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Generative AI Scaffolding in Physics Education: A Phenomenological Analysis of Its Role and Implications in STEM Learning

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ABSTRACT

Purpose of the study: This study investigates how generative AI tools—especially video generation—scaffold high school students' understanding of Newtonian mechanics, focusing on female learners in a STEM Honors Physics class. It explores how these tools impact conceptual mastery, critical thinking, creativity, and students' perceptions of AI use in education.

Methodology: Using a phenomenological qualitative design, the study involved 17 female students. It followed a three-phase structure—preparatory, scaffolding, and post-discourse—with tools like AI-generated videos, simulations, TAM-based surveys, and reflective journals, grounded in Constructivist Learning Theory and the Technology Acceptance Model.

Main Findings: AI-enhanced visualizations improved students' conceptual understanding and learning efficiency. Students gained critical thinking through prompt refinement and creativity. Ethical concerns and AI accuracy issues were noted. Overall, students showed moderate satisfaction, ease of use, and usefulness perceptions, but cautious intentions toward future AI use.

Novelty/Originality of this study: This is among the first studies to apply generative AI hypermedia in high school physics education through a structured, theory-driven framework. It uniquely highlights gender-specific engagement, ethical considerations, and practical integration of AI in fostering deeper conceptual and creative STEM learning.

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1. INTRODUCTION

The rapid advancements in artificial intelligence have given rise to innovative educational tools, offering new avenues to enhance learning experiences. One such application is the use of AI-generated hypermedia, such as diffusion models for video creation, to support students in visualizing and comprehending abstract concepts in physics, particularly Newtonian mechanics. Teaching Newtonian mechanics in traditional physics classrooms presents significant pedagogical challenges due to the abstract and often counterintuitive nature of concepts like inertia, force, acceleration, and projectile motion. These concepts require students to visualize dynamic interactions and grasp complex cause-and-effect relationships, which are difficult to convey through conventional methods such as lectures, static textbook diagrams, and rote problem-solving exercises. Traditional instruction often relies on text-heavy explanations and two-dimensional illustrations, which may fail to engage diverse learners, leading to superficial understanding and persistent misconceptions. For instance, students frequently struggle to conceptualize Newton's First Law due to conflicting everyday experiences with friction, which obscures the idea of an object maintaining its state of motion without an external force [1].

Recent literature highlights that traditional approaches often result in low student engagement, poor retention of concepts, and limited ability to transfer theoretical knowledge to practical applications [2]. Moreover, these methods may inadequately support diverse learning styles, particularly for visual or kinesthetic learners who benefit from interactive and experiential approaches, and can disproportionately disadvantage underrepresented groups, such as female students in STEM, due to a lack of inclusive pedagogical strategies [3].

The urgency of addressing these challenges is underscored by research showing that inadequate visualization tools in physics education contribute to persistent achievement and confidence gaps, particularly among underrepresented student groups. Female students, for example, often report lower confidence and self-efficacy in visualizing abstract physics concepts compared to their male peers, though studies demonstrate that these gaps can be narrowed through targeted interventions and the integration of effective visualization strategies. Improving how abstract STEM concepts are presented is therefore critical to fostering equity and deeper understanding in science education [4]. Furthermore, the rapid integration of AI in education, evidenced by the explosive growth in AI-powered educational technologies worldwide, underscores the urgent need for innovative tools and pedagogies designed to bridge learning gaps and promote equitable outcomes in STEM contexts. Current market analyses forecast that the global AI in education sector will continue expanding at a high annual growth rate, reflecting accelerating institutional adoption and investment [5]. The overemphasis on mathematical derivations without sufficient conceptual scaffolding can also overwhelm students, reducing motivation and interest in physics [6]. These challenges highlight the need for innovative tools, such as AI-generated hypermedia, to provide dynamic, interactive visualizations that enhance conceptual understanding and address the limitations of static, text-based instruction in physics education. Generative hypermedia, which employs AI to produce dynamic and interactive multimedia content, has been extensively utilized in industries like marketing [7], entertainment [8], and the creative arts for content generation and audience engagement. However, its potential integration into educational settings, particularly in complex disciplines such as physics, remains an underexplored area.

Several areas of concern regarding the integration of AI-generated hypermedia tools into physics education need to be addressed. These include students' ethical considerations about using AI tools in academic work, the perceived legitimacy of AI-generated content in educational contexts, and the potential disparities in how STEM students engage with and benefit from these tools. Recent studies highlight ethical concerns, such as the risk of over-reliance on AI, which can undermine critical thinking, with 48.2% of students expressing concerns about the accuracy of AI-generated content. Additionally, privacy issues and algorithmic biases in AI tools raise questions about equitable access and fairness, particularly for students with disabilities or from underrepresented backgrounds [9]. This study investigates the influence of AI-powered video generation tools on students' conceptual grasp of physics, particularly in facilitating their understanding of abstract concepts. It examines students' views on leveraging AI generative tools to visualize complex ideas and their willingness to incorporate these technologies across STEM disciplines. Additionally, the research explores the wider educational implications of integrating AI video generation tools into STEM education, focusing on their impact on fostering creativity, critical thinking, and conceptual mastery.

While prior research has explored AI applications in education, significant gaps remain in the context of AI-generated hypermedia for physics education, particularly Newtonian mechanics. A systematic review of AI in education from 2014–2023 found that most studies focus on general science or programming, with only 10% addressing physics-specific applications, and even fewer targeting the visualization of Newtonian concepts [10]. For instance, studies on intelligent tutoring systems for STEM often emphasize feedback and assessment over dynamic visualization, leaving a gap in tools that support interactive, student-driven exploration of abstract physics phenomena [11]. Additionally, current scholarship on AI-generated hypermedia in STEM education seldom investigates how these tools interact with diverse learning modalities—especially visual and kinesthetic preferences, which many students rely on but that traditional instruction often undervalues. Although multimodal design—incorporating visual, auditory, kinesthetic, and linguistic channels—is recognized as educationally beneficial, there is limited empirical evidence examining whether AI-powered hypermedia tools effectively support these learner preferences or promote deeper learning outcomes in STEM domains [12]. Ethical concerns, such as data privacy and bias in AI-generated content, are acknowledged but lack comprehensive analysis in physics education, with only 1.4% of studies critically addressing these issues [13]. Finally, there is a lack of research on how AI tools can be integrated with constructivist pedagogies to enhance conceptual understanding in physics, particularly for underrepresented groups, highlighting the need for studies that combine pedagogical theory with AI innovation [14].

This study offers several novel contributions to the field of AI in STEM education. First, it is among the first to specifically investigate AI-generated hypermedia, such as diffusion-based video generation, for visualizing Newtonian mechanics, addressing a gap in physics-specific AI applications [10]. Unlike prior studies that focus on static or text-based AI outputs, this research emphasizes dynamic, interactive visualizations that align with constructivist learning principles, enabling students to actively construct mental models of abstract concepts like inertia and projectile motion. Second, it integrates the Technology Acceptance Model with

Constructivist Learning Theory to explore both the cognitive and affective dimensions of AI tool adoption, a novel combination that provides a holistic understanding of student engagement [15]. Third, the study addresses ethical concerns by examining students' perceptions of AI legitimacy and potential biases in hypermedia content, responding to calls for greater ethical scrutiny in AI application in education [16]. Finally, it investigates the impact of AI tools on underrepresented groups in STEM, particularly female students and those with disabilities, aiming to reduce achievement gaps through inclusive visualization strategies, an area underexplored in prior research [17].

This study is grounded in two theoretical frameworks: Constructivist Learning Theory and the Technology Acceptance Model. Together, these frameworks offer a robust foundation for exploring how students learn and engage with AI-powered generative tools in the context of physics education. Constructivist Learning Theory, rooted in the works of Jean Piaget [18] and Lev Vygotsky [19], emphasizes that learning is an active process where learners construct knowledge and meaning through their experiences and interactions. This theory aligns with the goals of the study by providing a foundation to understand how students can use AI generative tools to engage with and internalize abstract concepts in Newtonian mechanics. Piaget's theory focuses on the development of schemas mental frameworks used to organize and interpret information. Learning occurs through two primary processes: assimilation, where new information is integrated into existing schemas [20], and accommodation, where schemas are modified to adapt to new information [21]. In the context of this study, AI video generation tools enable students to visualize and engage with abstract concepts, facilitating the refinement of their mental models of physics. For example, creating visual representations of Newtonian principles like inertia or projectile motion allows students to incorporate these ideas into their understanding through a hands on, interactive process.

Vygotsky's sociocultural perspective complements Piaget's individual focus by emphasizing the importance of social interaction and guidance in learning. Vygotsky's concept of the Zone of Proximal Development identifies the gap between what a learner can accomplish independently and what they can achieve with appropriate support [22]. AI generative tools can serve as a form of scaffolding within this zone [23], helping students bridge the gap between basic understanding and deeper comprehension of Newtonian mechanics. Using these tools, students can visualize abstract phenomena and manipulate representations to explore cause-and-effect relationships, which may be difficult to grasp through traditional text-based or lecture-driven instruction. Recent research supports this approach, showing that AI-driven scaffolding can improve conceptual understanding by 25% in physics education compared to traditional methods [24]. The constructivist approach aligns with the study's goal of enhancing conceptual understanding, as it highlights the importance of active engagement, visualization, and guided exploration key features enabled by AI generative tools.

The Technology Acceptance Model (*TAM*), developed by Fred Davis [25], provides a framework for understanding how and why individuals adopt and use new technologies. This model is crucial to the study as it explores students' willingness to engage with AI generative tools and identifies factors that may encourage or hinder their integration into educational practices. *TAM* asserts that core determinants, namely perceived usefulness (PU) and perceived ease of use (PEU), significantly influence an individual's intention to accept and utilize a given technology [26]. Perceived usefulness refers to students' belief that AI video generation tools can significantly enhance their understanding of Newtonian physics [27]. For instance, students may find these tools beneficial in visualizing the trajectory of a projectile or the forces acting on an object, thereby rendering abstract concepts more tangible and comprehensible. Perceived ease of use, on the other hand, focuses on the degree to which students find the tools straightforward to use and integrate into their learning processes [28]. If the generation and manipulation of AI-powered visualizations are perceived as effortless, students are more likely to adopt and utilize these tools in their studies. Furthermore, the TAM framework also considers other external variables that may influence technology acceptance, including individual differences [29], social influences [30], and organizational factors [31].

TAM also incorporates *attitude toward using technology (ATU)* and *behavioral intention to use technology (BIU)* as integral components that facilitate the acceptance process [32]. *ATU* reflects students' overall positive or negative perceptions about utilizing AI generative tools in their learning. A favorable attitude, shaped by high perceived usefulness and ease of use, increases the likelihood of sustained engagement with the technology [33]. Likewise, *BIU* denotes students' intention to adopt and apply AI tools in their learning activities. A strong behavioral intention often leads to actual use, indicating a higher level of technology acceptance [34]. Furthermore, the *TAM* framework also considers external variables that may influence technology acceptance, including individual differences, social influences, and organizational factors. These elements interact with *PU, PEU, ATU, and BIU* to determine the overall adoption and sustained use of AI generative tools in physics education. Thus, incorporating these components, the study aims to provide a comprehensive understanding of the factors influencing students' acceptance of AI-powered learning technologies.

The *Constructivist Learning Theory* and the *Technology Acceptance Model* offer complementary perspectives on the use of AI generative tools in education. Constructivism explains how students actively construct knowledge and develop deeper conceptual understanding through interactive experiences with these tools [35]. Meanwhile, TAM focuses on the practical and psychological factors that influence students' willingness to adopt and engage with AI technologies [36]. Together, these frameworks support the study's goal of exploring the potential of AI generative media to enhance learning in physics. Integrating insights from both theories, the study can address the pedagogical, technical, and psychological dimensions of integrating AI tools into education, providing a holistic understanding of their impact on students' learning experiences and outcomes. This comprehensive approach ensures that both the cognitive and affective aspects of learning are considered, paving the way for thoughtful and effective AI integration in STEM education.

2. RESEARCH METHOD

The study employed a phenomenological, exploratory approach to investigate the impact of generative AI tools on female students' understanding and creativity in an all-girls Honors Physics class, focusing on Newtonian mechanics. Conducted during the second and third quarters of the 2024-2025 academic year, the research involved 17 participants, with parental consent obtained due to their minor status. The methodology was structured into three phases—preparatory, scaffolding, and post-discourse—each designed to assess students' experiences, perceptions, and learning outcomes when using AI-powered generative tools. Data collection included qualitative open-ended questions, quantitative Likert-scale questionnaires, and thematic analysis using NVivo software, with participant validation to ensure credibility. The study integrated Constructivist Learning Theory and the Technology Acceptance Model (TAM) to frame the investigation, focusing on how AI tools facilitate conceptual understanding and technology adoption in STEM education.

2.1. Preparation Phase

The preparatory phase established a baseline for students' prior knowledge, familiarity, and perceptions of AI generative tools. Open-ended questions were administered to explore their experiences and expectations, including:

- "Have you ever used AI tools or digital platforms (like video generators or image creators) in any way before? How would you describe your experience with them?"
- "What is your initial opinion on using AI tools to visualize complex physics concepts, like Newton's Laws? How do you think it could help or hinder your learning?"
- "Can you think of a time when you used or created a visual representation (such as a diagram, sketch, or video) to help explain or understand something in your learning? What was your experience like?"
  "If you were to imagine a digital tool that could assist you in learning physics, what would it look like? What features would you find most helpful?"

These questions elicited qualitative insights into students' familiarity with AI tools, their views on AI's potential in physics education, and their reliance on visual learning. Responses were analyzed using NVivo software to identify recurring themes and subthemes based on common keywords, followed by participant validation to confirm the trustworthiness of the findings. This phase provided a foundation for understanding students' initial attitudes and experiences, aligning with Constructivist Learning Theory's emphasis on building knowledge through prior experiences [18] [19].

2.2. Scaffolding Phase

The scaffolding phase introduced students to a diverse set of AI-powered generative tools through structured weekly instructional sessions and assignments, aligned with physics lessons on topics such as projectile motion, Newton's Laws, friction, and tension. Both open-source and paid AI applications were utilized to facilitate the creation of educational content, enabling students to visualize and explore complex physics concepts. Tools such as ChatGPT, Claude-AI, Copilot, Gemini, Perplexity, Squibler, Chatsonic, and TextCortex were employed for idea generation and scriptwriting, leveraging large language models (LLMs) to help students articulate physics concepts and develop coherent narratives for video presentations. For image generation, MidJourney, Stable Diffusion, ReMaker, Flux, and RenderNet were used to create visual representations, such as force diagrams or projectile trajectories, enhancing students' ability to visualize abstract ideas. ElevenLabs facilitated music and sound generation, producing background music and sound effects to enrich video engagement, while the combined use of ElevenLabs and HeyGen supported voice-over generation for clear narration. Video scene generation and editing were enabled by Filmora, StoryboardAI, Kling AI, Kaiber AI, Pika, and HeyGen, allowing students to compile images, voice-overs, and music into cohesive, dynamic video presentations that illustrated physics principles. These tools also supported interactive simulations and animations, enabling students to manipulate variables and observe real-time effects, thereby deepening their understanding through hands-on exploration. Instructional sessions systematically built proficiency, starting with tutorials on idea generation, followed by scriptwriting, image design, audio creation, and culminating in video production, all synchronized with physics curricula to ensure practical application. This approach aligns with Vygotsky's Zone of Proximal Development, where AI tools served as scaffolding to bridge the gap between students' existing knowledge and deeper conceptual mastery [22], [23]. After completing the tutorials and creating their content, students responded to the following reflective open-ended questions to evaluate their experiences:

- How did creating an AI-generated video enhance your understanding of Newtonian mechanics compared to traditional learning methods?
- What problems and challenges did you encounter when using AI tools to generate pictures, videos, and animations, and how did you address them?
- How did AI-generated images and animations help in explaining abstract physics concepts?
- In what ways did this project impact your creativity and critical thinking skills?
- Would you consider using AI video generation tools for future STEM projects? Why or why not?

These questions prompted students to reflect on the effectiveness of AI tools, challenges such as prompt misinterpretation or technical constraints, and the impact on their creativity and critical thinking. Responses were analyzed using NVivo software to identify key themes, including enhanced visualization, learning efficiency, and challenges in AI use, with participant validation ensuring the trustworthiness of the findings. The integration of diverse AI tools and reflective exercises supported Constructivist Learning Theory's focus on active knowledge construction through interactive, experiential learning [35].

2.3. Post-Discourse Phase

The scaffolding

The post-discourse phase evaluated students' self-assessments of their AI-generated content and perceptions of generative AI's role in physics learning through quantitative Likert-scale questionnaire[37]es based on the Technology Acceptance Model (TAM) [25]. These questionnaires, comprising positive and negative statements rated from Strongly Disagree to Strongly Agree, assessed students' experiences and attitudes. To ensure the validity of the questionnaire items in this qualitative study, data triangulation was employed, cross-referencing quantitative responses with qualitative data from the scaffolding phase's reflective questions. This triangulation strengthened the trustworthiness of findings by confirming consistency across data sources, a critical practice in qualitative research to enhance credibility and reduce bias [36], [37]. Specifically, themes identified in qualitative responses, such as improved conceptual clarity or challenges with AI usability, were mapped to corresponding questionnaire items, ensuring that the quantitative measures accurately reflected students' lived experiences. For instance, qualitative insights about AI's role in visualizing abstract concepts corroborated high ratings on items like "Generative media enhanced my understanding of physics," reinforcing content validity [38]. This approach aligns with recommendations for mixed-methods studies, where qualitative data contextualizes and validates quantitative instruments [39].

i. Self-Assessment of Generated Video Content: This questionnaire evaluated video quality and effectiveness with items such as: "My AI-generated video clearly explains my physics topic"; "My AI-generated video is confusing and hard to follow (-);" "My AI-generated video is visually engaging"; "My AI-generated video contains noticeable errors (-);" "The audio and visuals are well synchronized"; "The production quality of my video is poor (-);" "My AI-generated video is well organized and structured"; "My AI-generated video lacks depth in explaining the topic (-);" "My AI-generated video effectively highlights key physics points"; and "My AI-generated video fails to capture my interest (-)." These items assessed clarity, engagement, and accuracy, validated through qualitative reports of video creation experiences.
ii. Self-Assessment of Learning Physics Concepts with Generative AI: This questionnaire measured AI's impact on conceptual understanding with items including: "I feel confident about physics concepts explained via generative media"; "Generative media left some physics concepts ambiguous (-);" "Generative media enhanced my understanding of physics"; "I struggle to apply physics concepts taught via generative media (-);" "Generative media clarified key physics principles effectively"; "The use of generative media did not boost my problem-solving skills in physics (-);" "I can easily explain physics concepts learned through generative media"; and "Generative media failed to help me fully grasp the physics content (-)." Qualitative reflections on conceptual gains corroborated these items, ensuring their relevance.
iii. Modified TAM Questionnaire: Tailored from Davis (1989) [25][40], this questionnaire assessed Perceived Usefulness (PU), Perceived Ease of Use (PEU), Attitude Toward Using (ATU), and Behavioral Intention to Use (BIU), with balanced positive and negative items for validity [29][32]:
    a. Perceived Usefulness (PU): "Generative AI deepens my physics understanding"; "AI provides little insight into complex physics problems (-);" "AI tools boost my learning efficiency in physics"; "Using AI does not improve my grasp of physics (-);" "Using AI enhances the value of my physics education"; "AI has minimal impact on my physics learning (-)."

b. Perceived Ease of Use (PEU): “I find AI tools easy to use for physics”; “Using AI for physics is often confusing (-);” “Learning physics with AI is intuitive”; “AI tools for physics are difficult to navigate (-);” “Interacting with AI for physics is straightforward”; “I struggle with the AI interface in physics applications (-).”
c. Attitude Toward Using (ATU): “I feel positive about using AI for physics”; “I am uneasy relying on AI for physics (-);” “AI makes physics learning engaging”; “AI in physics makes learning impersonal (-);” “I enjoy exploring physics with AI tools”; “I doubt the benefits of AI in physics education (-).”
d. Behavioral Intention to Use (BIU): “I intend to use AI for my physics studies”; “I prefer traditional methods over AI in physics (-);” “I will regularly use AI to enhance my physics learning”; “I am unlikely to recommend AI for physics education (-);” “I plan to incorporate AI into my physics coursework”; “I do not plan to use AI for future physics learning (-).”

Qualitative data from the scaffolding phase, detailing students’ perceptions of AI’s usability and effectiveness, validated these TAM items, ensuring they captured authentic experiences [36]. Quantitative data provided insights into AI’s perceived effectiveness and usability, while triangulation with qualitative responses confirmed themes like enhanced visualization and usability challenges, aligning with TAM’s framework [25][33].

3. RESULTS AND DISCUSSION

3.1. Preparation Phase

The preparatory phase of the study analyzed quantitative and qualitative data to evaluate students’ comprehension of Newtonian concepts, their utilization of AI tools, and their preferred learning methods. Employing data triangulation, the findings underscored key themes and ensured reliability. Quantitative self-assessments indicated that students possessed moderate confidence in their grasp of Newtonian principles, suggesting a basic understanding yet challenges in practical application. Similarly, their familiarity with AI tools was confined to rudimentary or exploratory levels. Conversely, students exhibited a proactive stance toward mastering complex concepts, engaging in strategies such as discussions, real-world example exploration, and supplementary resource use. However, their digital creativity and skills were limited to proficiency with basic tools, lacking advanced capabilities for problem-solving or conceptual visualization. These results laid the groundwork for identifying student needs and exploring the potential of customized digital tools to bridge learning gaps.

Thematic Analysis of Qualitative Data

The first major theme to emerge, "***Understanding and Application of Newton's Laws of Motion***," reflects students’ conceptual understanding and ability to link Newton’s Three Laws to real-life contexts, a theme that surfaced due to the study’s focus on assessing foundational physics knowledge and the observed need for practical application as students frequently encountered these laws in both theoretical and everyday settings. While most participants demonstrated a foundational knowledge of these laws, many highlighted the necessity for additional practice and visualization to fully assimilate and apply them. Within this theme, the subtheme "Awareness of the Laws" emerged from students’ consistent ability to recall and explain the laws, coupled with their expressed need for reinforcement, as they displayed a robust theoretical grasp of Newton’s Laws of Motion, capable of articulating precise definitions and distinctions. Nevertheless, many recognized a need for further practice and hands-on engagement to bolster confidence in problem-solving and quantitative tasks, with one student noting, “*I understand Newton’s 3 Laws of Motion: an object at rest remains at rest or an object in motion remains in motion unless acted upon by an external force,” evidencing a clear theoretical foundation, while another remarked*, “*One example that I have become hyper aware of is when I am pushing the mop bucket across my house*,” indicating growing awareness of these principles in daily activities, suggesting that while students possess a solid base, they require repeated practice and contextual application to enhance their skills. The second subtheme, "Application in Daily Life," surfaced as students naturally related physics to routine activities, reflecting their intuitive engagement with the subject matter, as they readily associated Newton’s Laws with everyday experiences, drawing insightful connections between theory and personal observations, with one student explaining, “*I experience these ideas when I drive my car... for example, when I am driving at a steady speed, the car will continue moving unless I apply a force like pressing on the brake*,” illustrating an understanding of inertia, which emphasizes the value of experiential learning in fostering an intuitive grasp of physical phenomena.

The second major theme, "***Importance of Visual Learning***," underscores students’ dependence on visual aids to comprehend and retain complex physics concepts, a theme that emerged due to the students’ frequent emphasis on visual tools as a critical factor in overcoming the abstract nature of physics, aligning with pedagogical research on visual learning efficacy. The subtheme "Visual Learning and Representation" arose from the students' expressed reliance on and proactive creation of visual aids to enhance comprehension, as they favored visual methods, such as diagrams, sketches, and simulations, to make abstract concepts more accessible, with one student stating, "*I think it would be very helpful as I am a visual learner*," highlighting this preference, and another adding, "*A visual learner can benefit from seeing the concepts applied in action rather than just hearing about them*," reinforcing the role of visual aids in retention. Additionally, students proactively created their own representations, with one noting, "*Just today, I created a sketch that represented a process for muscle contraction in my Anatomy and Physiology class. Drawing it out really helped me grasp the details of the mechanism better*," though limitations were acknowledged, as one student commented, "*Because it is AI and not hands-on, it might take a little longer to understand though*," suggesting that integrating hands-on activities with visual tools optimizes learning outcomes.

The third major theme, "***Cautious Use of AI Tools for Learning***," reveals students' recognition of AI as a beneficial educational resource, tempered by concerns about its limitations, a theme that emerged from the study's exploration of emerging technologies and the students' mixed reactions to AI, reflecting a balance between innovation and skepticism. The subtheme "Concerns About AI Limitations" surfaced as students weighed the benefits against potential drawbacks, indicating a critical approach to technology adoption, as they appreciated AI's potential for dynamic visualizations but expressed worries about over-reliance, oversimplification, and accuracy, with one student observing, "*If the AI oversimplifies or doesn't match the level of detail needed, it might leave gaps in understanding*," reflecting a desire for comprehensive content, another voicing, "*It could hinder my learning because I would probably tend to rely on it more*," indicating a concern about dependency, and a third noting, "*I think it can help visually, but it also might be inaccurate*," underscoring the need for validated AI outputs to maintain scientific integrity. Figure 1 presents a mind map summarizing the themes and subthemes, providing a visual overview of the preparatory phase findings.

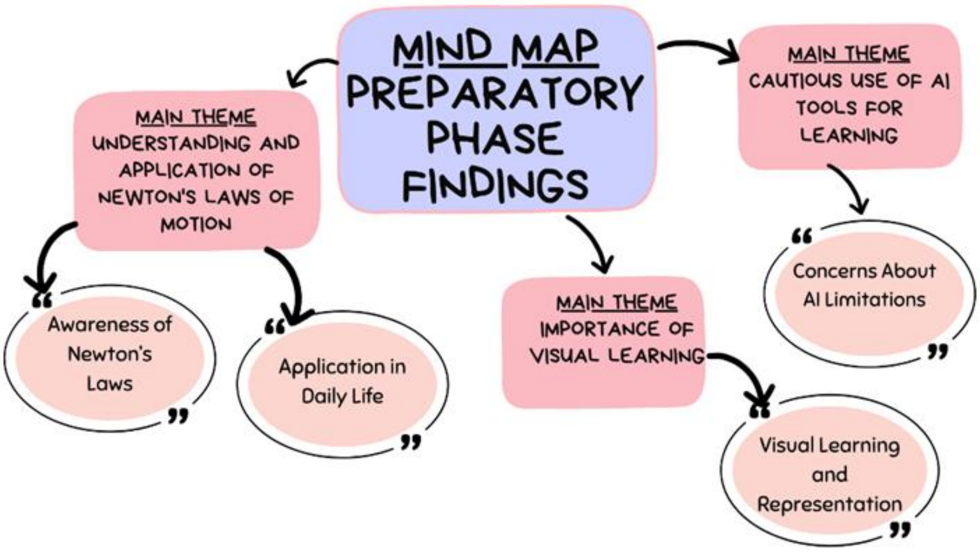

Figure 1. Themes in Preparatory Phase

Data Triangulation of Preparatory Phase

The triangulation of qualitative and quantitative data enhances the credibility and trustworthiness of the findings by establishing a coherent relationship between students' self-reported experiences and their measured competencies, as detailed in Table 1 below. The mean scores for each variable provide a nuanced perspective on students' capabilities and tendencies. For instance, the moderate confidence levels in "Confidence in Understanding Newtonian Concepts" (mean = 2.75, SD = 0.36) and "Perspectives and Comfort with AI Tools" (mean = 2.76, SD = 0.56) indicate a general grasp of fundamental principles and limited familiarity with AI tools, respectively, suggesting a need for further development to apply knowledge effectively in practical contexts. This points to the necessity for instructional strategies that emphasize both conceptual mastery and hands-on problem-solving. Similarly, the "Approach to Learning Complex Concepts" variable (mean = 3.40, SD = 0.40) reflects a proactive learning approach, indicating active engagement, though additional structured guidance and practice opportunities could optimize their analytical and problem-solving skills. This aligns with qualitative insights highlighting students' desire for practical application and real-world connections to deepen their understanding. In contrast, the "Digital Creativity and Skill Development" variable (mean = 2.80, SD = 0.36) reveals proficiency with basic digital tools but a lack of advanced skills, underscoring the potential for tailored digital interventions to address these gaps.

Table 1. Baseline understanding of the participants' perceptions

Variable Name	mean	sd
Confidence in Understanding Physics Concepts	2.75	0.36
Perspectives and Comfort with AI Tools	2.76	0.56
Approach to Learning Complex Concepts	3.40	0.40
Digital Creativity and Skill Development	2.80	0.36
N=17		

The first major theme, "Understanding and Application of Newton's Laws of Motion," corresponds with the quantitative variables "Confidence in Understanding Newtonian Concepts" and "Approach to Learning Complex Concepts," where moderate confidence and a proactive approach (mean = 2.75 and 3.40, respectively) suggest a foundational understanding tempered by a need for enhanced application. This theme emerged due to the study's emphasis on assessing core physics knowledge and the observed demand for practical engagement. The subtheme "Awareness of the Laws" arose from students' ability to articulate Newton's Laws theoretically, yet their expressed need for practice to boost problem-solving confidence complements the quantitative data, indicating that while students grasp basics, they require further support to apply these concepts independently. The subtheme "Application in Daily Life" surfaced as students linked laws to real-world scenarios (e.g., driving or mopping), reflecting intuitive engagement, though their moderate confidence levels suggest that structured guidance is needed to fully leverage these connections for problem-solving.

The second major theme, "Importance of Visual Learning," aligns with the "Approach to Learning Complex Concepts" variable (mean = 3.40, SD = 0.40), indicating a proactive yet improvable learning strategy, and emerged from students' frequent reliance on visual tools to navigate abstract physics concepts. The subtheme "Visual Learning and Representation" developed from their preference for and creation of visual aids (e.g., diagrams, sketches), with one student noting, "I think it would be very helpful as I am a visual learner," and another stating, "Just today, I created a sketch that represented a process for muscle contraction… Drawing it out really helped me grasp the details," reflecting active engagement. However, the moderate confidence (mean = 2.75, SD = 0.36) and a student's comment, "Because it is AI and not hands-on, it might take a little longer to understand though," suggest that while visual methods are effective, integrating hands-on activities could enhance their impact.

The third major theme, "Cautious Use of AI Tools for Learning," is supported by the "Perspectives and Comfort with AI Tools" and "Digital Creativity and Skill Development" variables (means = 2.76 and 2.80, respectively), reflecting moderate confidence, and emerged from the study's investigation into technology use alongside students' mixed reactions. The subtheme "Concerns About AI Limitations" arose from their cautious stance, with one student observing, "If the AI oversimplifies or doesn't match the level of detail needed, it might leave gaps in understanding," and another noting, "I think it can help visually, but it also might be inaccurate," highlighting concerns about oversimplification, accuracy, and dependency. This aligns with the quantitative data, suggesting that while students recognize AI's potential, they need guidance to use it effectively without compromising critical-thinking skills.

3.2. Scaffolding Phase

During the scaffolding phase, participants were given access to a suite of AI-enhanced tools aimed at strengthening their comprehension of Newtonian physics. These interventions included AI-powered tutoring videos that instructed students on utilizing generative media tools capable of automatically creating visualizations of physics concepts. Additionally, interactive simulation environments were made available, allowing students to manipulate variables and observe real-time effects. Reflective journal questions were assigned to students to document and evaluate their experiences. The following themes and subthemes emerged from the students' journal entries.

The first major theme from the Scaffolding Phase was ***"Enhanced Understanding Through Visualization".*** This highlights how AI tools made abstract physics concepts more accessible to students, especially in STEM fields where theoretical ideas can be challenging. Participants reported that AI-generated images and animations were helpful in clarifying difficult topics. A key subtheme was Clarification of Abstract Concepts, emphasizing how AI-assisted visuals broke down complex ideas like motion and forces into more understandable formats. One student said *"AI-generated images and animations helped explain abstract physics concepts by translating them into visual aids. Seeing these concepts as real-world examples assisted me in understanding and applying them."* Another stated *"It helped me comprehend complex concepts by providing me with visual presentations. It offers a refinement of knowledge, making things clearer."* These responses show that AI-generated visuals not only support comprehension but also aid students in reinforcing their knowledge. The ability to visualize abstract principles leads to improved retention and application, reducing cognitive load and making physics more approachable, especially for learners who struggle with conceptualization.

The second key subtheme, *"Practical Application of Physics,"* highlighted how AI-enabled tools helped students connect theoretical knowledge to their everyday lives. One student explained that *"Creating an AI-generated video enhanced my understanding by allowing me to see how my ideas can be transformed into something creative and educational."* This shows how AI promotes active learning by engaging students beyond just textbooks. Another participant shared that *"It helped me better understand Newton's Third Law of Motion. Before using AI, I couldn't apply the law to daily activities, but now I have a clearer grasp of how it works."* This suggests that AI scaffolding fosters a deeper conceptual connection by helping learners recognize the relevance of physics in their daily lives. Finally, one student expressed, *"AI converted an abstract concept into a visual one. Physics concepts like projectile motion can feel overly theoretical, but seeing the ball's path in action... It broke down the idea into smaller, more understandable parts."* This demonstrates how AI-driven visualization aids in making complex concepts more accessible, facilitating student comprehension and learning.

The second key theme from the Scaffolding Phase was the ***"Role of AI in Learning Efficiency"***. This shows how AI tools made the learning process more efficient and accessible. Students said the AI-powered tools saved time, made content creation easier, and allowed them to focus on understanding physics concepts rather than spending too much time on traditional methods. Within this theme, *Timesaving and Accessibility* emerged as a crucial sub-theme. Students reported that AI tools enabled them to rapidly generate educational materials, streamlining the process of initiating projects or research tasks. As one participant noted, *"AI tools can generate outcomes within seconds, making it easy to get started on a project or research without delay."* Another student shared, *"It was a straightforward experience, and not as stressful once I understood what I needed to do. The only challenging aspect was converting the files for submission."* Additionally, another response highlighted, *"Using AI tools made it easier to express these concepts compared to traditional methods because it is faster and it is easier to get more detail."* These accounts suggest that AI-driven scaffolding significantly mitigates time constraints in STEM learning by providing immediate access to relevant materials. This efficiency allows students to devote more attention to refining their understanding rather than being hindered by the process of manually creating resources.

Another key sub-theme, "*Overcoming Traditional Learning Constraints*," highlighted how AI tools provided an alternative to conventional learning methods, such as textbooks and hand-drawn diagrams, by offering dynamic and interactive visual aids. As one student explained, *"It made it easier to visualize when the prompts got the vision correct. When the prompt was misinterpreted though, it was a bit hard trying to determine how I could make my prompt clearer."* This statement suggests that while AI can enhance comprehension, the accuracy of AI-generated content depends on the user's ability to refine prompts. Another participant shared, *"Creating an AI-generated video helped explain complex concepts related to physics. Creating the script not only allowed me to practice making specific prompts, but it explained the physics concepts of my topic."* This highlights how AI tools not only assist in visualization but also enhance critical thinking by requiring students to structure their ideas effectively. However, a third student expressed concern about the reliance on AI, stating, *"I found it really useful, but I felt a little guilty since it felt like I was replacing my teacher. AI tools definitely make the learning process easier, but it should never serve as a substitute for traditional learning."* This reflection implies that while AI facilitates learning, students still value human instruction and recognize the need for a balanced integration of AI and traditional teaching methods.

The third emergent theme in the Scaffolding Phase, ***Challenges in Using AI for Learning***, underscores the difficulties students encountered while integrating AI tools into their physics education. Although AI proved beneficial in enhancing learning, participants grappled with issues like misinterpreted prompts, misaligned outputs, and concerns regarding over-reliance on technology. These challenges necessitated that students refine their approaches and critically evaluate the role of AI in their learning process. Within this theme, the issue of prompt misinterpretation emerged as a key challenge, highlighting the difficulties students faced in generating accurate AI outputs due to the need for precise and detailed prompts. One participant noted the challenge of finding freely accessible AI platforms, stating, *"The biggest challenge was finding AI websites and platforms that were completely free. Many require subscriptions for unlimited use, but to solve this problem, I used another AI source to search for free video platforms."* This underscores prompt-related issues and concerns regarding the accessibility of AI tools. Another student explained the learning curve associated with prompt engineering, a critical skill for effectively utilizing AI tools, stating, *"The main challenge I faced was writing a very specific, detailed prompt for my AI video generator. In the beginning, my prompt only consisted of my script, so the first few generated videos featured nothing relevant but a voiceover."* Additionally, a participant reflected on the iterative nature of using AI tools, noting, *"It was a tedious task in being specific to get the results that I wanted. I have also never really used AI to produce something, so it was a bit interesting as a first-time user."* This suggests that while AI tools offer new learning opportunities, novice users may experience difficulties in achieving desired outputs, necessitating refinement and experimentation.

Another critical sub-theme, *Over-Reliance on Technology*, reflects participants' concerns that excessive dependence on AI might undermine critical thinking and hands-on learning. One student remarked, *"I think AI tools are a great way of generating new ideas that have never been thought of before, and for the most part, it is* *still your work since you still need to do the STEM project itself."* This response suggests that AI serves as creative aid but should not replace active engagement in STEM projects. Another participant expressed a balanced perspective, stating, *"I think AI can be incredibly helpful by enhancing presentation and comprehension of the material. However, I believe it is efficient for visual comprehension but also very limiting in terms of applying your learned knowledge if you fully rely on it."* This highlights the importance of using AI as a supplementary tool rather than a primary means of learning. Lastly, one participant conveyed skepticism, stating, *"The reliance on pure AI still makes me skeptical, especially with an area so trivial like STEM."* This response indicates that while AI can enhance understanding, some students are cautious about its implications for deep learning and problem-solving skills.

The fourth theme, ***"Creativity and Critical Thinking"***, shows how AI tools helped students think creatively and solve problems effectively. Using AI-generated outputs encouraged students to create precise prompts, try different approaches, and refine their ideas. This improved their understanding and enhanced their problem-solving skills, which are crucial in STEM education. Within this theme, the sub-theme of Encouraging New Perspectives emerged. Using AI tools allowed students to approach problems from fresh angles and develop innovative solutions. For example, one student said, *"This project helped expand my creativity and critical thinking by finding ways to access AI platforms without paying."* This shows the students' ability to navigate technological and financial constraints, demonstrating their adaptability in problem-solving. Another student reflected, *"The project pushed me out of my comfort zone, making me think outside the box, since this was my first-time using AI tools."* This illustrates how integrating AI challenged students to explore unfamiliar digital tools, fostering a mindset of exploration and experimentation. Furthermore, one participant noted, *"This project really boosted my creativity and critical thinking. Using AI tools to generate images and animations made me think outside the box to represent complex physics concepts visually."* This indicates that using AI-generated visuals enabled students to conceptualize abstract ideas in novel ways, reinforcing AI's role in stimulating creative thought.

Another critical sub-theme was "*Problem-Solving as an AI Tool*". This highlights how students developed critical thinking skills while addressing challenges when using AI tools. Participants had to refine their inputs, experiment with different prompts, and adjust their expectations to get meaningful outputs. As one student explained, *"It required me to specifically outline the visual imagery for the background to ensure a better-quality video."* This underscores the importance of precision in AI-assisted content creation. Another participant stated, "I had to adjust the prompts and retry several times to get the exact concept visualization I wanted. It really taught me to be more specific in my communication." This demonstrates how AI tools encourage students to carefully consider their language and refine their ability to articulate complex ideas effectively. Additionally, a participant noted, "The process of putting this into a narrative allowed me to see the relationship between the angle of the slope, the normal force, and the friction force more clearly." This suggests that engaging with AI tools enabled students to bridge conceptual gaps and visualize interconnections between different physics principles.

The fifth emergent theme in the Scaffolding Phase, ***AI's Role in STEM Education*****,** highlights the transformative potential of AI tools in facilitating STEM learning while also raising concerns about their ethical and pedagogical implications. Participants acknowledged that AI enhances comprehension by breaking down complex scientific principles into more digestible formats. However, they also expressed apprehensions regarding over-reliance on AI, which could impact creativity and critical thinking. The sub-theme *AI as an Effective Educational Tool* emphasizes the role of AI in simplifying STEM concepts, making them more accessible to various learners. One participant noted, "AI tools can make STEM content more accessible to students with different needs. These tools can generate summaries, explanations, or alternative descriptions of complex STEM concepts." This suggests that AI can provide personalized learning experiences, meeting different learning styles and abilities. Another student shared, "AI tools are helpful for STEM topics. They're great at simplifying technical concepts and turning them into visuals or examples." This demonstrates AI's ability to complement traditional teaching by offering dynamic visuals that enhance understanding. Furthermore, a participant stated," AI makes complex ideas easier to understand than just reading about them. Seeing a visual of Newton's Third Law or a chemical reaction makes it much easier to understand." This highlights AI's effectiveness in connecting abstract theories and practical applications, promoting deeper learning.

The sub-theme of Ethical and Pedagogical Concerns highlights the potential downsides of using AI in education. A participant noted that while AI is user-friendly and offers various applications, there is a risk of misuse, such as using it for assignments, which could reduce student creativity. This raises critical ethical issues around AI's impact on academic integrity and originality. Although AI can be a helpful learning tool, there is a danger of students becoming overly reliant on it, potentially hindering their engagement in meaningful learning processes. Figure 2 presents a mind map summarizing the themes and subthemes, providing a visual overview of the preparatory phase findings.

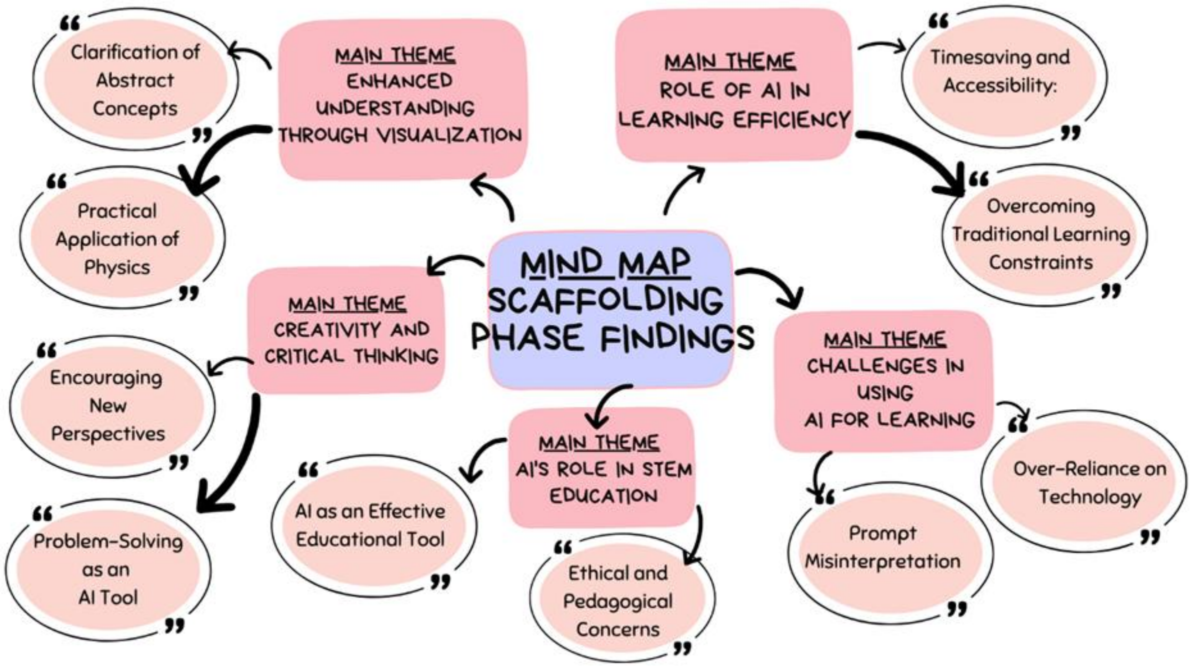

Figure 2. Themes of Scaffolding Phase

3.3. Post-Discourse Phase

The Post-Discourse Phase of the study aimed to assess the self-evaluation of the respondents on their AI-enhanced learning experience and generated content on the application of Newtonian physics principles. Furthermore, this section assessed how the respondents perceived the use of generative AI in learning physics based on the indicators of the Technology Acceptance Model framework. The results of this section were used to validate the main themes and sub-themes that were generated in the scaffolding phase.

Based on the data presented in Table 2, the respondents generally had a positive assessment of their experience with generative AI tools in learning physics concepts. The mean score for their self-assessment of the generated video content was 3.37, with a standard deviation of 0.48, indicating that the participants were generally satisfied with the quality of the AI-generated materials. This suggests that the respondents found the AI-powered tools to be effective in helping them create visually engaging and informative content related to Newtonian physics principles. Similarly, the mean score for their self-assessment of learning physics concepts with generative AI was 3.22, with a standard deviation of 0.47. This moderately positive evaluation implies that the respondents perceived the use of generative AI tools to be somewhat helpful in facilitating their understanding of complex physics topics. The perceived usefulness of the generative AI tools had a mean of 3.27 and a standard deviation of 0.50, further corroborating the participants' belief that these AI-powered applications were moderately useful in supporting their physics learning.

The respondents also found the generative AI tools to be moderately easy to use, with a mean perceived ease of use score of 3.29 and a standard deviation of 0.52. This suggests that the participants were able to navigate and leverage the AI-based tools without significant technical barriers, which likely contributed to their overall positive experience. The respondents' attitude towards the use of generative AI had a mean of 3.25 and a standard deviation of 0.61, indicating a somewhat positive inclination towards these technologies. However, the behavioral intention to use generative AI in the future had a mean of 2.93 and a standard deviation of 0.67, suggesting a more moderate intention to continue utilizing the AI tools. This may reflect the respondents' cautious approach to fully embracing generative AI, potentially due to lingering concerns about its long-term implications or a preference for more traditional learning methods.

Table 2. Participant’s Experiences in Using AI Tools

Variables	mean	sd
Self-Assessment of Generated Video	3.37	0.48
Self-Assessment of Learning Physics with AI	3.22	0.47
Perceived Usefulness of Generative AI	3.27	0.50
Perceived Ease of Use of Generative AI	3.29	0.52
Attitude towards the use of Generative AI	3.25	0.61
Behavioral Intention to Use Generative AI	2.93	0.67
N=17		

The positive evaluations of the respondents' self-assessment, perceived usefulness, and ease of use of the generative AI tools, as well as their somewhat positive attitude towards the technology, provide data triangulation that supports the main theme of "Enhanced Understanding Through Visualization" and the subtheme of "AI's Role in Learning Efficiency" identified in the Scaffolding Phase. The respondents' satisfaction with the quality of the AI-generated materials and their perception of the tools as moderately useful and easy to use align with the findings that AI-generated images and animations can clarify abstract ideas and streamline content creation to aid student learning

Additionally, the moderately positive evaluations of the respondents' self-assessment of learning physics concepts with generative AI, as well as their perception of the tools as moderately useful and moderately easy to use according to the data in Table 2, provide data triangulation that supports the main theme of "AI's Role in Learning Efficiency" and the subtheme of "Challenges in Using AI for Learning" identified in the Scaffolding Phase. This suggests that while the respondents found the AI-powered tools helpful in improving their learning efficiency by streamlining content creation and providing visualizations, they also encountered challenges that required them to refine their critical thinking skills. The respondents recognized that over-reliance on AI could potentially lead to a lack of deep understanding, as the tools may not fully capture the complexities and problem-solving skills necessary for mastering complex physics concepts.

The respondents' more cautious behavioral intentions to use generative AI in the future indicate that they recognized the potential limitations or risks associated with over-reliance on these technologies, aligning with the subtheme of "Ethical Considerations of AI Use" identified in the Scaffolding Phase. They acknowledged that while AI can enhance learning efficiency, it is essential to maintain a balance between AI-powered tools and traditional instructional methods to ensure the development of critical thinking, creativity, and academic integrity. The respondents' moderate intention to use generative AI in the future suggests a careful and thoughtful approach to integrating these technologies, reflecting an understanding that AI should supplement, rather than replace, active learning and rigorous problem-solving in physics education. Furthermore, the respondents' somewhat positive attitude towards the use of generative AI and their moderate intention to use these tools in the future provide data triangulation that supports the main theme of "Creativity and Critical Thinking Development" identified in the Scaffolding Phase. This indicates that the respondents recognized the potential of AI to foster creativity and critical thinking but also maintained a cautious approach to fully embracing technology.

The findings of this study demonstrate that generative AI tools significantly enhance students' comprehension of Newtonian mechanics by providing interactive visualizations and streamlining the learning process. During the preparatory phase, students exhibited a foundational understanding of physics concepts but struggled to apply them to real-world scenarios. AI-assisted learning bridged this gap by offering dynamic visual representations, such as simulations and animations, which helped students conceptualize abstract principles more effectively. This aligns with Vygotsky’s Zone of Proximal Development, where AI serves as a scaffold, guiding students from basic comprehension to deeper understanding with minimal intervention [41] [42]. Recent studies support these findings; Al-kfairy noted that AI-driven visualizations enhance STEM learning by making abstract concepts more tangible, improving engagement and retention [36]. Similarly, Chen et al. found that AI-generated multimedia significantly reduces cognitive load in physics education, facilitating deeper conceptual understanding and improved problem-solving abilities [43]. This study's novelty lies in its focus on an all-girls Honors Physics class, addressing a significant gap in existing literature by examining how generative AI influences female students’ engagement with physics, a discipline in which women continue to be historically underrepresented. Few studies to date have explored gender-specific responses to AI-generated physics resources, making this research essential to understanding how AI tools can support the engagement and identity development of female learners in STEM [44]. By employing a diverse suite of AI tools tailored to tasks like scriptwriting, image generation, and video production, this study offers a unique, gender-specific perspective on AI’s role in STEM education, contributing to the discourse on equitable technology integration.

The efficiency of AI tools enabled students to focus on problem-solving rather than labor-intensive tasks like creating diagrams or searching for resources, thereby enhancing engagement with complex STEM content [45]. However, challenges such as AI-generated misinformation, prompt misinterpretation, and potential over-reliance on automation highlight the need for structured AI literacy education to ensure effective use.This need for AI literacy seamlessly connects to the broader implications for integrating generative AI into STEM education. By converting abstract concepts into concrete visual depictions, AI tools enhance comprehension and retention, particularly for complex principles in physics and engineering. For instance, AI-generated simulations can render Newtonian mechanics more accessible, aligning with the Cognitive Theory of Multimedia Learning, which posits that combining verbal and visual elements significantly improves information retention [46]. Integrating these visualizations into STEM curricula can transform curriculum development, educational technologies, and teaching pedagogies by leveraging the human brain’s visual processing capabilities. This fosters more engaging and effective learning experiences, potentially driving the evolution of educational software and immersive learning environments [47]. Educators can design innovative teaching methods that incorporate AI visualizations to support deeper understanding, ultimately empowering students to grasp challenging subject matter with greater clarity.

The process of engaging with generative AI also promotes critical thinking and creativity through prompt engineering. Students and teachers must learn to craft precise prompts to generate accurate AI outputs, fostering skills essential for STEM fields. This interactive process encourages experimentation with diverse problem-solving strategies, aligning with constructivist learning theories that emphasize active knowledge construction through exploration [48]. By refining prompts and evaluating AI-generated outputs, learners cultivate creativity and critical thinking, enabling them to devise novel solutions to STEM challenges. This active engagement with AI tools not only enhances cognitive skills but also prepares students for real-world problem-solving, where iterative exploration is often necessary. However, effective AI integration requires a robust foundation in AI literacy to address challenges like misinformation and over-reliance. Educational programs must prioritize teaching students to critically evaluate AI-generated content and understand the underlying mechanisms of AI tools. This aligns with the Technology Acceptance Model, which suggests that perceived usefulness and ease of use drive technology adoption [49]. Intuitive, user-friendly AI interfaces, coupled with adequate training for students and teachers, can enhance acceptance and effective use.

Yet, educators must emphasize critical analysis of AI outputs, as generative AI is prone to errors, particularly when users lack a strong grasp of the STEM concepts being explored [50]. By fostering AI literacy, educational systems can empower students to use AI judiciously, mitigating risks of misinterpretation and ensuring informed decision-making. This cautious approach to AI integration challenges the Technological Determinism Theory, which assumes that technological advancements inherently lead to improved educational outcomes [51]. The study’s findings strongly indicate that users’ ability to critically evaluate information, the availability of guided instruction, and their skill in writing clear prompts significantly influence how effective AI tools are. Students’ moderate intention to continue using AI reflects a balanced understanding of its benefits and risks, such as over-reliance and a potential decrease in problem-solving skills if not supervised. While AI can help by simplifying tasks like gathering and organizing information, using it too much might hinder deep learning, weakening students’ ability to argue and think critically [52].

A balanced and supervised approach to artificial intelligence integration in education is essential to preserve students' capacity for active learning, critical thinking, and human interaction. While AI offers promising support for content delivery and administrative efficiency, it should be viewed as a supplementary tool, not a replacement for human-led instruction and social learning environments. Kamali et al. [53] highlights the diverse ethical concerns educators face when implementing AI tools and emphasizes the need for collaborative frameworks that uphold the human-centric role of teaching. Similarly, Bako [54] asserts that the ethical use of AI in schools must be grounded in privacy, transparency, and sustained human oversight, warning against over-reliance on automated systems that may erode learners’ critical engagement and decision-making skills. In support of this, Varghese et. al. [55] advocates for hybrid instructional models that combine AI-generated assistance with hands-on tasks and interpersonal collaboration to unleash learners’ full cognitive and social potential. In synthesis, these academics collectively maintain that AI ought to be deliberately managed to augment, rather than substitute, the core tenets of education, including human autonomy, substantive discourse, and rigorous investigation.

As a short-term recommendation, the study’s findings suggest immediate opportunities to integrate generative AI tools into high school physics curricula to enhance female students’ engagement and understanding of Newtonian mechanics. Using AI to create interactive visualizations and personalized explanations can reduce cognitive barriers and foster creativity. This approach is supported by recent research highlighting the benefits of AI-generated multimedia in lowering cognitive load and improving conceptual learning in physics [56]. For instance, Lademann et al. found that integrating AI-driven chatbots into physics instruction significantly improved learning performance, reduced cognitive load, and increased students’ interest, confidence, and perceived competence [56]. Moreover, structured AI literacy training is essential to mitigate issues such as prompt misinterpretation and overreliance on AI outputs. This aligns with emerging scholarship emphasizing the need for critical AI literacy to ensure equitable, meaningful student engagement with generative technologies [57], [58]. While the broader implications require long-term research, these interventions offer an actionable framework to address underrepresentation and foster early interest in STEM among female learners.

In the long term, this study supports a major shift in STEM education, positioning generative AI as a regular tool for visualizing concepts and solving problems. The demonstrated efficacy of AI in enhancing female students’ creativity and confidence suggests potential to increase female representation in physics, addressing systemic underrepresentation. Educational systems should invest in AI literacy frameworks and teacher training programs to ensure sustainable integration, as recommended by Al-kfairy [36]. The study’s use of diverse AI tools in a cohesive curriculum could inform the development of educational software combining language, image, and video generation for interdisciplinary STEM learning. This aligns with Cukurova’s vision for hybrid AI–human intelligence systems that tightly integrate multimodal AI capabilities with human cognition and pedagogy [59]. By fostering critical thinking and creativity, AI integration could prepare students for STEM careers where technology proficiency is paramount, contributing to a more equitable and innovative workforce.

The study has several limitations that constrain its findings. First, the small sample size of 17 female students in a single all-girls Honors Physics class limits generalizability to broader populations or co-educational settings, necessitating future research with larger, diverse cohorts to validate findings across genders and educational contexts. Second, the current focus on Newtonian mechanics may not reflect AI's efficacy in teaching other physics domains such as electromagnetism or thermodynamics [60], suggesting that expanding the scope could strengthen generalizability and applicability of results, as supported by recent physics education research reviews. Third, reliance on specific AI tools may introduce bias, as tool performance varies, and access to paid tools may not be universally feasible, potentially exacerbating inequities [61]. Finally, the short duration of the study limits insights into long-term outcomes such as retention or career impacts, indicating that longitudinal studies, as recommended by recent analyses, could provide deeper insights into sustained AI use [62].

4. CONCLUSION

This phenomenological study reveals the profound potential of generative AI tools to revolutionize physics education. The findings strongly indicate that AI-generated visualizations significantly boost students' grasp of abstract concepts and streamline the learning process, while also cultivating creativity and critical thinking, aligning seamlessly with Constructivist Learning Theory and the Technology Acceptance Model. Initial preparations showed students possessed a solid grasp of physics principles and expressed cautious optimism about AI tools, though they harbored concerns regarding accuracy and over-reliance. During the scaffolding phase, AI tools effectively supported students within Vygotsky's Zone of Proximal Development, enabling them to connect theoretical knowledge with practical applications through interactive visualizations. Nevertheless, challenges such as prompt misinterpretation and ethical considerations surrounding dependency underscore the critical need for AI literacy and a balanced integration with traditional pedagogical approaches. The post-discourse phase confirmed students' positive perceptions of AI's usefulness and ease of use, although their moderate intention to continue utilizing these tools suggests a prudent approach to full adoption. These results challenge the core tenets of Technological Determinism Theory, emphasizing that the true efficacy of AI in education is contingent upon guided instruction, rigorous critical evaluation, and alignment with established cognitive and pedagogical frameworks. Ultimately, this study compellingly demonstrates that generative AI holds immense promise for STEM education, provided it is implemented with a nuanced strategy that prioritizes enhancing, rather than replacing, critical thinking and hands-on learning.

Future research should rigorously examine the longitudinal impact of generative AI integration across a wider spectrum of STEM disciplines and diverse student demographics to effectively gauge its scalability and generalizability. Investigating the specific role of AI literacy programs in proactively mitigating challenges like prompt misinterpretation and over-reliance could yield invaluable insights into optimizing student engagement with AI tools. Furthermore, conducting comparative studies that assess the efficacy of AI-generated visualizations against traditional teaching methods in co-educational settings or across varying academic levels would substantially deepen our understanding of its contextual effectiveness. Researchers also need to investigate the ethical issues of AI in schools, like data privacy, bias, and honesty in schoolwork, to create clear rules for using it. Finally, exploring the synergistic integration of AI tools with other cutting-edge technologies, such as virtual reality or augmented reality, holds the potential to unveil innovative pathways for creating more immersive and impactful learning experiences in STEM education, thereby further aligning with key cognitive and constructivist learning theories.

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