.’ This indicated that the authors who discussed advantages and disadvantages of using AI in higher learning reported thousands of times that AI in higher learning had notable limitations. Then, in order to narrow down and focus the analysis of the texts, text search query was run on two different terminologies across all the files. These two terminologies were “disadvantages” and “fear” (see Figure 1 & 2). The text search query was set only at the level of ‘exact matches’ because both terminologies were already semantically related.

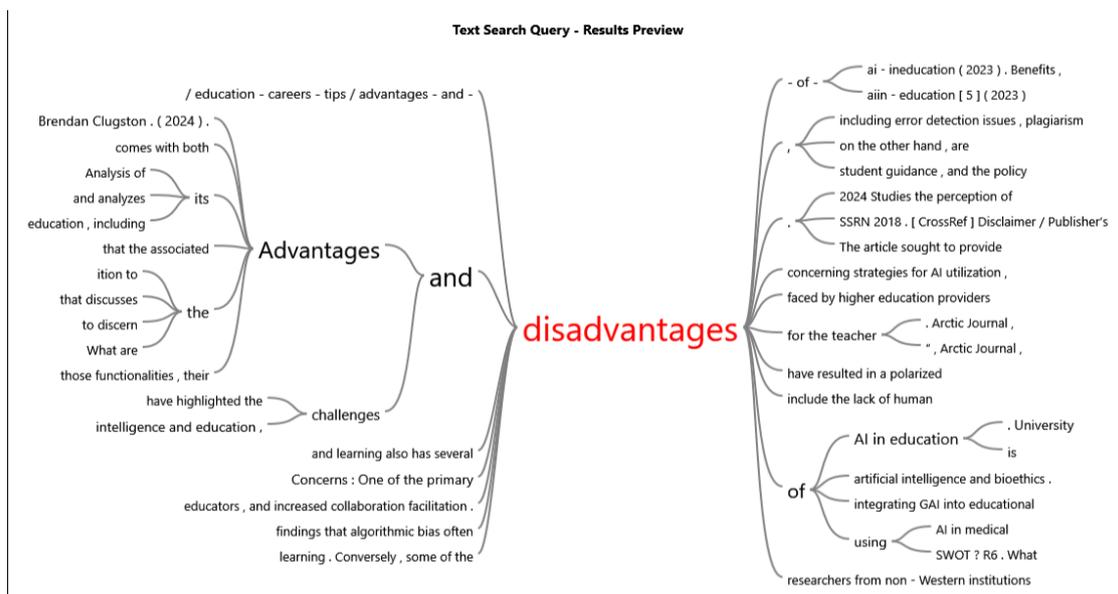


Figure 2. Text Search Query Results for the Word ‘Disadvantages’

As can be seen from the word tree visual (see Figure 2), the word ‘disadvantages’ appears several times in all the analysed texts. The authors admit that the introduction of AI into higher learning ‘comes with both advantages and disadvantages’ and that the process of including AI in higher education must consider ‘the associated advantages and disadvantages’; that policies should ask questions on ‘what are the advantages and disadvantages’ related to AI in higher learning; that AI in higher learning comes with ‘challenges and disadvantages’; that ‘one of the primary concerns of AI in education is the issue of data privacy.’ All these statements are examples to show that, to a large extent, authors of literature on AI in higher learning admit that there are disadvantages in using AI in higher education.

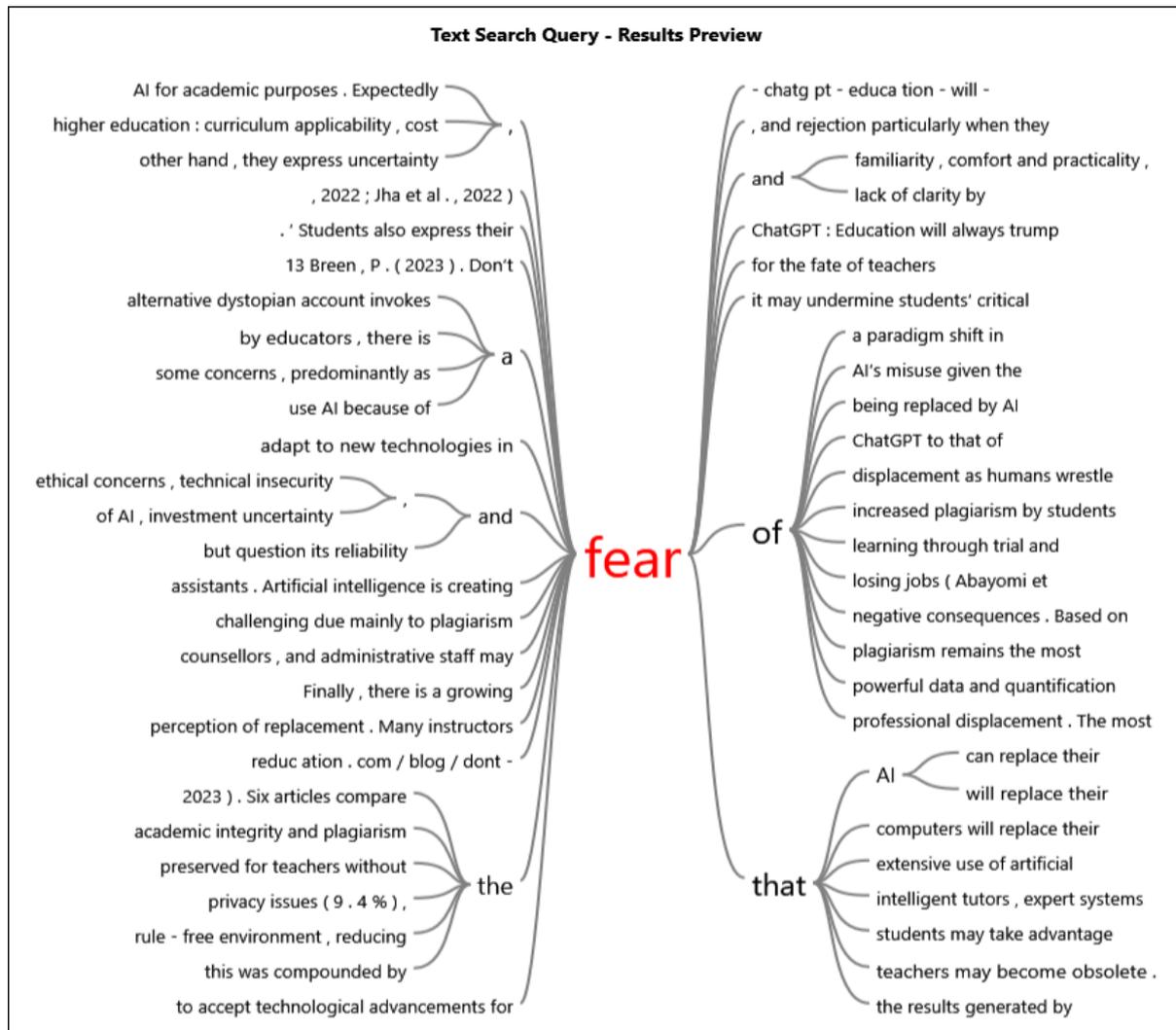


Figure 3. Text Search Query Results for the Word ‘Fear’

From these findings of the contents on disadvantages, the analysis was narrowed and focused specifically on reference to disadvantages of using artificial intelligence in learning in institutions of higher learning. Nine documents qualified for this analysis. The aim was to find out the extent to which authors related these disadvantages to apprehensions caused by negative impacts of artificial intelligence. This would help the analyst to pinpoint the sources of concern in the minds of researchers engaging in the use of artificial intelligence in learning in institutions of higher learning. In turn, this would answer the question: What are the identifiable sources

of apprehension related to using AI in higher learning? Therefore, from the references to the word ‘fear’ as it appeared in the word trees presented above, it was then necessary to narrow the analysis down to the references that actually talked about fear in relation to the use of artificial intelligence in learning in higher learning institutions. The summary results were found to be as presented in Table 3.

Table 3. Actual Reported Challenges of Using AI in Higher Learning

<b>Authors</b>	<b>Reported AI disadvantage/challenge</b>
Michel-Villarreal, Eliseo Vilalta-Perdomo, Ricardo Thierry-Aguilera, and Flor Silvestre Gerardou (2023)	<ul style="list-style-type: none"> <li>• Relying solely on ChatGPT for personalized learning experiences may overlook certain aspects of individual student needs, such as their learning style, preferences, and unique challenges</li> <li>• ChatGPT suggests that being an AI language model, it “might not possess the same level of human interaction and interpersonal skills as an instructor or peers”, which can limit its contribution to certain elements of the educational experience, such as facilitating group work and other collaborative activities</li> <li>• ChatGPT suggests that whilst it “strives to provide accurate and helpful information, there is still a possibility of generating an incorrect or misleading response”</li> </ul>
Sencer Yeralan, Laura Ancona Lee (2023)	<ul style="list-style-type: none"> <li>• While AI-based tools can be useful for brainstorming and generating initial drafts, there is concern about the potential for academic dishonesty</li> <li>• There is also the fear that students may take advantage of AI-based tools to complete their academic assignments with little or no genuine effort and with no understanding.</li> <li>• Professors may also use such tools to generate multiple-choice quizzes or presentations for their classes.</li> </ul>
Botelho, C. C., da Rocha, L. T. V., Fernandes, R. M., da Silva, J. M. N., & Martins, V. W. B. (2025).	<ul style="list-style-type: none"> <li>• While plagiarism has long been a challenge in academia, the advent of AI-generated content introduces new dimensions to academic dishonesty, intensifying concerns about integrity and ethical conduct in education concerns widely shared by educators and institutions alike.</li> </ul>
Hasan A. A. Emran, and Fathia. M. Elhony (2025)	<ul style="list-style-type: none"> <li>• Respondents expressed apprehension about the use of student data, algorithmic bias, and the potential misuse of AI-generated outcomes. (These fears are justified given the absence of comprehensive data protection laws)</li> </ul>
Fateme Jafari and Ahmad Keykha (2024)	<p>(There is fear of)</p> <ul style="list-style-type: none"> <li>• AI replacing thinking</li> <li>• Over-trust in AI-generated content</li> <li>• Unequal access</li> </ul>

Authors	Reported AI disadvantage/challenge
Doan Hong Nhung, Nguyen Xuan Bao, and Vu Thi Hong Ha (2024)	<ul style="list-style-type: none"> <li>In the educational process, content is often presented electronically, resulting in a passive learning experience for students.</li> <li>Uneven access to AI technology can lead to disparities among students across different universities.</li> <li>Over-reliance on AI may hinder the development of soft skills and social interaction abilities among students.</li> </ul>
Steffen Hoernig, André Ilharco, Paulo Trigo Pereira, and Regina Pereira (2024)	<ul style="list-style-type: none"> <li>May also lead to the students' [over-]reliance on software and result in reduced self-assessment and critical thinking among students</li> <li>Students might find themselves spending more time interacting with machines rather than engaging with peers and educators</li> </ul>
Krzysztof Walczak and Wojciech Cellary (2023)	<ul style="list-style-type: none"> <li>By their statistical nature, transformer models may generate right, wrong or mixed right-wrong texts. A person without knowledge is unable to distinguish between the right and wrong parts of the generated text</li> <li>In the case of text, this permits the determination as to whether the person who claims to have prepared a certain piece of text actually possesses the knowledge and skills required to write such material</li> </ul>
Nazir Ahmed Jogezaei, Diana Koroleva and Ivan Ivanov (2025)	<ul style="list-style-type: none"> <li>(There is) the higher risk of plagiarized content and cheating in exams (which) poses substantial threats to the academic honesty</li> <li>...and (compromised) critical thinking abilities of both faculty and students</li> </ul>

Authors who have discussed limitations, hurdles, challenges, risks, and apprehensions of using AI in higher learning have generally shown a leaning towards a concern for ethical compromise in terms of cheating and other forms of dishonesty in academics. Therefore, a further text search query on the 61 documents showed that the word 'ethics' (exact match) appeared in 40 documents. The total count was 285 references, meaning that the word "ethics" appeared 285 times. When the query was run on the word 'ethics' (with its synonyms), the results showed that there were 1,258 references appearing in a total of 57 documents meaning that 57 authors out of the 61 documents that were analysed, mentioned the word 'ethics' or its synonym in their discussion of the usage of AI in higher learning. This shows that one of the greatest fears of students, teachers, managers, and researchers is that AI in higher learning may very likely lead to (or it already is causing) an unethical compromise of academic quality standards. Another great fear (as seen in table 3) is that humans will eventually be replaced by machines in various ways, including cognitively, socially, and professionally.

In summary, this systematic review finds at least five categories of sources of apprehension of using AI in teaching and learning in institutions of higher learning.

### Fear related to Replacement

In the first sense, authors present a source of apprehension related to replacement in terms of learning. In this case the fear is that AI is depriving the students of their right or chance to learn and therefore the goal of education is

compromised. Overreliance on machines is killing critical thinking. In other words, with the use of AI in higher learning, what is happening is not active but passive learning dominated by machines. Students get more help than they need for true learning to occur. In another sense, professors are also thought to be professionally replaced by machines (computers/robotics) and teachers are becoming obsolete.

### **Fear related to Compromise of Morals**

Humans are not machines and machines cannot do what humans do in education because education is more than a mechanical transaction involving the transfer of information. Authors think that education systems must keep the human morality that always goes with the process of imparting knowledge. Likewise, dishonesty and cheating are human behaviours, but they are seriously exacerbated by AI in higher learning. Plagiarism becomes rampant, and mechanisms to control it are not effective enough. On the other hand, the use of AI in teaching may lead to the creation of lazy professors who are paid for work they did not do.

### **Fear related to Machine Shortcomings**

There is also the fear that machines are not perfect. Sometimes there are error results that are difficult to identify, control or correct. Some students may rely on wrong answers due to two factors. The first is that they may be too lazy to verify the answers, choosing the easier way of copying and pasting results, and the second is that they may lack the technical know-how to realize that the answers are wrong to begin with. Also, when there is a machine breakdown or malfunction, learning may get stuck altogether.

### **Fear related to Breakdown in Social Bonds**

Humans are social beings. Authors present another source of apprehension related to a perceived compromise in interpersonal skills among users. Interpersonal skills are very important for the social, psychological and mental development of students. With AI in higher learning, students may end up interacting more with machines rather than with their peers and their educators. This may result in anti-social behaviours and unhealthy loneliness. On the other hand, authors raise a concern that the use of AI in teaching and learning may lead to disregard for individual student needs in learning. This creates inequality, which could be easily avoided by a human tutor.

### **Fear related to Data Privacy**

AI systems in learning carry massive amounts of data. Some of this data is personal and private. The use of AI, in many cases, requires students to store electronic personal data on various issues. The data may carry information on students' family, health, history, performance etc. These kinds of data may require advanced legal systems to ensure privacy of AI users. Authors indicate that, in the absence of strict laws directing data handling, AI users are exposed to vulnerability in terms of data privacy.

Finally, a general terminology for the negative effects of AI in higher learning was sought, and a text search query

was run to increase the authenticity of the findings and the reliability of the discussion. This terminology was the word ‘compromise,’ which was set at the level of ‘with synonyms’ to ensure wider coverage of its application in the analysed texts. The results were as shown in Figure 4.

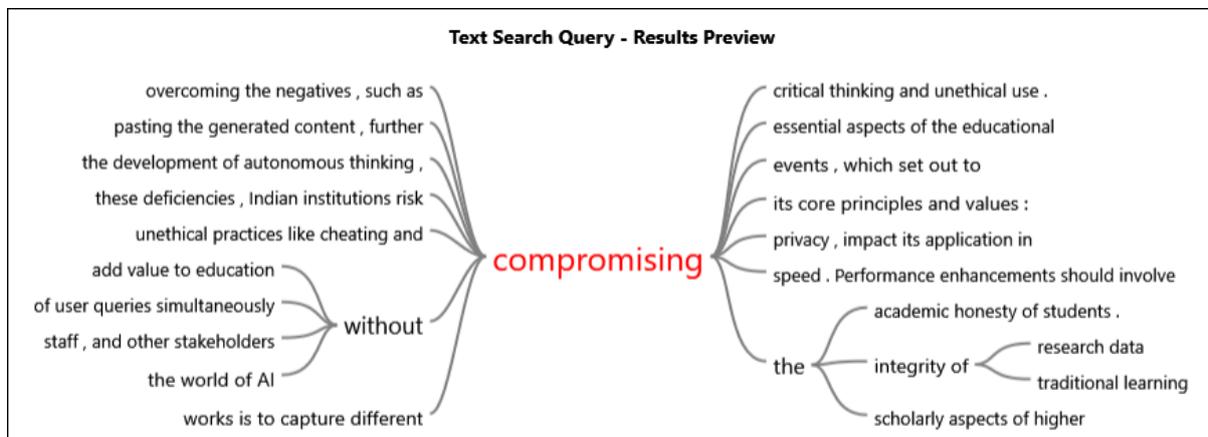


Figure 4. Text Search Query Results for the Word ‘Compromise’

As figure 4 shows, on the left-hand side are such phrases as ‘overcoming negatives,’ ‘pasting generated content,’ ‘the development of autonomous thinking,’ unethical practices’, and ‘add value to education’. The NVIVO 12 output as presented in the word tree shows that these phrases are directly related to other phrases on the right-hand side. These phrases are ‘critical thinking and unethical use’, ‘essential aspects of the educational’. ‘its core principles and values’, ‘privacy, impacts its application in’, ‘academic honesty of students’, ‘integrity of traditional learning’, and finally ‘scholarly aspects of higher education’.

It was then necessary to rerun the text search query to reveal the broad coding context of the phrases, and the results were the following complete statements as directly quoted from texts:

1. ‘We conclude that the response from HEIs across the globe is benefiting from the positives, such as personalized learning and online tutoring, and overcoming the negatives, such as compromising critical thinking and unethical use. Key measures such as developing comprehensive guidelines, engaging relevant institutions and providing them with adequate support can mitigate the risks GAI (Generative AI) poses to critical thinking and address broader safety and security concerns’ (Jogezai et al., 2025).
2. ‘This convenience may tempt some students to misuse generative AI as a substitute for original thinking and research, leading to a decline in academic integrity. There is a risk of simply copying and pasting the generated content, further compromising the academic honesty of students. Moreover, the ability of generative AI to produce high-quality works might entice students to rely on such content instead of engaging in in-depth thinking and research. Additionally, the emergence of generative AI poses challenges in detecting and addressing academic misconduct. As generated works often lack comparability with existing databases and literature, detecting plagiarism and fraudulent practices becomes increasingly challenging (Yang, 2024).

3. 'Challenges, such as biases in GAI outputs and unethical practices like cheating and compromising privacy, impact its application in education and the attainment of SDG4 targets' (Jogezai et al., 2025).
4. 'Overall, students advocate for a thoughtful and responsible approach to AI integration, emphasizing its potential to enhance the learning process when used in a balanced and well-regulated manner. The analysis of these themes highlights the importance of ensuring AI tools add value to education without compromising the integrity of traditional learning methods' (Vieriu and Petrea, 2025).

These quotes further prove that authors of the analysed texts present several apprehensions of using AI in higher learning, relating them to identifiable factors. They also include some recommendations on how to tackle some of the challenges posed by AI in higher learning.

## Conclusion

Using content analysis techniques assisted by NVIVO 12 qualitative data analysis tool, this systematic review of literatures aimed at identifying the sources of apprehension of using AI in higher learning. The analysis concludes that, to a great extent, authors acknowledge the existence of several disadvantages or limitations or challenges brought into higher learning by the introduction of AI. The review reveals further that this apprehension of using AI in teaching and learning in higher education is related to several factors, the main among which are fear of professional replacement of humans by machines and ethical compromise of academic standards. Finally, the review finds that these several types of fears could be categorized into at least five groups summarized in terms of fear of replacement, moral compromise, machine shortcomings, compromise of social relations, and data privacy issues. In a nutshell, the apprehensions are based on what AI seems to compromise in already established ways of learning in higher education. Since the use of AI in higher learning is inevitable, policymakers and managers of higher learning need to take precautions before they introduce AI-supported systems in higher education and provide clear, effective, and dependable guidelines once the systems are in place.

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## Investigating Research Skills and Artificial Intelligence Attitudes Among Residents in Surgical Medicine Departments

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### Abstract

This research aims to examine the relationship between scientific research skills and attitudes towards artificial intelligence among residents in surgical medicine departments, considering gender and seniority. A quantitative research approach with a comparative correlational survey model was adopted; data was collected via online questionnaires from 127 surgical residents in training and research hospitals and university public hospitals in Ankara, Konya, and İzmir provinces. The findings revealed that participants' scientific research skills were at a moderate level, while their attitudes towards artificial intelligence were at a high level. Male participants showed significantly higher scientific research skills compared to their female peers, while no gender-based difference was found in attitudes towards artificial intelligence. As seniority increased, scientific research skills also increased significantly; however, attitudes towards artificial intelligence did not change with seniority. Regression analysis showed that attitudes towards artificial intelligence did not significantly predict scientific research skills. Based on these results, it is recommended to strengthen research methodology training in the early stages of specialist training, to investigate the causes of gender inequality using qualitative methods, to integrate artificial intelligence tools into the curriculum, and to expand the study to include a wider sample and different disciplines.

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## Introduction

Medical specialization training constitutes the most critical link in postgraduate medical education, and at this stage, doctors are expected to develop both their clinical decision-making skills and their scientific thinking capacity (Mokhtari et al., 2024). Acquiring research skills in this process is of great importance not only for individual professional development but also for the dissemination of evidence-based practices for public health (Aneese et al., 2019). Doctors with high research competence are observed to adopt a more systematic and critical approach in clinical decision-making processes (Mohr et al., 2015). Accordingly, many medical faculties and specialization training programs are integrating medical education and scientific research components into their curricula (Liviñi et al., 2021). Therefore, the role of research skills in the specialization training process and how these skills can be developed are increasingly being studied in the medical education literature (Wood et al., 2018; Woo et al., 2024).

In today's healthcare environment, where digital transformation is accelerating, artificial intelligence technologies have become an integral part of medical research and practice (Charow et al., 2021; Tolentino et al., 2024). AI has the potential to fundamentally transform healthcare services through the opportunities it offers in areas such as medical image analysis, clinical decision support systems, and big data processing (Lee et al., 2021). In this context, research on AI literacy and attitudes towards these technologies among surgical residents is increasing internationally (Mousavi Baigi et al., 2023; Rjoop et al., 2025). The relevant literature emphasizes that attitudes towards AI may differ according to professional training level, specialization area, and individual research experience (Heinrichs et al., 2025; AlZaabi et al., 2023). In this context, preparing medical education for the integration of artificial intelligence is directly related not only to raising technological awareness but also to reinforcing critical thinking and research skills (Civaner et al., 2022). Therefore, revealing the relationship between attitudes towards artificial intelligence and research skills is important for medical education policies.

## Problem Statement

The inadequacy of research skills among surgical residents is considered one of the most significant problems in postgraduate medical education (Mokhtari et al., 2024). It is known that the vast majority of these students feel inadequate in research methodology, statistics, and scientific writing, while clinical intensity significantly restricts the time allocated to research (Carter et al., 2019). In addition to this problem, research self-efficacy is also seen as a determining factor. Relevant studies show that students with low research self-efficacy have significantly more limited scientific productivity (Liviñi et al., 2021; Nyenge et al., 2024; Woo et al., 2024). However, it is observed that not only individual competencies but also institutional research culture and mentor support directly shape the research behavior of residents (Mohr et al., 2015). In this context, identifying deficiencies in research skills is a necessary first step for effectively restructuring educational programs (Özcan & Polat, 2023; Wood et al., 2018). Therefore, determining the research skills profile of surgical residents based on multidimensional measurements fills an important gap in this field.

It has been observed that surgical residents can simultaneously perceive artificial intelligence as both a potential

workforce threat and a tool that increases clinical efficiency (Pawelczyk et al., 2024; St John et al., 2024). However, it is seen that whether these students are ready to use artificial intelligence tools has not been sufficiently investigated, and most of the existing studies are limited to medical school students (AlZaabi et al., 2023; AlZaabi & Masters, 2025; Vosoughmatin, 2025). The relevant literature emphasizes that doctors' attitudes are decisive in the adoption of clinical decision support systems and AI-based diagnostic tools, and that these attitudes are directly linked to professional experience and education (Civaner et al., 2022; Khairat et al., 2018; Kouri et al., 2022). In this context, the relational pattern between attitudes towards artificial intelligence and research skills has not been systematically examined specifically within the context of medical specialization training.

## **The Gap in the Literature and the Importance of the Research**

When examining research in medical education, it is observed that studies addressing research skills and attitudes towards artificial intelligence separately occupy a significant portion of the literature. However, studies that examine these two phenomena together on a relational basis, specifically in the context of residents in surgical medicine departments, remain limited (Mousavi Baigi et al., 2023; Tolentino et al., 2024). While a significant portion of studies focusing on attitudes towards artificial intelligence have been conducted with medical students, nursing students, or general practitioners, findings reflecting the unique dynamics of residency training remain quite limited (Abou Hashish & Alnajjar, 2024; Allam et al., 2024; Pinto Dos Santos et al., 2019). Furthermore, the vast majority of studies on research skills have focused on measurement tools and program evaluation, leaving the question of how research skills relate to individual attitudes in the background (Livinçi et al., 2021; Wood et al., 2018). In this context, efforts to close this gap constitute a critical contribution to both medical education policies and discussions on the integration of artificial intelligence.

In the specific case of Turkey, the effective integration of artificial intelligence into medical specialty training depends on concretely measuring students' current attitudes and readiness levels (Civaner et al., 2022). In this regard, revealing the relationship between research skills and attitudes towards artificial intelligence will provide a valuable data source for educational planners, showing which student groups can benefit most from AI training and how this training can be personalized. Indeed, understanding the interaction between professional competence and attitudes towards technology adoption is crucial for developing digital transformation strategies for healthcare professionals. Investigating the moderating roles of sociodemographic variables such as specialty area, years of education, and gender on this relationship will increase the generalizability and explanatory power of the findings (Pawelczyk et al., 2024). In this context, the study is expected to create a unique knowledge base that will lay the groundwork for a holistic educational approach for surgical residents.

## **Research Skills in Medical Specialty Training**

Research skills encompass complementary sub-competencies such as critically reading and evaluating scientific literature, formulating research questions, selecting appropriate methodologies, data analysis, and scientific writing (Aneese et al., 2019). Systematic reviews and meta-analyses have shown that evidence-based medicine components integrated into the curricula of residency programs significantly improve the research competencies

of resident doctors (Wood et al., 2018; Mohr et al., 2015). However, the relevant literature emphasizes that research skills should be reinforced not only through theoretical training but also through active research participation and mentorship support (Carter et al., 2019). Therefore, research skills should be positioned not only as a curriculum element in the design of residency training but also as an integral part of professional identity development (Aneese et al., 2019; Mokhtari et al., 2024). For this reason, adopting a systematic program approach in acquiring research skills is a decisive factor in terms of the quality of education.

The concept of research self-efficacy expresses an individual's belief in their ability to successfully complete research processes and is considered a strong predictor of research behavior (Liviñi et al., 2021). In this context, studies conducted on doctoral students and researchers in the health sciences consistently show a positive and significant relationship between research self-efficacy and research productivity (Woo et al., 2024). Similarly, it is observed that individuals with low research self-efficacy among surgical residents avoid participation in research activities and lag behind in scientific production (Mokhtari et al., 2024). Accordingly, providing structured experiences in residency training programs aimed at increasing research self-efficacy will also positively support the academic identity development of individuals (Carter et al., 2019). In this context, the quality of the research training environment, the quality of the student-advisor relationship, and positive feedback loops also stand out as effective variables in strengthening self-efficacy (Liviñi et al., 2021).

When evaluating the attitudes and challenges of surgical residents towards research, it is observed that students understand the importance of research for their professional development, but they face structural obstacles such as time constraints, inadequate methodological preparation, and lack of mentor support (Aneese et al., 2019). In this context, it is understood that residents, especially those working in intensive clinical rotations, may neglect their research responsibilities, and academic motivation shows significant differences depending on the semester and specialty area (Carter et al., 2019; Wood et al., 2018). It is thought that restructuring evidence-based medical education plays a critical role in overcoming these difficulties; in particular, the inclusion of supervised clinical research experiences and statistical applications in the curriculum has been observed to yield positive results (Mohr et al., 2015). Studies report that student participation and publication output significantly increase in models where research skills are taught in an integrated manner with clinical practice (Carter et al., 2019). Therefore, it is crucial to consider research skills not merely as a specialization requirement, but as the foundation of a learning culture that a physician will maintain throughout their entire professional life.

## **Integration of Artificial Intelligence Technologies into Medical Education and Research**

The integration of artificial intelligence into medical education has gained importance in recent years, and many medical schools and specialty programs are beginning to include AI literacy in their curricula (Lee et al., 2021; Paranjape et al., 2019). Research shows that consensus frameworks are being developed for the inclusion of AI competencies in medical curricula; these frameworks are seen to encompass data literacy, algorithmic thinking, and AI ethics as key components (Ang, 2025; Çalışkan et al., 2022). When examining the integration of AI into medical research processes, it is seen that this technology is beginning to be used in a wide range of applications, from literature review and data analysis to image interpretation and clinical decision support systems (Michel et

al., 2021; Fischer et al., 2023).

When evaluating the factors influencing the adoption of clinical decision support systems and machine learning-based diagnostic tools in healthcare, it is understood that users' level of knowledge and attitudes towards technology play a decisive role (Khairat et al., 2018; Kouri et al., 2022). In this context, the integration of artificial intelligence tools into research processes is directly related not only to the technical infrastructure but also to the researchers' readiness level for these tools (Pumplun et al., 2021; AlZaabi & Masters, 2025). Various qualitative studies report that professional training level, area of expertise, and institutional incentive mechanisms are effective in the adoption of AI-supported research tools (Fischer et al., 2023; Pumplun et al., 2021). Furthermore, it is observed that this integration brings with it ethical, confidentiality, and accountability dimensions, and these concerns can negatively affect the adoption of artificial intelligence, especially in clinical applications (Çalışkan et al., 2022; Michel et al., 2021). Accordingly, it is believed that surgical residents who can successfully integrate artificial intelligence into their research processes can gain significant advantages in terms of both their scientific productivity and critical thinking skills.

### **Attitudes and Usage Trends of Artificial Intelligence Among Doctors Undergoing Specialty Training**

Attitudes towards artificial intelligence among healthcare professionals and medical students have been extensively studied in different countries and specialties in recent years (Mousavi Baigi et al., 2023; Lambert et al., 2023). Findings from these studies reveal that, in general, attitudes towards AI are moderately positive; however, concerns, uncertainty, and ethical anxieties also play a significant role (Pinto Dos Santos et al., 2019). Multicenter studies conducted with medical students and resident doctors show that while there is a widespread belief that AI can contribute to diagnostic and treatment processes, concerns about potential threats to professional roles cannot be ignored (Rjoop et al., 2025; Sit et al., 2020). In this context, it is noteworthy that attitudes differ according to specialty; AI applications in fields such as radiology and surgery show both positive and negative attitudes more sharply (Pawelczyk et al., 2024). Similarly, relevant studies consistently report that individuals who have received AI training adopt more positive and knowledge-based attitudes toward this technology (AlZaabi et al., 2023; Heinrichs et al., 2025; Stewart et al., 2023). Therefore, it is considered that attitudes toward AI are not a fixed individual characteristic but can be shaped through intervention and experience.

When AI usage trends are examined, it is seen that the speed at which healthcare professionals adopt these technologies is determined by a complex interaction of individual, institutional, and systemic factors (Lambert et al., 2023). At the individual level, AI literacy, technological self-efficacy, and risk perception can be said to have a decisive impact on the tendency to use them (Baumgartner et al., 2022). At the institutional level, it is observed that technical infrastructure, peer support, and managerial incentive mechanisms facilitate the adoption process (Wang et al., 2024). However, several mixed methods studies highlight that a lack of trust and concerns about transparency negatively impact doctors' willingness to use clinical decision support systems (Khairat et al., 2018; Pumplun et al., 2021). On the other hand, it is observed that increased awareness of artificial intelligence alone does not translate into a positive attitude towards its use; practical experience and critical evaluation skills must

also be acquired (Ziapour et al., 2025). In this context, relating artificial intelligence usage trends to the level of professional development raises a research question that has both descriptive and predictive value for educators (Heinrichs et al., 2025).

## **The Relationship Between Research Skills and Attitudes Towards Technology**

Research suggests that professionals with high research self-efficacy are more open to new tools and methodologies, and therefore more inclined to integrate innovative technologies such as artificial intelligence into their research processes (Kouri et al., 2022; Liviñi et al., 2021; Woo et al., 2024). In this context, it can be said that a researcher who has acquired critical thinking and evidence evaluation skills can also more accurately assess the limitations of artificial intelligence algorithms. Supporting this relationship, conceptual frameworks emphasize that digital health literacy includes cognitive and practical components that overlap with research skills (Abou Hashish & Alnajjar, 2024; Baumgartner et al., 2022). However, empirical evidence regarding the direction and strength of the relational pattern between the two variables remains quite limited (Ziapour et al., 2025). While examining technology adoption patterns reveals that perceived usefulness and ease of use play a decisive role in influencing attitudes and behavioral intentions, professional competence level appears to have a moderating function in this relationship (Khairat et al., 2018). In this context, it can be said that individuals with high research skills will have a more qualitative understanding of the nature of integration through their subjective assessment of whether artificial intelligence contributes to research processes. Similarly, it is stated that residents who learn to use AI tools as a component of evidence-based medical education achieve positive gains in terms of both research productivity and attitude towards technology (AlZaabi & Masters, 2025; Tolentino et al., 2024). It should also be considered that the relationship between research skills and attitudes towards artificial intelligence may be shaped by factors such as sociodemographic variables, institutional context, and area of expertise (Allam et al., 2024; Ang, 2025; Liviñi et al., 2021). Accordingly, establishing multivariate models that consider the relationship between the two variables, along with possible moderator and mediator effects, will enable a more detailed understanding of causal mechanisms. In this context, the research aims to make a meaningful and original contribution to the field by quantitatively examining the relationship between research skills and attitudes towards artificial intelligence, specifically among surgical residents.

The aim of this research is to determine the relationship between the scientific research skills and attitudes towards artificial intelligence of residents in surgical medicine departments, in terms of certain variables. Based on this general aim, the following questions were investigated:

1. What is the level of scientific research skills and attitudes towards artificial intelligence among residents in surgical medicine departments?
2. Do the scientific research skills and attitudes towards artificial intelligence of residents in surgical medicine departments differ according to their gender?
3. Do the scientific research skills and attitudes towards artificial intelligence of residents in surgical medicine departments differ according to their seniority in the specialty?
4. Do the attitudes towards artificial intelligence of residents in surgical medicine departments predict their scientific research skills?

## Method

### Research Model

This study was conducted using a comparative correlational survey model within a quantitative research approach. This type of research aims to identify relationships between variables (Karasar, 2005). In other words, a model that aims to measure the relationships between two or more variables and determine cause-and-effect relationships between these variables is defined as a correlational survey model (Johnson & Christensen, 2008). In a survey model, the tendencies, attitudes, and opinions of a sample selected from a population are described quantitatively and numerically (Creswell & Creswell, 2017). Therefore, in such studies, the relationships between variables are also expressed numerically. In this study, the scientific research skills and attitudes towards artificial intelligence of surgical residents were examined relationally in terms of gender and seniority variables.

### Research Group

This study, which assesses the scientific research skills and attitudes towards artificial intelligence of surgical residents, was conducted through a literature review followed by a comprehensive, relational and complementary research. The study was carried out in Ankara, Konya, and Izmir provinces of Turkey, at training and research hospitals and university public hospitals providing medical specialty training in surgical branches. Purposive sampling was employed. Inclusion criteria were being in the surgical specialty training process and voluntary participation. The demographic distribution of the research group is presented in Table 1.

Table 1. Demographic Distribution of Participants

Variables	Options	Frequency	Percent
Gender	Female	56	44.1
	Male	71	55.9
Branch	General Surgery	35	27.6
	Gynecology	32	25.2
	Cardiovascular Surgery	19	15.0
	Ear-Nose-Throat Surgery	9	7.1
	Orthopedics and Traumatology	9	7.1
	Other	23	18.1
Specialist Training Seniority	1 Year	32	25.2
	2 Years	30	23.6
	3 Years	31	24.4
	4-5 Years	34	26.8
	Total	127	100.0
Age	Mean	29.13	
	St. Dev.	3.26	

Data was collected from surgical residents in surgical branches at public and university hospitals, primarily via

the "Google Forms" application. The forms were distributed to participants through WhatsApp groups and individual communication, and 133 participants voluntarily completed the forms. However, 6 questionnaires were excluded from the study due to incomplete information, resulting in a total of 127 participants.

### **Data Collection Tools**

Survey data was used to collect research data. The survey form contains a total of 45 items. The first section contains 5 demographic survey items, the second section contains 20 survey items about the scientific research skills of surgical residents, and the third section contains 20 survey items about participants' attitudes towards artificial intelligence.

#### *Scientific Research Skills Scale*

The Scientific Research Ability Scale was developed by Veliöglu and Özdemir (2023). The scale, which is in Likert form with five points, consists of 20 items. Veliöglu and Özdemir (2023) conducted Exploratory Factor Analysis and Confirmatory Factor Analysis to test the construct validity of the scale. In the factor analysis process, the KMO value was found to be 0.953. After determining that the Kaiser-Meyer-Olkin (KMO) and Bartlett values were appropriate, the other analyses of the scale development process were carried out, and factor analysis was performed. As a result of the factor analysis, it was observed that the item factor loadings were above 0.40. The result of the confirmatory factor analysis was found to be chi-square ( $c2/df$ ) = 2.613, RMSEA = 0.066; and SRMR = 0.034. NFI = 0.94; NNFI = 0.942; CFI = 0.963; The RFI was obtained as 0.926. The Cronbach's Alpha reliability coefficient of the scale was calculated as 0.80. In light of all this information, the data obtained show that the scale has acceptable construct validity and reliability.

#### *Attitude Scale Towards Artificial Intelligence*

The scale of items regarding the attitudes of surgical residents towards artificial intelligence was developed by Schepman and Rodway (2020), adapted and validated in Turkey by Kaya et al. (2022). The Attitude Towards Artificial Intelligence Scale developed by Kaya et al. (2022) stands out as a scale designed to assess individuals' attitudes towards artificial intelligence. This scale includes various statements to measure positive and negative attitudes towards artificial intelligence. The scale contains two sub-dimensions, negative attitudes towards artificial intelligence and positive attitudes towards artificial intelligence, and 20 questions. The scale is scored on a 5-point Likert scale. This scoring system is a 5-point Likert type scale consisting of Strongly disagree, Disagree, Undecided, Agree, and Strongly agree. This scoring system is used to qualitatively evaluate participants' attitudes towards artificial intelligence. The total mean score reflects the participant's attitude towards artificial intelligence. In this context, a high average score indicates a positive attitude, while a low average score indicates a negative attitude. In the study conducted by Kaya et al. (2022), the Cronbach Alpha value was calculated for the reliability analysis of the Attitude Towards Artificial Intelligence Scale. The obtained Cronbach Alpha value was found to be 0.87. The reliability coefficient was calculated as 0.85 on the participants of this study. These values show that the scale has high internal consistency and reliably measures the attitudes of the participants.

## Data Analysis Techniques

In the data analysis processes, the SPSS 26 software package was used to perform statistical evaluations. Frequency and percentage distributions were given for the demographic characteristics of the participants. Descriptive statistics values were obtained for the scores of the artificial intelligence attitude and scientific research skills scales. Since the number of data points ( $N > 50$ ) was high, skewness and kurtosis values were examined to determine the normality of the scale scores. If these values are between  $\pm 2$ , the distribution is normal (George and Mallery, 2010). Regression analysis was used to examine the relationship between artificial intelligence attitude and scientific research skills scale scores. In relation to this method, the necessary assumptions regarding the continuity of the dependent variable, normality, and multicollinearity were tested, and the relevant assumptions were met. Parametric methods, namely the Independent Samples t-test and F-test techniques, were used to determine whether there was a difference in artificial intelligence attitude and scientific research skills scores according to the demographic characteristics of the participants. In statistical comparisons, evaluations were carried out using the criterion of  $p < .05$  as the significance level.

## Findings

This section of the study first presents the descriptive statistics of the scores obtained by medical surgical residents on scales measuring scientific research skills and attitudes towards artificial intelligence. Then, the mean scores obtained by the participants on these scales are compared according to gender and training duration/seniority variables. Table 2 shows the descriptive statistics of the scores obtained by surgical residents on the scientific research skills and artificial intelligence attitudes scales. According to the findings, the mean scores on the scientific research skills scale ranged from 1.05 to 5.00, with an average score of  $3.31 \pm 0.88$ . Furthermore, the average score obtained by the participating surgical residents on the artificial intelligence attitudes scale was calculated as  $4.16 \pm 0.76$ . Based on these average values, it was understood that the scientific research skills of the surgical residents were at a moderate level, while their attitudes towards artificial intelligence were at a high level.

Table 2. Descriptive Analysis of Scientific Research Skills and AI Attitudes of Surgical Residents.

	N	Minimum	Maximum	Mean	Std. Deviation
Scientific Research Skills	127	1.05	5.00	3.31	0.88
AI Attitude	127	1.00	5.00	4.16	0.76

As shown in Table 3, the mean score on the scientific research skills scale for female and male surgical residents is ( $M=3.10$ ), while the mean score for male participants is ( $M=3.48$ ).

Table 3. A Comparison of Scientific Research Skills of Medical Surgical Residents by Gender

	Gender	N	Mean	Std. Deviation	t	p
Scientific Research Skills	Female	56	3.10	0.81	-2.456	0.015*
	Male	71	3.48	0.91		

\* $p < 0.05$

An Independent Samples t-test was used to analyze whether the differences in mean scores between genders were statistically significant, and it was found that the mean scores differed significantly ( $p < 0.05$ ). Based on the group means, it was found that male participants had significantly higher scientific article writing skills compared to their female peers.

As shown in Table 4, the mean score on the scientific research skills scale for female and male surgical residents is ( $M=4.11$ ), while the mean score for male participants is ( $M=4.20$ ). The differences in mean scores on artificial intelligence attitudes based on gender were found to be statistically insignificant ( $p > 0.05$ ).

Table 4. A Comparison of AI Attitudes of Medical Surgical Residents by Gender

	Gender	N	Mean	Std. Deviation	t	p
AI Attitude	Female	56	4.11	0.51	-0.670	0.504
	Male	71	4.20	0.91		

Table 5 shows the results of a comparison of the mean scores on the scientific research skills scale among medical specialty training participants based on their training duration. The differences between the mean scores based on specialty training seniority were analyzed using the F-test to determine if they were statistically significant, and it was found that the mean scores differed significantly ( $p < 0.05$ ). Further analysis using the Tukey test revealed that participants with 3 years and 4-5 years of specialty training seniority possessed higher scientific research skills compared to those with 1 or 2 years of specialty training seniority.

Table 5. Comparison of Scientific Research Skills of Medical Surgical Residents According to Specialist Training Seniority

	Specialist Training Seniority	N	Mean	Std. Deviation	F	p
Scientific Research Skills	1 year	32	2.05	0.91	5.81	0.001**
	2 years	30	2.95	0.98		
	3 years	31	3.38	0.62		
	4-5 years	34	3.71	0.79		

\*\* $p < 0.01$

Table 6 shows the results of a comparison of the mean scores on the artificial intelligence attitude scale among medical specialty training participants based on their training duration. No significant difference was found in the mean artificial intelligence attitude scores of the participants based on their specialty training seniority ( $p > 0.05$ ).

Table 6. Comparison of AI Attitudes of Medical Surgical Residents According to Specialist Training Seniority

	Specialist Training Seniority	N	Mean	Std. Deviation	F	p
AI Attitude	1 year	32	4.23	0.81	0.670	0.504
	2 years	30	4.19	0.51		
	3 years	31	3.93	0.86		
	4-5 years	34	4.26	0.59		

According to Table 7, scientific problem-solving skills are the dependent variable, and attitudes towards artificial intelligence are the independent variable. Participants' attitudes towards artificial intelligence did not significantly explain the variation in scientific research skills ( $F= 2.093$ ,  $p>0.05$ ). There is a low, non-significant correlation between attitudes towards artificial intelligence and scientific research skills ( $\beta=-0.126$ ;  $p>0.05$ ). Furthermore, attitudes towards artificial intelligence explain only 1.6% of scientific research skills.

Table 7. Results of Simple Regression Analysis Between Participants' Scientific Research Skills and Attitudes towards Artificial Intelligence

	Unstandardized Coefficients		Standardized Coefficients	t	p
	$\beta$	Std. Error	$\beta$		
(Constant)	2.689	0.437		6.155	0.000
AI Attitude	0.149	0.103	0.128	1.447	0.150

Dependent Variable: Scientific Article Writing Skills  
 $R=0.128$ ;  $R^2=0.016$ ;  $F=2.093$ ;  $p>0.05$

## Discussion and Conclusion

This research aimed to examine the relationship between the scientific research skills and attitudes towards artificial intelligence (AI) of surgical residents. The research findings indicate that surgical residents have a moderate level of research skills and a high level of attitudes towards AI. Furthermore, the effects of gender and residency seniority on research skills were examined; however, these variables did not significantly differentiate attitudes towards AI. The findings regarding the predictive effect of AI attitudes on scientific research skills clearly highlight the necessity of addressing research culture and digital transformation processes together in medical residency training. Within this framework, the findings are discussed in the context of the relevant literature, and inferences that will contribute to the development of the field are presented.

Regarding the first research question, the findings reveal that surgical residents have a moderate level of scientific research skills. This finding indicates that while surgical residents are willing to participate in research processes, they have significant deficiencies in terms of methodological preparation and skill levels. The relevant literature highlights that surgical residents feel inadequate in research methodology, statistics, and scientific writing (Aneese et al., 2019; Mokhtari et al., 2024; Pinto Dos Santos et al., 2019). In this context, this finding is consistent with previous studies showing that clinical intensity and insufficient mentoring significantly restrict the development of research skills (Carter et al., 2019; Wood et al., 2018). In surgical branches specifically, this gap may be further amplified by the master-apprentice learning model that dominates operating theatre settings, where procedural competence is prioritized over research engagement. In this context, the structural difference between practical surgical training and academic skill development may represent a discipline-specific factor that distinguishes surgical residents from those in internal medicine branches and may also partially explain potential differences in attitudes towards artificial intelligence between these two training contexts.

The study determined that participants had a high level of positive attitude towards artificial intelligence,

indicating that resident doctors working in surgical fields are open to adopting AI as a tool to increase clinical efficiency. International literature indicates that healthcare professionals and resident doctors generally have positive attitudes towards AI; however, ethical concerns and perceptions of professional threats cannot be ignored (Allam et al., 2024; Pawelczyk et al., 2024; Pinto Dos Santos et al., 2019). In this context, it is known that both positive and negative attitudes are more clearly observed in fields where AI applications are significantly felt, such as radiology and surgery (Pawelczyk et al., 2024; St John et al., 2024). Therefore, the findings of this study reveal that surgical residents have already developed a high level of interest and positive attitudes towards AI; however, the research infrastructure to support this attitude is not sufficiently strong. The combined evaluation of these two findings strongly supports the need for an integrated approach to research skills and technological literacy in specialist training programs.

The findings related to the second research question reveal that male participants have significantly higher scientific research skills compared to female participants. This finding indicates that the impact of gender-based differences on research behaviors in the context of medical specialty training should be carefully considered. The relevant literature reports that female researchers in academic settings face various structural barriers compared to their male colleagues, and this can negatively affect research productivity (Andersson, 2025; Carter et al., 2019; Mokhtari et al., 2024). However, it should not be overlooked that this difference may be related not only to individual competency levels but also to institutional pressures based on gender roles, mentoring inequalities, and imbalances in clinical workload distribution (Wood et al., 2018). Medical education research shows that female resident doctors do not lag behind their male peers in terms of academic achievement and competency levels; However, it reveals that structural opportunities and access to mentorship are not equal (Liviñi et al., 2021). In this context, the findings of the current research support this discussion in the literature with empirical data specific to surgical branches and highlight the need to design gender-sensitive research training programs.

It is noteworthy that no significant gender-based difference was found in attitudes towards artificial intelligence. This finding indicates that positive attitudes towards artificial intelligence are widespread in surgical residency training, regardless of gender. Similar findings are reported in international studies; it is seen that attitudes towards artificial intelligence are shaped by individual and professional experience, and that gender alone is not a determining factor (AlZaabi et al., 2023; Mousavi Baigi et al., 2023). This situation shows that artificial intelligence literacy training can be designed for all surgical residents regardless of gender, while research skills training needs to be restructured from a gender equality perspective.

The findings related to the third question of the study reveal that scientific research skills differ significantly depending on seniority; participants with three years or more of seniority exhibit significantly higher research skills compared to participants with one or two years of seniority. This finding confirms that research skills develop as a result of a cumulative learning process over time. The relevant literature shows that research participation, conference presentations, and publication experiences in the later years of specialist training significantly increase scientific productivity (Carter et al., 2019; Mokhtari et al., 2024; Wood et al., 2018). However, the relatively low level of research skills in the early years of seniority indicates that research support is insufficient in the initial stages of specialist training and that there is a high need for structured intervention

programs during this period (Aneese et al., 2019). The positive relationship between research self-efficacy and seniority can be interpreted as individuals' confidence in research and their perception of competence strengthen as they gain experience (Livinți et al., 2021; Woo et al., 2024). In contrast, attitudes towards artificial intelligence do not differ significantly according to specialist seniority. This finding indicates that positive attitudes towards artificial intelligence remain relatively high at all seniority levels, regardless of experience. This finding aligns with related studies suggesting that healthcare professionals' attitudes toward artificial intelligence are shaped by individual awareness, personal interest, and environmental stimuli rather than their level of professional experience (Heinrichs et al., 2025; Lambert et al., 2023). In this context, it is considered necessary to support the enhancing effect of seniority on research skills at the program level, particularly by making structured research experiences mandatory for early-stage surgical residents.

The findings related to the fourth question of the study reveal that the attitudes towards artificial intelligence of surgical residents do not statistically significantly predict their scientific research skills. This finding shows that a positive attitude towards artificial intelligence alone does not stand out as a determining factor in research skills. Indeed, the relevant literature emphasizes that empirical evidence regarding the direction and strength of the relational pattern between attitudes towards artificial intelligence and research skills is still quite limited (Ang, 2025; Pumplun et al., 2021; Ziapour et al., 2025). In this context, this finding supports the theoretical discussions that an increased level of awareness regarding artificial intelligence alone does not directly contribute to research skills. When examining technology adoption models, although the determining roles of perceived usefulness and ease of use on attitudes and behavioral intentions are known, it is seen that the level of professional competence plays a moderating function in this relationship (Khairat et al., 2018; Pumplun et al., 2021). However, it is considered that the effect of attitude towards artificial intelligence on research skills may not be direct, but indirect, through mediating variables such as professional experience, critical thinking, and the use of applied technology (Woo et al., 2024). Therefore, it is understood that measuring only the attitude level is insufficient, and the actual integration of artificial intelligence tools into research processes should also be considered. AlZaabi and Masters (2025) report that residents who use artificial intelligence tools practically as a component of evidence-based medical education achieve positive gains in terms of both research productivity and attitude towards technology. Therefore, the finding of this research highlights the importance of designing multi-component training models that aim not only at attitude measurement but also at the integration of artificial intelligence into research practice.

The findings of this research offer significant theoretical and practical implications regarding research skills and attitudes towards artificial intelligence within the context of medical residency training. At the theoretical level, this study, conducted within the framework of research self-efficacy theory and technology adoption models, empirically confirms that these theoretical structures also serve an explanatory function in medical residency training. However, the lack of a statistically significant relationship between attitudes towards artificial intelligence and research skills suggests that one-dimensional explanatory models directly linking these two variables may be insufficient; it highlights the need to examine this relationship using more comprehensive multivariate models that include moderator and mediator variables.

At the practical level, the findings contain critical guidelines for the content and structure of residency training

programs. The fact that research skills develop significantly with residency seniority clearly indicates that programs should offer structured research experiences, evidence-based medicine modules, and active mentoring mechanisms, particularly for first and second-year students. The impact of gender-based differences on research skills necessitates the adoption of gender-sensitive approaches in educational settings and the implementation of institutional policies that guarantee equal opportunities. The generally high level of positive attitudes towards artificial intelligence indicates that educational initiatives in this field are well-established; it also emphasizes the need to move beyond attitude development and adopt applied education models that actively integrate AI tools into research practice.

Several limitations must be considered when interpreting the findings of this study. Firstly, the research was limited to individuals undergoing surgical specialty training in specific research and university hospitals in Ankara, Konya, and Izmir provinces in Turkey; this restricts the generalizability of the findings to different geographical regions, specialties, and institutional structures. Secondly, the use of purposeful sampling and voluntary participation is considered a methodological factor limiting the representativeness of the sample. Since the research has a cross-sectional design, it is not possible to establish causal relationships between variables; the findings only point to relational patterns, and longitudinal studies are needed to explain causal mechanisms.

The assessment of both scientific research skills and attitudes towards artificial intelligence using self-report scales can lead to social desirability bias and subjective response tendencies. While the use of adapted and validated versions of the measurement tools in Türkiye provides significant assurance of reliability, content validity needs to be further examined within the context of the unique dynamics of surgical specialty training. These limitations necessitate a cautious interpretation of the study's findings and require future research to be designed to address these constraints.

## **Recommendations**

Based on the findings, several recommendations are offered for both current practice and future research. Specialty training programs, especially for first-year residents, should include mandatory research components encompassing structured evidence-based medicine modules, research workshops, and statistical applications. Designing these components to provide both theoretical knowledge and practical experience will contribute to the earlier reinforcement of research skills. To address gender-based disparities, it is crucial that academic mentoring programs are structured with a gender-sensitive perspective and that institutional mechanisms supporting the academic productivity of female residents are strengthened. While high levels of positive attitudes towards artificial intelligence have been identified, adopting applied training models that actively integrate AI tools into research processes is necessary for this positive attitude to translate into research practice. Future research is recommended to utilize longitudinal designs to uncover causal mechanisms between variables, while simultaneously testing the generalizability of findings with larger and more diversified samples. Future research should also consider that the role of artificial intelligence in surgical training is not limited to practical skill acquisition. In this context, AI-based systems are expected to play an important role in supporting surgical residents' access to current clinical guidelines, rapid knowledge synthesis, and evidence-based clinical decision-

making processes. It is thought that for surgical residents working under intensive clinical conditions, AI-supported tools can contribute to the more effective use of current literature and guideline knowledge, thereby strengthening evidence-based surgical practice. Therefore, future studies should evaluate the role of artificial intelligence in surgical education not only at the level of theoretical knowledge, but also in terms of its effects on clinical application and decision-making processes. Finally, mixed-methods studies that examine the multidimensional relationship between research skills, attitudes towards artificial intelligence, and professional performance indicators, along with moderator and mediator variables, will make significant contributions to the field.

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## Emerging Trends in Virtual Simulation for Education: A Systematic Review of Technology–Pedagogy Alignment

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Virtual simulation has become a transformative approach in education, particularly in contexts that require practical, skill-oriented learning. This systematic review examines emerging trends in virtual simulation for education by synthesizing evidence on educational technologies and instructional design approaches applied in virtual laboratory environments. Guided by the PRISMA protocol and the PSALSAR framework, 20 peer-reviewed journal articles published between 2020 and 2024 were systematically selected and analyzed. The results indicate a growing emphasis on virtual laboratories and immersive technologies, especially virtual and augmented reality, to support hands-on learning across science, engineering, medical, and vocational education. These technologies are predominantly implemented through learner-centered instructional designs, including experiential, inquiry-based, and constructivist approaches, which facilitate active engagement, repeated practice, and meaningful knowledge construction. While immersive and simulation-based technologies dominate current implementations, the integration of AI-supported and analytics-driven systems remains limited, suggesting an emerging area for future development. This review contributes a synthesized conceptual framework that illustrates how virtual simulation technologies are pedagogically operationalized through instructional design themes to produce meaningful learning outcomes. By integrating technological and pedagogical perspectives, the findings provide a structured foundation to inform evidence-based instructional design, implementation, and future research on virtual simulation-based education.

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## Introduction

The rapid advancement of digital technologies has significantly transformed educational practices, particularly in domains that require hands-on experimentation and skill development (Johnson et al., 2023; Thompson et al., 2023). Among these innovations, virtual simulation has emerged as a powerful educational approach, enabling learners to engage with complex, hazardous, or resource-intensive tasks within safe, repeatable, and flexible digital environments (Mariscal et al., 2020; Peterson & Zhang, 2024). The increasing adoption of virtual simulation in education has been driven by advances in immersive technologies, such as virtual reality (VR) and augmented reality (AR), alongside the integration of artificial intelligence (AI), cloud computing, and learning management systems (Kim & Park, 2024; Wang & Liu, 2024). These developments have expanded opportunities for experiential and practice-based learning across disciplines, including science, engineering, medicine, and vocational education (Barrow et al., 2024; Corbi et al., 2020).

Virtual simulation gained further prominence during the global shift toward remote and blended learning, highlighting its potential to address limitations associated with physical laboratories, such as high costs, safety concerns, limited access, and geographical constraints (Karara et al., 2021; Bunse et al., 2023). Prior studies have reported that virtual laboratories and simulation-based environments can support learner engagement, conceptual understanding, and skill acquisition by allowing repeated practice and immediate feedback without the risks inherent in real-world experimentation (Anderson & Kim, 2023; Lee et al., 2024). Consequently, virtual simulation is increasingly viewed not only as an alternative to traditional laboratory instruction but also as a complementary pedagogical strategy capable of enhancing instructional flexibility and learning scalability (Papadimitropoulos et al., 2021; Santyadiputra et al., 2024).

Despite its growing adoption, the educational effectiveness of virtual simulation does not depend solely on technological sophistication. Research consistently emphasizes that learning outcomes are strongly influenced by how simulation technologies are embedded within instructional design (Chen et al., 2023; Rodriguez-Martinez, 2024). Learner-centered strategies, including inquiry-based learning, experiential learning, gamification, and collaborative activities, have been identified as critical factors in leveraging the affordances of virtual environments (Rebecca et al., 2021; Serrano-Ausejo & Mårell-Olsson, 2024). When instructional design is poorly aligned with technological capabilities, even highly immersive systems may fail to achieve meaningful learning outcomes, underscoring the importance of pedagogical alignment in simulation-based learning environments (Byukusenge et al., 2023; Aldosari et al., 2022).

A substantial body of research has investigated virtual simulation technologies in isolation, focusing on specific tools such as VR, AR, or virtual laboratories, or evaluating learning outcomes within particular disciplines (Kim & Park, 2024; Kulkarni & Harne, 2024). Parallel strands of literature have explored instructional design approaches suitable for technology-enhanced learning environments, including constructivist, experiential, and inquiry-based frameworks (Huang et al., 2024; Yu et al., 2024). However, existing reviews often emphasize either technological trends or pedagogical practices without systematically synthesizing the relationship between educational technologies and instructional design approaches across contexts (Johnson et al., 2023; Peterson &

Zhang, 2024). As a result, there remains limited consolidated evidence on how different types of virtual simulation technologies are pedagogically operationalized and aligned with learning theories across diverse educational settings.

Moreover, prior reviews frequently adopt descriptive perspectives, reporting technology frequencies or summarizing outcomes without offering integrative frameworks to guide instructional design and implementation (Thompson et al., 2023; Martinez et al., 2024). This lack of synthesis poses challenges for educators, instructional designers, and policymakers who seek evidence-based guidance on selecting and designing virtual simulation environments that are both pedagogically sound and technologically appropriate (Wilson et al., 2023). Given the rapid pace of innovation in immersive and intelligent educational technologies, an updated and analytically grounded synthesis is necessary to capture emerging trends and inform future practice.

To address these gaps, the present study conducts a systematic review of research published between 2020 and 2024 to examine emerging trends in virtual simulation for education. Guided by the PRISMA protocol and the PSALSAR approach (Mengist et al., 2020), this review analyzes peer-reviewed journal articles to (1) identify trends in virtual simulation research related to skill development, (2) examine the types of educational technologies employed in virtual laboratories, and (3) synthesize the learning theories and instructional design approaches underpinning their implementation. By integrating technological and pedagogical perspectives, this review aims to provide a coherent synthesis that supports evidence-based instructional design, informs educational practice, and highlights directions for future research in virtual simulation-based learning.

## Literature Review

### Conceptualizing Virtual Simulation in Education

Virtual simulation has become a core modality in technology-enhanced education, enabling learners to engage with complex, hazardous, or resource-intensive tasks in safe, repeatable environments. Recent scholarship frames virtual simulation not merely as a digital substitute for physical practice, but as a pedagogical space where interactivity, feedback, and authenticity can be designed to support conceptual understanding and procedural fluency (Johnson et al., 2023; Thompson et al., 2023). This shift has been accelerated by rapid advances in immersive interfaces and intelligent systems, positioning virtual simulation as a strategic approach to skill development across science, engineering, medicine, and vocational contexts.

### Technological Trajectories: From Virtual Labs to Immersive and Intelligent Systems

The technological evolution of virtual simulation can be characterized as a progression from conventional screen-based simulations and virtual laboratories to immersive, data-driven learning systems. First, virtual labs and simulation platforms have expanded access to experimentation and practice, particularly for remote and blended learning contexts, with reported advantages in scalability and cost-efficiency (Peterson & Zhang, 2024). Second, immersive technologies such as virtual reality (VR) and augmented reality (AR) have increased the fidelity of learning experiences by supporting spatial visualization, embodied interaction, and realistic scenario rehearsal

(Kim & Park, 2024; Davidson & Roberts, 2024). Third, the integration of artificial intelligence (AI) and real-time analytics has begun to enable personalization, adaptive feedback, and learning support aligned with individual learner characteristics (Wang & Liu, 2024; Martinez et al., 2024). Collectively, these trajectories indicate that technological innovation is reshaping not only the form of simulations but also the instructional possibilities within virtual learning environments.

### **Instructional Design as the Determinant of Learning Value**

Although technological sophistication is often highlighted, the educational value of virtual simulation is largely determined by instructional design choices. Contemporary design discourse emphasizes learner-centered approaches, meaningful interaction, and structured learning sequences rather than technology features alone (Chen et al., 2023). Effective virtual simulation design typically includes (a) explicit learning outcomes and alignment with tasks, (b) guided inquiry or scaffolded exploration, (c) formative feedback and assessment mechanisms, and (d) opportunities for collaboration and reflection (Rodriguez-Martinez, 2024). In this view, virtual simulation functions as an instructional system: its effectiveness depends on how learning activities, supports, and evaluations are orchestrated to leverage the affordances of virtual environments.

### **Learning-Theoretical Foundations Supporting Virtual Simulation**

Multiple learning theories have been used to justify and design virtual simulation experiences. Constructivist perspectives support simulations that enable learners to construct understanding through exploration, experimentation, and reflection actively. Experiential learning and activity-based approaches are commonly invoked to explain learning gains when simulations provide authentic tasks, iterative practice, and feedback loops. Cognitive and cognitive-load perspectives highlight the importance of managing information complexity, sequencing, and visualization to avoid overload while supporting comprehension. Theoretically grounded design is therefore essential for translating immersive and interactive technologies into measurable learning outcomes (Anderson & Kim, 2023; Lee et al., 2024). However, the literature also suggests that theory is often referenced at a high level, with limited operationalization into explicit design principles, leaving a gap in evidence-based alignment between learning theories and simulation design features.

### **Evidence on Learning Outcomes and Implementation Constraints**

Evidence indicates that virtual simulation can enhance learning outcomes, particularly for applied competencies and problem-solving in domains requiring practice-based learning (Anderson & Kim, 2023; Lee et al., 2024). Reported benefits include risk-free rehearsal, improved engagement, and opportunities for repeated practice. Nonetheless, implementation barriers remain substantial. Financial constraints, infrastructure readiness, and instructor professional development are repeatedly identified as persistent challenges that may limit scalability and sustainability (Peterson & Zhang, 2024; Wilson et al., 2023). These constraints highlight that successful adoption requires not only technical procurement but also institutional capacity-building, pedagogical training, and inclusive design considerations.

## Synthesis Gap and Rationale for the Present Review

Despite growing scholarship, prior work has tended to emphasize either (a) technological innovation (e.g., VR/AR/AI features) or (b) pedagogical approaches (e.g., inquiry-based, active learning) in isolation. Consequently, a critical gap remains in systematically synthesizing how educational technologies used in virtual simulation align with instructional design approaches and learning-theoretical rationales, particularly in the context of virtual laboratories across disciplines and educational levels. Addressing this gap is important because misalignment between technology affordances and instructional design may reduce effectiveness and limit transfer to practice. Therefore, the present systematic review examines emerging trends in virtual simulation for education by mapping educational technologies and instructional design approaches, with the aim of informing evidence-based development, implementation, and future research directions.

## Method

The research employs a systematic review methodology to investigate the growth trends of Virtual Simulation technology in the development of comprehensive learner outcomes, alongside the design of instructional practices tailored to this technology's capabilities. The methodological framework follows the PSALSAR approach (Protocol, Search, Appraisal, Synthesis, Analysis, Report) proposed by Mengist et al. (2020). Furthermore, the study adheres to the PRISMA protocol (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) for the systematic identification, screening, and selection of literature.

Figure 1 presents the systematic process of identifying, screening, and selecting journal articles using the PRISMA 2020 protocol. The steps include initial identification of records from databases (ERIC, ACM Digital Library, ScienceDirect, and Scopus), removal of ineligible and duplicate articles, screening for relevance, and final eligibility assessment. After thorough appraisal and quality assessment, 20 studies were ultimately included in the review.

## Protocol Stage

The first stage involved developing a protocol, which entailed defining the research scope, formulating key research questions, and establishing the review's boundaries. The primary focus was on the growth trends of Virtual Simulation technology and the theories and instructional design employed in virtual laboratories. The research aimed to address the following questions:

RQ1. What is the trend of their growth in Virtual Simulation research for developing hard skills?

RQ2: Which technologies have been used for virtual labs?

RQ3. What learning theories and instructional design features have been applied in virtual laboratories?

To ensure a focused investigation, the study's scope was limited to journal articles published between 2020 and 2024, with an emphasis on sources available in ERIC, ScienceDirect, ACM Digital Library, and Scopus.

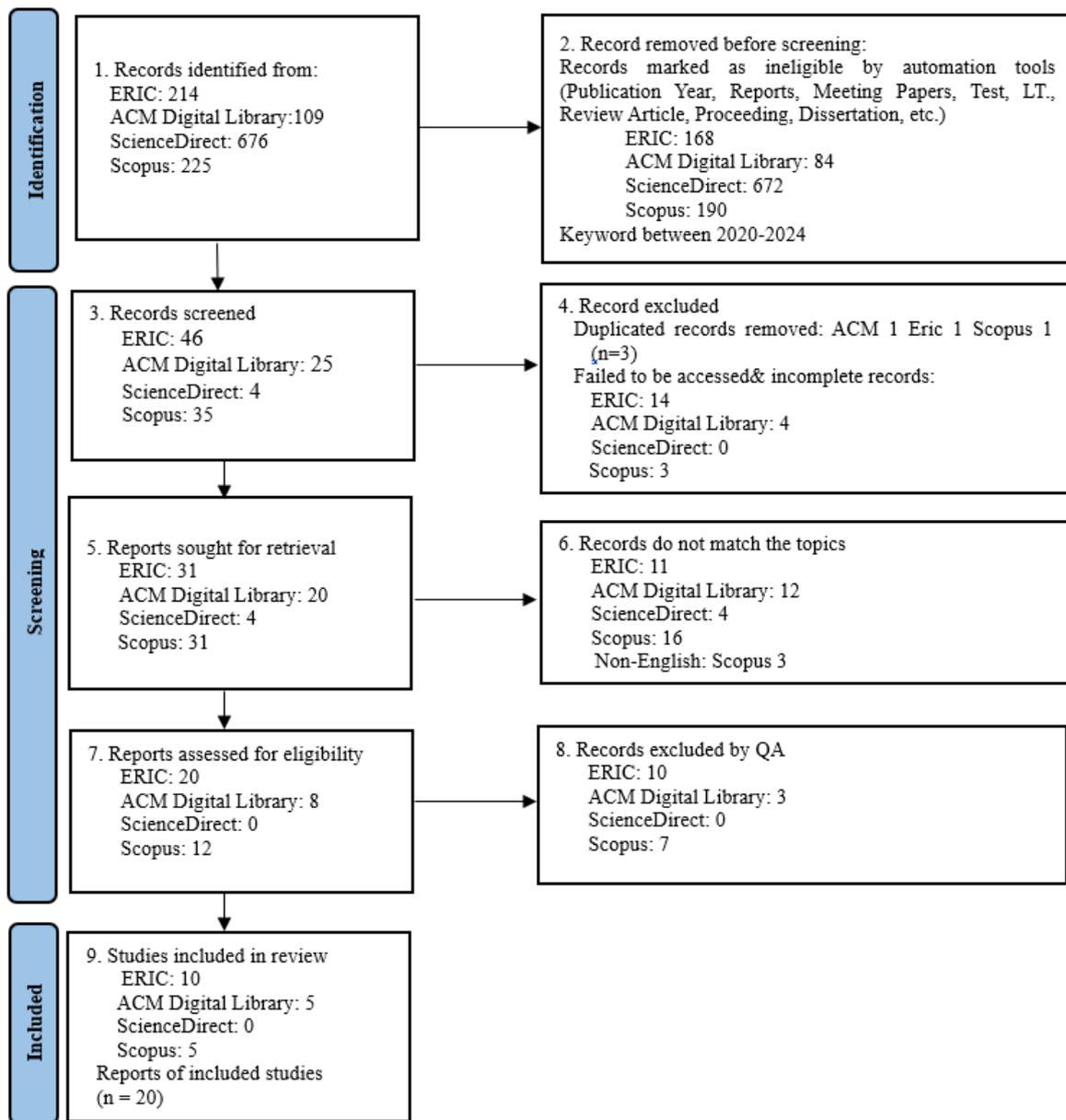


Figure 1. Result of Article Search Using PRISMA 2020

**Search Stage**

The literature search process meticulously identified and refined key terms during the search phase. The primary keywords included “simulation,” “virtual labs,” and “technology,” alongside related terms outlined in Table 1. These terms were systematically adapted to align with each database's search algorithm to optimize the retrieval of relevant scholarly sources.

Table 2 summarizes the search results for the selected keywords across three databases: ERIC, ScienceDirect, and ACM Digital Library. Among these, ScienceDirect produced the most articles, totaling 676, followed by Scopus with 225, ERIC with 214, and ACM Digital Library with 109. These findings highlight the extensive availability of literature and emphasize the importance of systematic screening in the review process.

Table 1. Keywords and Their Derivatives in Journal Article Searches

Main Keywords	Derivative Keywords
simulation	Simulation, Virtual simulations
virtual labs	Virtual simulations lab, Virtual laboratory
technology	Virtual Labs & Simulations, Simulation Technology, Virtual & Augmented Reality (VR/AR), Cloud Computing, Artificial Intelligence & Machine Learning (AI/ML), Learning Management Systems (LMS) & E-learning, Communication & Collaboration Tools, 3D Modeling & Game Engines, Visualization & Digital Content Creation, Gesture-Based & Interactive Technologies

Table 2. Search Journal Articles by Keyword

Database	Search keywords	Results
ERIC	"simulation" AND "virtual labs" AND "technology"	214
ScienceDirect	"simulation" AND "virtual labs" AND "technology"	676
ACM Digital Library	"simulation" AND "virtual labs" AND "technology"	109
Scopus	"simulation" AND "virtual labs" AND "technology"	225

### Appraisal Stage

The appraisal stage involved rigorous screening to ensure the inclusion of high-quality and relevant articles. Table 3 outlines the criteria used to include or exclude studies. Inclusion criteria focused on peer-reviewed articles discussing Virtual simulation contexts, published within the defined timeframe, and accessible in full text. Articles were excluded if they were duplicates, inaccessible, or irrelevant to the research focus.

Table 3. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Journal articles on the topic of Technologies Virtual Simulations in Education	Journal articles that cannot be accessed
Journal articles published on ERIC, ScienceDirect, ACM Digital Library, Scopus.	Duplicate journal articles (previously found)
Journal articles published in 2020 – 2024	Journal articles that are not complete (not full text) Journal articles in the form of literature reviews, books, and websites

The inspection stage of appraisal incorporates both quality and literature evaluation. Rechecking the inclusion and exclusion criteria constitutes a component of the literature appraisal process. The two assessments that make up the quality assessment are as follows:

QA1: Does the journal article discuss using Technologies Virtual Simulations in Education?

QA2: Is the journal article in the form of Classroom Action Research, or contains classroom

experiments?

## **Synthesis and Analysis**

The synthesis stage consisted of extracting and classifying data from the selected journal articles, which were then organized into tables. The analysis stage involved evaluating the synthesized data, extracting meaningful information, and summarizing the selected journal articles. At this stage, the research questions formulated would be answered.

## **Reporting Stage**

In the reporting stage, the findings of the systematic review were organized and presented in alignment with the research questions and the adopted synthesis framework. The results were reported using descriptive statistics, tabular summaries, and thematic categorization to ensure transparency and traceability between the reviewed studies and the synthesized outcomes.

Specifically, publication trends and research contexts were reported to address RQ1, highlighting patterns in the adoption of virtual simulation for skill-oriented learning across educational domains. To address RQ2, the educational technologies employed in virtual laboratory environments were systematically categorized and summarized, with Tables 4 and 5 presenting the distribution of technology types and their application contexts. For RQ3, learning theories and instructional design approaches were synthesized and reported thematically, as presented in Tables 6 and 7, illustrating recurring pedagogical patterns across the reviewed studies.

In addition, a conceptual framework was developed during the reporting stage to integrate the synthesized findings. This framework visually represents the relationships between virtual simulation technologies, instructional design themes, and reported learning outcomes, providing a coherent summary of the review results. The reporting approach ensures that all findings are directly derived from the reviewed evidence and are consistently aligned with the objectives and scope of this systematic review.

## **Results**

This section presents the synthesized results of the systematic review based on the analysis of 20 peer-reviewed journal articles published between 2020 and 2024. The findings are organized in alignment with the three research questions, focusing on (1) research trends in virtual simulation for skill development, (2) educational technologies used in virtual laboratories, and (3) learning theories and instructional design approaches underpinning their implementation.

### **Trends in Virtual Simulation Research for Skill Development (RQ1)**

The analysis reveals a clear upward trend in virtual simulation research related to skill development between 2020

and 2024. As illustrated in Figures 2 and 3, scholarly output increased steadily over the review period, with a notable rise after 2022 and a peak in 2024, accounting for 30% of the total publications. This growth indicates growing academic interest in leveraging virtual simulation to support practical, hands-on learning, particularly in contexts where physical laboratories are constrained by cost, safety, or accessibility.

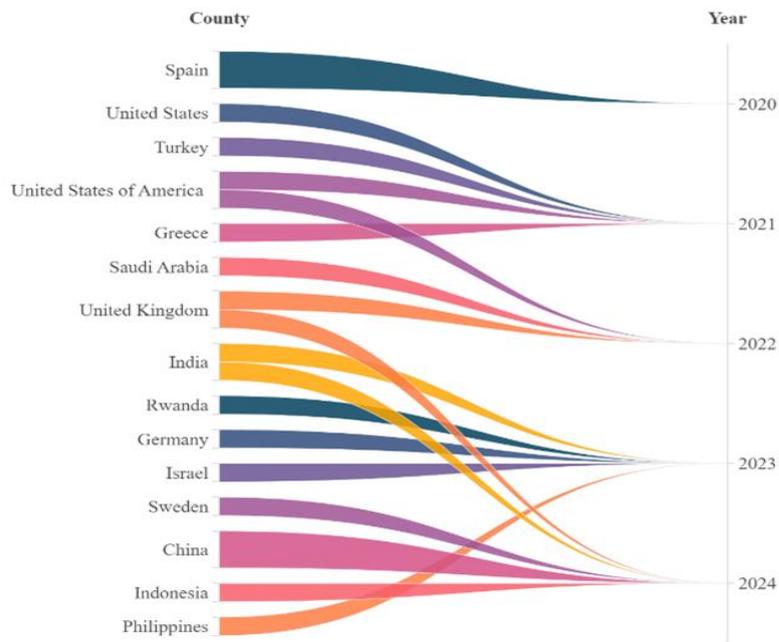


Figure 2. The Publication of Articles from Each Country between 2020 to 2024

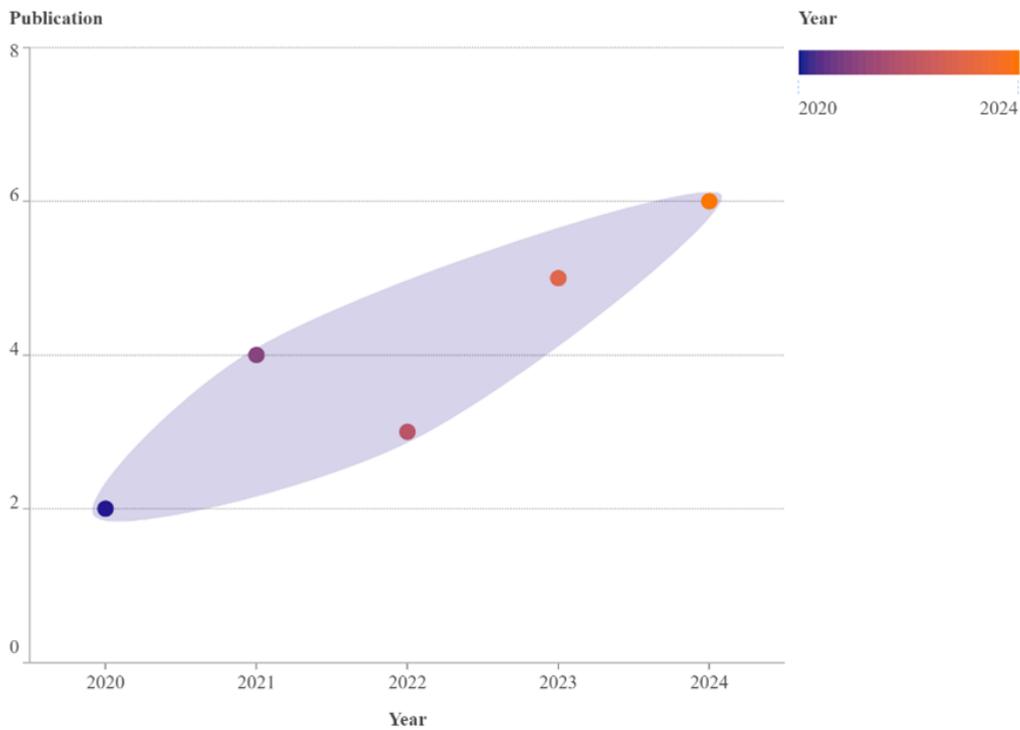


Figure 3. The Number of Articles Published between 2020 and 2024

Geographically, research activity was distributed across multiple regions, with higher publication frequencies observed in technologically advanced countries such as the United States, the United Kingdom, and several European nations. At the same time, emerging contributions from developing regions highlight the growing global relevance of virtual simulation as a scalable educational solution. Across contexts, the dominant focus of the reviewed studies was the development of practical or hard skills, including laboratory procedures, technical operations, and applied problem-solving. These findings suggest that virtual simulation research has increasingly shifted from conceptual demonstrations toward skill-oriented and performance-based learning outcomes.

### Educational Technologies Used in Virtual Laboratories (RQ2)

The reviewed studies employed a diverse range of educational technologies to support the implementation of virtual laboratories. As summarized in Tables 4 and 5 and visualized in Figure 4, Virtual Labs and Simulations and Virtual and Augmented Reality (VR/AR) emerged as the most prevalent technology categories, each accounting for 24% of total usage. These technologies were commonly applied in science, engineering, medical, and vocational education to facilitate interactive experimentation and immersive learning experiences.

Simulation-based technologies, including virtual simulations and domain-specific simulation software, represented 12% of the reviewed implementations. Cloud computing and infrastructure-related technologies accounted for 14%, reflecting the growing role of scalable platforms, virtualization, and remote access in supporting virtual laboratory environments. Learning management systems (LMS) and e-learning tools, as well as communication and collaboration technologies, were used less frequently but played supportive roles in structuring learning activities and enabling remote collaboration.

Advanced technologies such as artificial intelligence, learning analytics, and 3D modeling engines were comparatively underrepresented, indicating that most implementations prioritized experiential access and visualization over adaptive or data-driven instructional features. Overall, the results demonstrate that current virtual laboratory practices are predominantly grounded in immersive and simulation-based technologies, with emerging but limited integration of intelligent and analytics-driven systems.

Table 4. Technology Utilized in Virtual Labs

ID	Author	Type of Technology	Key Features	Education level
P1	Aridan N., 2024	1. VR 2. AR	1. Photogrammetry-based 3D brain models enhance neuroanatomical education. 2. A custom-built virtual laboratory facilitates interactive learning. 3. Evaluation results indicate improved spatial comprehension and learning satisfaction	Medical and Neuroscience students

ID	Author	Type of Technology	Key Features	Education level
P2	Rebecca M., 2021	1. VR 2. Virtual lab simulations.	1. Virtual reality (VR)-based glove hygiene education enhances lab safety awareness 2. A collaborative initiative among chemistry, computer science, and library faculty 3. Evaluation results indicate improved user navigation and engagement	Undergraduate, students first-year chemistry
P3	Yildirim, F.S., 2021	1. Virtual laboratory 2. Virtual simulations.	1. Virtual lab applications in science education 2. Virtual labs enhance students' interest and motivation	Secondary school, eighth-grade students
P4	Karara AH., 2021	1. Blackboard Collaborate Ultra® for live sessions. 2. Labster® science lab simulations. 3. Sniffy the Virtual Rat® simulations. 4. Virtual Interactive Clean Room®	1. Virtual format adapted due to COVID-19 pandemic. 2. Social media for community building among	high school
P5	Kabilan J., 2023	1. Google Sites 2. Virtual labs. 3. Digital curation tools.	1. Google Sites is utilized for virtual lab creation. 2. Curates digital resources relevant to biochemistry topics. 3. Facilitates access from multiple devices (PC, mobile)	higher education
P6	Alfredo C., 2023	1. Digital modular distance learning (DMDL). 2. Free messaging platforms. 3. Virtual simulations lab	1. The study investigates distance learning modalities in physics education 2. Pretest-posttest and repeated measures research designs are utilized. 3. Findings highlight the effectiveness of virtual and physical labs	Senior High School (SHS) students in STEM strand

ID	Author	Type of Technology	Key Features	Education level
P7	Barrow, J., 2024	1. VR 2. Visualization tools 3. Simulations	1. Utilizes Virtual Reality for biochemistry education 2. Participants engage in a virtual lab environment, electrodermal activity sensors. 3. Supports immersive and interactive learning experiences, MetaQuest2 headset	University biochemistry students
P8	Serrano-Ausejo., 2024	1.VR 2.AR	1.Utilizes VR and AR technologies for teaching stereochemistry. 2. Focuses on immersive learning experiences in K–12 education.	Grade 8 students K-12 education
P9	Papadimitropoulos, N., 2021	1. Virtual Chemistry Labs	1. Integration of Technology in Chemistry Education 2. Interactive and Adaptive Learning 3.Accessibility and Cost-Effectiveness	3rd grade of Junior High school
P10	Byukusenge, C., 2023	1. Virtual labs	1.Technology-Enhanced Learning of Nerve Cells 2.Effectiveness of Instructional Approach 3.Implications for Education	secondary school students
P11	Villanueva, A., 2022	1. Tangible Augmented Reality (TAR) technology is utilized.	1. Remote Collaboration and Hands-on Learning 2. Enhanced User Experience 3. Empathetic Collaboration	undergraduate students
P12	Bunse, C., 2023	1. Distance labs 2. Centralized infrastructure 3. Virtualization 4. Scalable and portable technology	1. Remote and Scalable Learning 2. Support for Engineering Courses 3. Infrastructure and Maintenance	engineering education
P13	Alharbi, A. 2022	1. Web-based Integrated 2. E-learning tools	1. Support for Multiple Languages and Collaboration 2 Code Management 3. Mobile Access and Limitations	undergraduate first-year computer science students.

ID	Author	Type of Technology	Key Features	Education level
		1. VR 2. Simulations.	1. Immersive Virtual Reality and Remote Access 2. Cost and Space Efficiency 3. Realistic Simulations	higher education.
P15	Huang, G., 2024	1. VR 2. Unreal Engine 4 3.3DsMax 4. Interactive human-machine	1. Immersive Learning with Virtual Reality 2. Integration with Teaching Models 3. Virtual Laboratory for Practical Learning	junior high school education level
P16	Aldosari, S. S., 2022	1. Gesture-based technology 2. Virtual simulation	1. Virtual Simulation and Molecular Visualization 2. Interactive Learning Tools 3. Exam Preparation and Performance Tracking	secondary school education.
P17	Mariscal, G., 2020	1.VR	1. Virtual Reality for Medical Training 2. Evaluation and Comparison 3. Safety and Emergency Response	higher education
P18	Corbi, A., 2020	1. Virtual engineering labs. 2. Container technology. 3. Cloud 4. Simulation	1. Scientific Simulations and Modern Computing 2. Engagement and Learning Tools 3. Physics and Engineering Applications	engineering undergraduates' education
P19	Kulkarni, R., 2024	1.AR 2. Virtual engineering labs 3. Mixed and Augmented Reality Studio (MARS)	1. Interactive Learning with AR 2. Performance and Motivation 3. Real-Time Tracking and Model Access	engineering education.
P20	Santyadi Putra, G. S., 2024	1. Vilanets 2. Simulation 3. Moodle 4. Google Cloud 5. Videos and Cisco Packet Tracer files.	1. Integration of VLEs and Virtual Labs 2. Collaborative and Cloud-Based Learning 3. Structured Learning and Complex Objectives	higher education students.

Table 5. Classification of Technologies Used in Virtual Labs

Technology Category	Item	Count	Percentage
Virtual Labs & Simulations	Virtual engineering labs	2	24.00%
	Labster Virtual Simulations labs	2	
	Virtual Chemistry Labs	2	
	Virtual Interactive Clean Room®	1	
	Virtual labs	1	
	Virtual labs Simulations	2	
	Remote laboratories	1	
	Virtual and Remote Laboratories,	1	
Simulation Technology	Simulation	3	12.00%
	Virtual simulations	2	
	Sniffy the Virtual Rat® simulations	1	
Virtual & Augmented Reality (VR/AR)	VR	6	24.00%
	AR	3	
	Tangible Augmented Reality (TAR)	1	
	Mixed and Augmented Reality Studio (MARS)	1	
	Vilanets	1	
Cloud Computing & Infrastructure	Cloud	1	14.00%
	Google Cloud	1	
	Container technology	1	
	Centralized infrastructure	1	
	Virtualization	1	
	Scalable and portable technology	1	
	Web-based Integrated	1	
Learning Management	Moodle	2	6.00%
	Blackboard Collaborate Ultra	1	
Systems (LMS) & E-learning	E-learning tools	1	4.00%
	Digital modular distance learning (DMDL)	1	
Communication & Collaboration Tools	Free messaging platforms	1	4.00%
	Google Sites	1	
3D Modeling & Game Engines	Unreal Engine 4	1	2.00%
Visualization & Digital Content Creation	Visualization tools	1	6.00%
	Videos and Cisco Packet Tracer files	1	
	Digital curation tools	1	
Gesture-Based & Interactive Technologies	Gesture-based technology	1	4.00%
	Interactive human-machine	1	

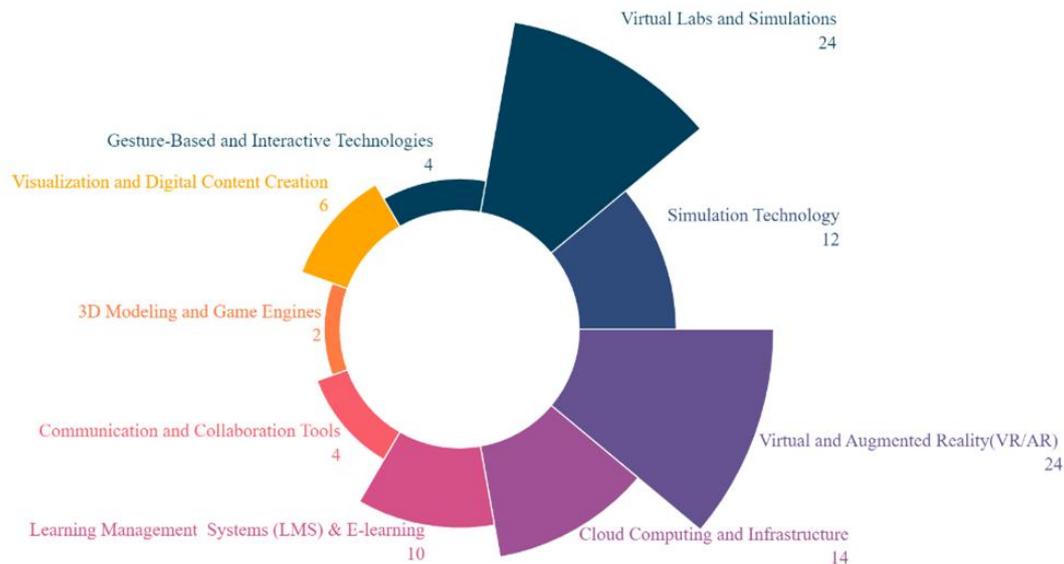


Figure 4. Percentage of Technology Category from 2020 to 2024

### Learning Theories and Instructional Design Approaches in Virtual Laboratories (RQ3)

Analysis of instructional design practices revealed strong alignment with learner-centered and activity-oriented pedagogical frameworks. As presented in Tables 6 and 7, constructivist, experiential, and inquiry-based learning approaches were the most frequently reported theoretical foundations across the reviewed studies. These approaches emphasized active engagement, exploration, and problem-solving within virtual laboratory environments.

Instructional design strategies commonly incorporate guided inquiry, self-directed learning, gamification elements, and collaborative tasks. Assessment practices primarily relied on formative mechanisms, including pre- and post-tests, task-based evaluations, and iterative feedback loops. However, explicit integration of advanced assessment analytics and adaptive feedback systems was limited, suggesting an emphasis on traditional evaluation methods adapted to virtual contexts rather than fully data-driven assessment models.

The relationship between instructional design and technology use also revealed consistent patterns. VR and AR technologies were frequently associated with experiential and immersive learning designs, particularly in higher education and medical contexts. In contrast, conventional virtual laboratories were more commonly paired with inquiry-based and scaffolded instructional approaches in secondary and undergraduate education. These patterns indicate that both technological affordances and educational levels influenced instructional design choices.

Consistent with the synthesized themes presented in Table 7, the reviewed studies demonstrated recurring instructional design patterns, including instructional design adaptation, active and inquiry-based learning, assessment and feedback, gamification and interactive learning, and collaboration and remote learning. Instructional design adaptation was reflected in pre-planning strategies, accessibility considerations, and

structured communication to support virtual learning environments. Assessment and feedback practices primarily involved formative approaches such as pre- and post-tests and iterative task-based evaluations, while gamification and interactive learning strategies were employed to enhance learner engagement through immersive and interactive modules. These themes collectively illustrate how instructional design practices were systematically aligned with virtual simulation technologies across educational contexts.

Table 6. Relationship Between Instructional Design and Virtual Labs

ID	Learning theory	Virtual laboratory	Instructional Design
P1	1. VR and Neuroanatomy Learning 2. Enhanced Spatial Understanding 3. Improved Exam Performance	1. Custom-Built Virtual Laboratory 2. Immersive Learning with VR 3. Enhanced Learning Outcomes	1. Neuroanatomy using Virtual Reality (VR) to enhance learning. 2. Self-Guided Learning in Virtual Lab 3. Assessment through Exams
P2	1. VR for Active Learning in Lab Safety 2. Enhancing Glove Hygiene Awareness 3. Promoting Engagement and Interaction	1. VR Laboratory Application for Chemistry Education 2. Realistic Lab Experience 3. Glove Hygiene Training and Immersive Technology	1. Active Learning 2. Familiarization with Lab Settings 3. Safety and Compliance Focus
P3	1. Constructivist Approach in Education 2. Virtual Laboratories for Meaningful Learning 3. Technology-Supported Learning	1. Safe Experimentation in Virtual Laboratories 2. Enhancing Academic Success and Motivation 3. Understanding Complex Physics Concepts	Virtual laboratory applications in science education.
P4	1. Lab Simulations for Experiential Learning 2. Interactive, Gamified Virtual Labs 3. Engagement through Social Media	1. Transition to Virtual Format 2. Use of Labster® for Interactive Simulations 3. Simulated On-Campus Lab Experiences	1. Adaptation of instructional design for virtual learning 2. Evaluation design with process and outcome data 4. Hands-on training in drug discovery and biomedical research 5. Use of lab simulation software
P5	1. Effective Online Teaching-Learning	1. Remote-Controlled Simulations	1. Adaptation of instructional design for

ID	Learning theory	Virtual laboratory	Instructional Design
	2. Google Sites for Collaborative Learning 3. Virtual Curation Lab for Student Engagement	2. Web-Based Digital Learning 3. Feasibility and Accessibility	virtual curation labs 2. Importance of pre-planning 3. Accessibility of digital resources 4. Clear communication of objectives
P6	1. Metacognition's Influence 2. Distance Learning 3. Modalities Study Focus on Metacognition	1. Improved Learning with Virtual Labs 2. Better Achievement with Virtual Labs 3. Complementary Role of Labs	1. Inquiry-based learning 2. Static PDFs for learning modules 3. Challenge prompts 4. guided learning Comprehensive module content
P7	1. VR for Biochemical Understanding 2. Hierarchical and Dynamic Learning Structure 3. Challenges in Biochemical Pathways	1. VR Visualization Model for Biochemistry 2. Immersive 3D Learning 3. Improved Learning in Virtual Labs	1. VR-based learning environment 2. Interactive virtual lab experience 3. Mixed-methodology approach
P8	1. Activity Theory in Learning 2. Exploring VR and AR in Education 3. Student Challenges in Virtual Learning	1. Effectiveness of Virtual Labs 2. Motivation and Understanding 3. Positive Learning Outcomes	1. Collaboration 2. VR and AR technologies 3. Gamification and iterative testing
P9	1. Cognitive Load and Neural Mirroring 2. Declarative Knowledge Acquisition 3. Learning Gains from Arduino and Virtual Labs	1. Alternatives to Real Labs 2. Impact on Chemistry Knowledge 3. Integration with Arduino Experiments	1. Digital Application (DA) for teaching Chemistry 2. Learning path and guidance 3. Course objectives and concept maps
P10	1. Cognitive Theory Application 2. Effective Learning Tools 3. Deep Learning Promotion	1. Virtual labs Enhanced Understanding 2. Improved Performance 3. Independent Learning	1. Technology-enhanced instruction 2. Effective selection and integration of tools
P11	1. The study emphasizes hands-on learning in laboratory-based classes.	1. Virtual labs lower costs and enhance academic performance. 2. They facilitate distance	1. Enabling Complex and Flexible STEM Environments

ID	Learning theory	Virtual laboratory	Instructional Design
	2. Instructors noted a better understanding through scientific experimentation. 3. Students preferred flexible setups for exploring experiments.	learning and promote health and safety. 3. Virtual labs support various subjects like chemistry and physics, providing hands-on learning through augmented reality and haptic feedback.	2. Remote Collaboration and Engagement 3. Facilitating Hands-on, Practical Learning
P12	1. Promotes self-organized learning and practical experience 2. Enhances learning flexibility 3. Bridges theory with real-world problem-solving	1. High-fidelity digital replication 2. Preparation through virtual twins 3. Standardization in engineering education	1. Study Design and Grouping 2. Compares two teaching methods: distance lab versus traditional lab. 3. Assessment and Feedback
P13	1. Integration of theory and practice 2. Bridging theory and practice 3. Hands-on programming experience	1. Transition to virtual laboratories 2. Overcoming physical limitations 3. Positive student experiences and effectiveness	1. web-based 2. Traditionally conducted in computer labs. 2. Virtual Lab Framework and Technology 3. Collaborative and Remote Learning
P14	1. Enhancing distance and blended learning. 2. Interactive and immersive learning 3. Limitations of traditional methods	1. High simulation and open accessibility 2. Support for distance and blended learning 3. Immersive and interactive learning	1. Use of digital twin technology and simulation 2. collaborative and remote experiments
P15	1. Enhanced immersive and interactive learning 2. Deeper learning engagement 3. Support for constructivist learning	1. Enhanced learning through immersion 2. Observation beyond traditional limits 3. Improved understanding of abstract concepts	1. BOPPPS model 2. Combines experiments and theories for comprehensive learning 3. Assessment through pre- and post-tests
P16	1. Exploration of experiential learning 2. Comparison of learning outcomes 3. Better understanding of the proposed system	1. Virtual chemistry lab for experimentation 2. Safety in virtual labs 3. Integration of virtual simulation and molecular visualization	1. Combines virtual simulation and molecular visualization, utilizing a Leap Motion controller to enhance interactive learning experiences.

ID	Learning theory	Virtual laboratory	Instructional Design
		4. Positive student attitudes	2. Pre-test and Post-test Design 3. Interactive and immersive learning environment
P17	1. Clear learning outcomes in instructional design 2. Enhancement through virtual reality 3. Simulation-based training for skill development 4. Feedback promoting critical thinking	1. UE Risk Simulator for laboratory training 2. Safe simulation of laboratory accidents 3. Enhancing learning in lab work courses 4. Learning safety and basic operations	VR and other immersive technologies
P18	1. Novel virtual lab for teaching x-ray basics 2. Combining science and modern computing 3. Motivation through practical applications 4. Focus on distance learning for adult learners	1. Novel virtual lab for teaching X-ray basics 2. Enhancing physics learning for engineering students 3. Utilizing cloud and computing techniques 4. Engaging and successful pedagogy	Virtual Laboratories
P19	1. Optimizing educational outcomes with digital tools 2. Enhancing engagement through AR technology 3. UTAUT2 framework for assessing AR labs 4. Improved visualization and interaction with e-learning	1. Virtual AR laboratory for engineering education 2. Improved learning experiences in engineering labs 3. Integration of geo-location for interactivity 4. Boosting student engagement 4. Facilitating knowledge acquisition without physical labs	1. AR tools 2. UTAUT2 model for evaluating adaptability.
P20	1. Enhancing practical skills and problem-solving 2. Bridging theory and practice 3. Immersive learning with Vilanets	1. Utilizing Unetlab for virtual functions 2. Enhanced compatibility with networking vendors 3. Better preparation for practical exercises 4. Improved learning outcomes with Vilanets	Advanced Virtual Learning Environments

Table 7. Synthesized Instructional Design Themes and Learning Approaches in Virtual Simulation

Main Instructional Design Themes	Publication ID	Author(s) and Year
Virtual Reality (VR) and Augmented Reality (AR) in Education: Enhancing learning through immersive technologies such as VR, AR, and digital twins	P1	Aridan et al., 2024
	P7	Barrow et al., 2024
	P8	Serrano-Ausejo & Mårell-Olsson, 2024
	P16	Aldosari et al., 2022
	P17	Mariscal et al., 2020
	P19	Kulkarni & Harne, 2024
	P20	Santyadi Putra et al., 2024
Virtual Laboratories: Applications of virtual laboratories in science education, including remote and collaborative experiments	P3	Yildirim, 2021
	P4	Karara et al., 2021
	P11	Villanueva et al., 2022
	P13	Alharbi, 2022
	P14	Yu et al., 2024
	P18	Corbi et al., 2020
Instructional Design Adaptation: Adapting instructional methods for virtual learning, including pre-planning, accessibility, and clear communication	P4	Karara et al., 2021
	P5	Kabilan, 2023
	P10	Byukusenge et al., 2023
	P15	Huang et al., 2024
Active and Inquiry-Based Learning: Promoting engagement through active learning, inquiry-based methods, and challenge prompts	P2	Rebecca et al., 2021
	P6	Alfredo et al., 2023
	P12	Bunse et al., 2023
Assessment and Feedback: Evaluating learning through exams, pre-/post-tests, and iterative testing	P1	Aridan et al., 2024
	P12	Bunse et al., 2023
	P15	Huang et al., 2024
	P16	Aldosari et al., 2022

Main Instructional Design Themes	Publication ID	Author(s) and Year
Collaboration and Remote Learning: Facilitating remote collaboration and hands-on learning in STEM environments	P8	Serrano-Ausejo & Mårell-Olsson, 2024
	P11	Villanueva et al., 2022
	P13	Alharbi, 2022
	P14	Yu et al., 2024
Gamification and Interactive Learning: Using gamification, interactive modules, and immersive environments to enhance engagement	P8	Serrano-Ausejo & Mårell-Olsson, 2024
	P16	Aldosari et al., 2022
	P19	Kulkarni & Harne, 2024
Technology Integration: Effective selection and integration of tools such as simulation software, gesture-based controllers, and AR tools	P4	Karara et al., 2021
	P10	Byukusenge et al., 2023
	P16	Aldosari et al., 2022
	P19	Kulkarni & Harne, 2024

### Cross-Pattern Synthesis of Technologies and Instructional Design

Cross-analysis of the reviewed studies highlights several dominant and underrepresented patterns in virtual simulation research. Dominant trends include the widespread use of immersive technologies for enhancing engagement and spatial understanding, as well as the application of inquiry-based and experiential pedagogies to support skill acquisition. Conversely, underrepresented areas include the use of artificial intelligence for adaptive learning, the integration of learning analytics for real-time assessment, and systematic consideration of accessibility and equity in virtual laboratory design. Additionally, contextual patterns emerged across educational levels. Higher education and professional training contexts tended to adopt advanced immersive technologies, whereas secondary and K–12 settings favored cost-effective virtual laboratories and simulation tools. These findings suggest that contextual constraints, including infrastructure readiness, learner characteristics, and institutional capacity, shape technological and instructional design decisions.

### Conceptual Synthesis of Virtual Simulation, Instructional Design, and Learning Outcomes

Figure 5 presents a conceptual framework derived from the synthesis of instructional design themes and learning approaches identified across the reviewed studies. The framework illustrates the structured relationship between categories of virtual simulation technologies, instructional design themes, and observed learning outcomes in educational contexts.

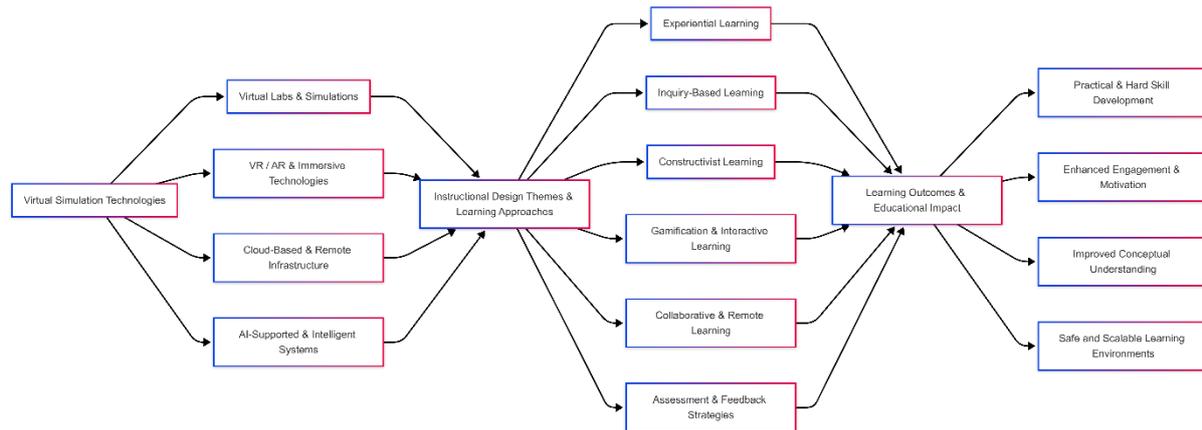


Figure 5. Conceptual Framework Illustrating the Alignment between Virtual Simulation Technologies, Instructional Design Themes, and Learning Outcomes in Education

At the technological level, the reviewed studies predominantly employed four categories of virtual simulation technologies: virtual laboratories and simulation platforms; immersive technologies such as virtual and augmented reality (VR/AR); cloud- and remote-based infrastructures; and emerging AI-supported systems. These technologies served as foundational enablers, providing learners with access to interactive, scalable, and immersive learning environments. Virtual laboratories and simulation platforms were most frequently associated with structured experimentation and procedural practice, while VR/AR technologies emphasized spatial visualization and immersive interaction.

At the instructional design level, the synthesis revealed that technological affordances were operationalized through recurring instructional design themes and learning approaches. These included experiential learning, inquiry-based learning, constructivist learning, gamification and interactive learning, collaborative and remote learning, and assessment and feedback strategies. Experiential and inquiry-based learning approaches were most commonly aligned with immersive and simulation-based technologies, supporting active exploration and hands-on practice. Constructivist learning approaches emphasized learner autonomy and knowledge construction within virtual environments, while gamification and interactive strategies enhanced engagement and sustained participation. Collaborative and remote learning approaches leveraged cloud-based infrastructure to facilitate learner interaction, and assessment strategies primarily focused on formative evaluations embedded within virtual tasks.

At the outcome level, the framework synthesizes learning outcomes reported across the reviewed studies. The most frequently observed outcomes included the development of practical and hard skills, enhanced learner engagement and motivation, improved conceptual understanding, and the provision of safe and scalable learning environments. These outcomes were consistently associated with instructional designs that aligned technological capabilities with learner-centered and activity-oriented pedagogical approaches. The framework highlights that learning outcomes emerged not from the use of technology alone, but from the systematic integration of instructional design strategies within virtual simulation environments.

Overall, the conceptual framework represents a synthesized model of how virtual simulation technologies are pedagogically enacted through instructional design themes to produce educational outcomes. This synthesis provides a structured representation of patterns identified across the reviewed studies and serves as an integrative summary of the empirical results reported in this systematic review.

## Conclusion

This systematic review demonstrates that the educational effectiveness of virtual simulation is determined not by technological sophistication alone, but by the alignment between educational technologies and instructional design approaches (Chen et al., 2023; Rodriguez-Martinez, 2024). The synthesized results indicate that immersive technologies, particularly virtual and augmented reality, are most effective when integrated with experiential, inquiry-based, and constructivist learning approaches, which emphasize active engagement and knowledge construction (Mariscal et al., 2020; Serrano-Ausejo & Mårell-Olsson, 2024).

The predominance of virtual laboratories and VR/AR applications across the reviewed studies reflects a strong focus on practical and hard-skill development, especially in science, engineering, and medical education (Barrow et al., 2024; Corbi et al., 2020). These findings are consistent with prior evidence showing that simulation-based environments support skill acquisition through repeated practice and risk-free experimentation (Anderson & Kim, 2023; Lee et al., 2024). However, the limited presence of AI-supported and analytics-driven systems suggests that most current implementations prioritize immersion and accessibility rather than adaptive personalization (Wang & Liu, 2024; Martinez et al., 2024).

The conceptual framework proposed in this study synthesizes these patterns by illustrating how virtual simulation technologies are pedagogically operationalized through instructional design themes to generate meaningful learning outcomes. This integrative perspective contributes a structured lens for understanding technology–pedagogy alignment in virtual simulation-based education and supports evidence-informed design and future research directions (Johnson et al., 2023; Peterson & Zhang, 2024).

This systematic review synthesized recent research on virtual simulation in education to examine how educational technologies are aligned with instructional design approaches across diverse learning contexts. The findings indicate that virtual laboratories and immersive technologies, particularly VR and AR, are predominantly used to support practical, skills-oriented learning. At the same time, learner-centered instructional designs such as experiential, inquiry-based, and constructivist approaches play a critical role in transforming technological affordances into meaningful educational outcomes. The conceptual framework developed in this study offers a synthesized perspective by illustrating the structured relationships among virtual simulation technologies, instructional design themes, and learning outcomes, thereby providing an integrative lens for understanding technology–pedagogy alignment in virtual simulation-based education. This contribution aligns with broader trends in the field that emphasize aligning technological innovation with pedagogical design to enhance the effectiveness and scalability of educational simulations (Johnson et al., 2023).

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