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RESEARCH ARTICLE

Exploring how generative AI contributes to the motivated engagement and learning production of science-oriented students

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ABSTRACT

Generative AI is transforming the educational landscape by offering new ways for students and educators to engage in personalized, adaptive learning. Unlike traditional tools, generative AI enables students to access a vast repository of information, interact with content in real-time, and generate responses, which collectively support individualized learning pathways. This study explored the role of generative AI, particularly ChatGPT, in students' self-directed learning (SDL) process. College students (n=15) from science-oriented programs were purposively sampled to be interviewed. Findings revealed that students used AI to enhance efficiency in completing tasks, generate content, and engage in deeper learning experiences. Students reported that AI tools, such as ChatGPT, helped break down complex subjects, provided instant feedback, and allowed them to manage learning at their own pace. These features supported autonomy, motivation, and competence, core components of SDL, by enabling students to make independent learning choices and confidently tackle challenging content. Student narratives illustrated how generative AI aided in organizing study material, understanding science topics, and even learning to troubleshoot code, which supported mastery of complex science program skills. The findings also suggested that AI tools contributed to active learning, as students engaged more meaningfully with content, enhancing their analytical and problem-solving abilities. The integration of generative AI in education may shape future pedagogical approaches, enabling educators to promote personalized and adaptive learning environments that support students' intrinsic motivation, SDL, and critical thinking.

Keywords: generative AI; motivation; science education; self-directed learning

1. Introduction

Generative Artificial Intelligence (AI) has surfaced as a groundbreaking technology, exhibiting extensive applications across numerous industries, including education. This consists of AI systems capable of generating various forms of content, including text, images, or videos, frequently through the emulation or creation of human-like creative expressions[1,2]. Generative AI can be utilized for academic activities, including the development of educational materials, the generation of intended recommendations, and support in the design of instructional frameworks[3]. Nonetheless, the rapid growth of generative AI technologies has prompted inquiries regarding their efficacy and ethical application in educational contexts[4,5].

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Considering the relevance of generative AI in education, this paper was positioned to explore how AI use links to students' motivational engagement in learning processes and how this engagement transcends to their learning production. The emergence of generative AI large language models, along with interfaces utilizing these models like ChatGPT, has significantly transformed the world of self-directed learning activities of students[6]. Since their introduction, these tools have been widely utilized to facilitate various activities, offering support in educational contexts and showcasing their potential as effective teaching aids[7,8]. The influence of generative AI conversational interfaces on educational fields, including programming, mathematics, economics, and sciences has generated significant academic curiosity and research activity[9-11]. The advancements in conversational agents have significantly expanded the boundaries of natural language processing and coding functionalities. For example, their application in software development has become widespread, aiding programmers through code suggestions, debugging assistance, and the generation of code snippets[12].

Neumann, Rauschenberger and Schön[13] recognize the significance of incorporating AI tools within higher education, highlighting their probable longevity and the resulting imperative for cultivating AI competencies to equip individuals for future challenges. Integrating generative AI into educational systems requires more than the mere acquisition of a new skill—it likely entails a transformation in cultural mindset and might require adaptations to current educational practices[14]. This paper was expected to open the discussion about the possibility of using generative AI in self-directed learning (SDL) activities of students. AI has the potential to adapt educational experiences, deliver immediate feedback, and enhance student involvement and motivation[15]. Applications of generative AI have the potential to facilitate the creation of educational materials, including quizzes, flashcards, and study guides[16]. This has the potential to furnish students with supplementary resources that may enhance their learning experiences and contribute to improved academic performance[17].

One of the primary driving factors of SDL among students is their motivation. Motivation influences students' individual goal orientation, which can impact retention of content and participation in collaborative efforts[18]. Learning persistence is a facet of SDL attitude, pertaining to students' sustained involvement in courses and indicating the degree to which learners achieve the educational objectives set forth by instructors as possibilities for online learning[19]. Further, in online learning environments, self-directed learners will assess the causative factors influencing their attitudes and motivation to enhance their engagement to fulfill their educational attainment requirements[20]. Fundamentally, Reschly and Christenson[21] asserted that the student engagement framework is influenced by students' perceived learning value about their belief in SDL.

Although intensive studies were conducted about generative AI use in education, little was known about how it can be applicable to SDL. Studies primarily focused on its implications to students' learning process, but without clear emphasis on its role to students' SDL. This paper discussed how students use generative AI (particularly ChatGPT) in learning science topics, and how this approach becomes effective in their learning. This preliminary study aimed to address the critical question of how generative AI contributes to students' SDL.

2. Literature review

The 21st century has witnessed a significant transformation in educational practices, primarily driven by technological advancements, including artificial intelligence. Generative Pre-trained Transformer (GPT) models utilize extensive datasets of publicly accessible digital content to engage in natural language processing (NLP). These models are capable of reading and generating human-like text across multiple languages, demonstrating a degree of creativity that allows them to produce coherent writing ranging from a single paragraph to an entire research article on any subjects[22-24]. One of these is generative AI, a machine learning framework that operates in an unsupervised or partially supervised manner, facilitating the generation of artificial artifacts through the application of statistical methods and probabilistic models[25]. Advancements in deep learning have enabled generative AI to produce artificial artifacts by analyzing existing digital content, including but not limited to videos, images, illustrations, text, and audio. This process involves examining training examples to discern their underlying patterns and distributions[26,27].

There are many kinds of generative AI in the internet market, but this paper was concerned about how ChatGPT can be used within the education setting. A more advanced version of the Generative Pre-trained Transformer (GPT)-3 was lately created[28]. The development of GPT-3, utilizing 175 billion parameters, aims to improve task-agnostic capabilities and demonstrates competitiveness with previous state-of-the-art fine-tuning methodologies[28]. The foundational NLP engine, GPT-3, drives the newly developed language model ChatGPT, which has garnered significant attention across various fields, including education[29], engineering[30], medicine[31], economics and finance[32], and journalism[24].

Generative AI has introduced innovative methods for educators to enhance motivation, utilizing large language models to offer adapted learning resource suggestions and customized assistance for students[33,34]. The integration of AI in Education (AIEd) is transforming the educational environment by improving learning, making decisions, and teaching processes for school stakeholders, including administrators, students, and teachers[14]. AI tools can provide intelligent, customized solutions that could transform conventional educational methods. It transcends basic academic support by offering clear comments and promoting a cooperative learning atmosphere[35,36]. Nonetheless, students are pioneering the use of new AI technologies, particularly with OpenAI's release of ChatGPT and the AI integration of Microsoft into their products, which has provided widespread accessibility. This knowledge could assist educators in harnessing potential of AI for high-quality teaching and learning while guiding safe and effective adoptions of these technological tools.

SDL also becomes prominent in the education system, with teachers emphasizing the role of students' autonomy in learning. The expanding areas within SDL research underscore its crucial role in educational research and suggest that educational researchers are progressively acknowledging the necessity of encouraging learners' self-directed learning abilities[37]. Research indicates that SDL is a fundamental attribute of the ability to engage in lifelong learning and significantly contributes to both academic and personal development in students[38]. SDL necessitates that individuals proactively pursue resources and gather knowledge adapted to their personal interests and requirements. This proactive approach enables learners to engage in comprehensive exploration of learning subjects and encourages critical thinking regarding knowledge, consequently effectively enhancing deep learning processes among students[38,39]. This learning method is dependent upon the intrinsic motivation of students, their self-efficacy, and their readiness for facing challenges[37].

ChatGPT is an open-access generative AI resource, making it ideal for SDL activities among students. However, discussions about how ChatGPT is used in SDL were limited. Meanwhile, it is greatly established that generative AI technologies facilitate the development of interactive and immersive educational content, which in turn promotes critical thinking, enhances problem-solving abilities, nurtures creativity, and promotes collaboration among students[40]. Generative AI possesses the capacity to influence student cognitive achievement through multiple avenues, such as enhancing students' computational thinking skills, fostering programming self-efficacy, and boosting motivation[41]. For example, Yilmaz and Yilmaz[42] observed that AI has the potential to assist students in coding by offering suggestions, detecting errors, and generating code automatically. This approach can enhance students' ability to produce more efficient and precise code, thereby minimizing the time and effort needed to fulfill programming assignments. Consequently, the benefits that ChatGPT offered during the coding process facilitated the enhancement of students' self-efficacy related to coding. Similarly, Huang and Qiao[43] discovered that students in the experimental group, who underwent AI training, exhibited significantly greater self-efficacy compared to their counterparts in the control group, who did not participate in this training. Research conducted by Li and Wang[44] indicates that the implementation of AI capabilities within higher education institutions has a beneficial impact on creativity and self-efficacy of students in their learning performance. Given that generative AI in education is still in its cradle, there is a need to explore its effects on students. This paper opened the discussion on how generative AI develops students' learning motivation. Hence, this paper examined how students integrate generative AI into their learning processes, how it fosters learning motivation, and the relevant implications for their academic success. This paper particularly discussed about one critical aspect of SDL, *i.e.,* autonomy, where students show motivation in learning engagement. This paper explored how generative AI encourages students to seek knowledge proactively, ultimately enhancing both their confidence and competence in mastering complex science topic.

3. Methods

3.1. Research design

This paper is an exploratory study about how generative AI could potentially contribute to motivation and learning production of science-oriented students. An exploratory study is a type of research designed to gain a preliminary understanding of a phenomenon, typically one that is not well understood or lacks substantial prior research[45,46]. Rather than confirming hypotheses or testing theories, exploratory studies are primarily focused on *discovering new insights*, answering fundamental questions, or documenting emerging trends. They aim to build a basic framework that can guide more specific, focused research in the future[47,48]. In exploratory research, the approach is often qualitative, involving flexible methodologies like interviews, observations, or open-ended surveys, which allow for a comprehensive exploration of a topic. This flexibility enables researchers to identify primary patterns and themes within social or psychological phenomena, which contributes to a richer understanding of the topic[49-51]. These studies may lead to the generation of new hypotheses or inform future research directions, laying the groundwork for more rigorous investigations. Though sometimes viewed as lacking scientific rigor, exploratory studies are valued for their efficiency in gathering initial data and providing initial perspectives[46]. This is essential in fields, like AI use in education, where rapid changes or new phenomena are emerging, as they allow researchers to collect preliminary data and frame the context effectively.

3.2. Participants and sampling

Sampling in exploratory research is typically characterized by small sample sizes, as the primary goal is to gain in-depth understanding rather than broad generalization[52]. This approach often employs purposive sampling, a non-probability method that allows researchers to intentionally select participants with specific characteristics pertinent to the study's focus[10]. By selecting a specific sample, exploratory studies can concentrate on unique insights from individuals who have direct experience or knowledge relevant to the research question[53]. In qualitative designs, particularly phenomenology, narrative inquiry, and case study, Subedi[54] suggested having at least one to 20 participants in a single study. Hence, following the exploratory nature of this paper, only 15 college students enrolled in science-related courses (like engineering, architecture, computer science, and biology) were sampled. The sampling criteria included (1) students actively enrolled in at least one science or technology course, (2) a minimum age of 18 to ensure participants could consent independently, and (3) a consistent grade point average above the passing level in their science subjects to ensure familiarity with course content. **Table 1** presents the demographics of the 15 participants interviewed in this study, with mean age of 20.13 and mean GPA of 1.93 points.

Table 1. Demographics of the participants.

Name	Sex	Age	GPA (1.00-5.00)	Science Program	AI Activities Used
Alex	Male	20	1.75	Engineering	Data analysis, coding assistance, project research
Beatrice	Female	21	2	Architecture	Design visualization, drafting assistance, project planning
Carl	Male	22	1.5	Computer Science	Coding assistance, AI model training, data analysis
Dana	Female	19	1.9	Biology	Research simulations, report writing, data interpretation
Ethan	Male	18	2.25	Engineering	CAD design help, material analysis, research support
Fiona	Female	21	1.8	Computer Science	Coding assistance, language model training, debugging
George	Male	20	2	Biology	Data entry, lab analysis, report generation
Hannah	Female	19	2.1	Architecture	Concept generation, design rendering, architectural modeling
Ian	Male	22	1.7	Engineering	Circuit design, project modeling, data processing
Julia	Female	20	2.3	Biology	Hypothesis testing, lab report automation, data visualization
Kevin	Male	18	1.6	Computer Science	Programming aid, AI algorithm experimentation
Leah	Female	19	2.2	Engineering	Mechanical simulations, project documentation
Mike	Male	21	1.85	Architecture	Virtual modeling, site analysis, project collaboration
Nina	Female	20	1.95	Biology	Environmental modeling, lab report writing, data visualization
Oscar	Male	22	2.05	Computer Science	Software development, coding debugging, data organization

Note: *GPA 3.00 is the passing grade for all programs.*

Flexibility is a key attribute of purposive sampling, enabling researchers to adjust criteria based on emerging findings and new concepts identified during data collection[55]. This flexible, deliberate approach is especially useful in exploratory studies, as it maximizes the depth of data obtained from participants who are highly knowledgeable about the subject[56].

3.3. Research instrument

A semi-structured interview guide was developed to gather the narratives from participants. Creating a semi-structured interview guide in qualitative research involves systematic planning to ensure the collection of relevant, in-depth data. This guide balances flexibility with structure, allowing participants to freely express their experiences and viewpoints while keeping the conversation aligned with the objectives[57,58]. The development process begins with identifying prerequisites, which include understanding the study's context and objectives and any prior knowledge that may shape the interview questions[59]. Once prerequisites are clear, preliminary questions are crafted, designed to encourage narratives while covering essential themes. Pilot testing is conducted to refine the questions, ensuring they are clear, accessible, and effective in prompting detailed responses. Final adjustments are made based on pilot feedback, creating a flexible yet structured framework that guides the interview without imposing strict adherence[60,61]. An independent panel of experts reviewed the interview guide questions to ensure relevance, clarity, and alignment with the objectives. The panel consisted of experienced educators and AI specialists familiar with technology-driven educational practices. **Table 2** presents the final interview guide questions developed.

Table 2. Final interview guide questions.

Objective	Interview Questions
To examine the ways in which Generative AI tools develop motivation engagement among college students.	1.Can you describe your experience using Generative AI tools in your coursework? What specific features do you find most motivating or engaging? 2.How do you believe Generative AI tools influence your interest in the subject matter? Can you provide examples of instances where these tools increased your motivation to learn? 3.In what ways do you think Generative AI tools foster collaboration and interaction with your peers during group projects or discussions? How does this impact your motivation to participate? 4.Have you noticed any changes in your study habits or learning strategies since using Generative AI tools? How have these changes affected your overall motivation and engagement in your studies? 5.Do you feel that Generative AI tools provide you with a sense of autonomy in your learning process? How does this perceived autonomy influence your motivation to engage with course materials?
To explore students' perceptions of the effectiveness of Generative AI in supporting their academic production and learning outcomes.	6.How effective do you believe Generative AI is in improving your academic performance and outcomes? 7.Can you provide examples of how Generative AI has positively impacted your assignments or projects? 8.How do you perceive the reliability and accuracy of information generated by AI in your coursework? 9.What are your thoughts on the role of Generative AI in enhancing critical thinking and analytical skills? 10. In your opinion, what are the potential drawbacks or limitations of using Generative AI tools in your academic work?

3.4. Data gathering procedure

In this study, one-on-one interviews served as the primary method for gathering narrative data, allowing for an in-depth exploration of participants' experiences and perspectives. Interviews are known as an effective method for actively listening to and interpreting personal narratives, strengthening recognition of how participants ascribe meaning to their experiences[62,63]. This qualitative approach is particularly prevalent in phenomenological research, where the aim is to investigate the lived experiences of individuals[64]. The flexibility of qualitative interviews, often employing semi-structured formats, allows for a more organic conversation that can elicit rich and detailed responses from participants[65]. To ensure a systematic and effective interview process, the study adhered to established qualitative research protocols. This included clearly defining research objectives, selecting appropriate participants, and communicating the purpose of the study, along with assurances of confidentiality and data usage[66]. During the interviews, thematic questions were used to guide the discussion, along with follow-up inquiries to encourage participants to elaborate on their responses. This conversational style presents a natural and informal atmosphere, which is essential for eliciting insightful narratives[65,67]. Language barrier challenges were mitigated by urging participants to articulate themselves in their chosen dialects, thus promoting ease and confidence during the interview process. By employing culturally sensitive communication strategies and adapting to participants' linguistic needs, the study ensured that responses were accurately captured and contextualized, ultimately enhancing the quality and reliability of the qualitative data collected[59]. The use of audio recording, with participants' consent, facilitated accurate data capture, while preliminary notes helped organize key points for later analysis[68]. Furthermore, qualitative interviews often prioritize the continuity of narrative and the establishment of positive rapport to mitigate interviewer bias and enhance the authenticity of the data[70].

3.5. Data analysis

Thematic analysis serves as a powerful qualitative method for systematically identifying and interpreting patterns of meaning within narrative data, particularly in the context of one-on-one interviews[70]. This method is particularly useful for exploring shared experiences and meanings, enabling researchers to uncover the significance of participants' narratives[51]. The flexibility of thematic analysis makes it well-suited for exploratory research, allowing for the emergence of themes that reflect the richness of participants' lived experiences[49,71]. The coding process in thematic analysis typically involves three distinct levels—beginning with descriptive codes and progressing toward more interpretative analyses[72,73]. In employing reflexive thematic analysis, researchers actively engage with the data, recognizing that their values, experiences, and assumptions can shape the interpretation process[74]. This method emphasizes the subjective nature of coding, requiring researchers to reflect on how their perspectives might influence the analysis and findings[75]. To minimize potential bias, the data analysis in this study utilized an inductive method. This approach allows themes and patterns to emerge directly from the data itself, rather than being influenced by preconceived theories or assumptions[76]. The study adhered to the six phases of reflexive thematic analysis outlined by Braun and Clarke[77] as shown in **Figure 1**, which emphasizes flexibility while maintaining methodological rigor. This iterative process allows researchers to refine their understanding of the data as they identify underlying meanings organized around central themes.

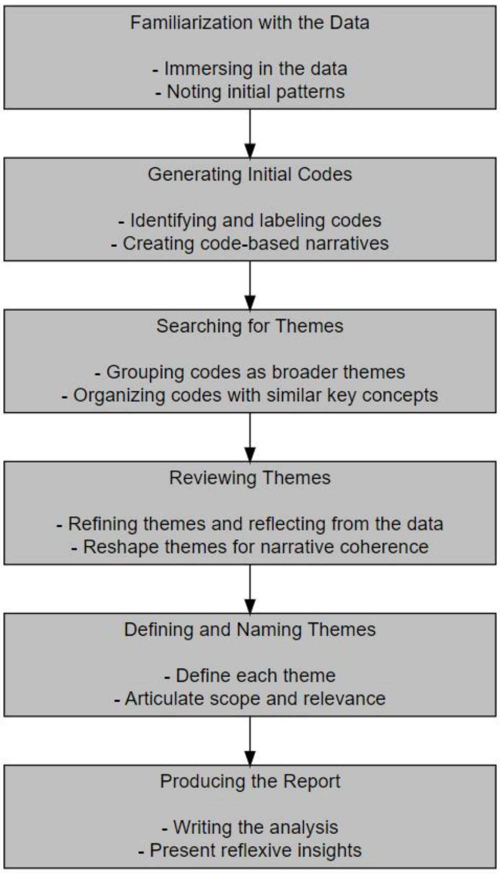

Figure 1. Six phases of reflexive thematic analysis.

4. Results

Objective 1: To examine the ways in which Generative AI tools develop motivation engagement among college students.

This paper highlighted two primary ways in which Generative AI tools enhance motivation and engagement among college students: Work Efficiency and Content Generation. In terms of work efficiency, students appreciated AI tools for their ability to simplify complex topics and summarize large amounts of information, which allowed them to save time and focus more on analysis and understanding. This efficiency not only improved organization and comprehension but also supported students in managing heavy workloads, especially during high-stress periods like exams. Secondly, students emphasized how AI facilitated connections between theoretical knowledge and real-world applications, particularly in environmental issues and science topics. By providing instant feedback and adapting to individual learning styles, AI tools offered personalized learning that boosted engagement and made studying more interactive and enjoyable.

Theme 1: Work Efficiency

Work Efficiency revealed that college students find Generative AI tools essential in enhancing productivity and time management in their studies. A recurring code in the responses was summarization, as students frequently express appreciation for AI's ability to condense topics and information into manageable summaries.

> "I appreciate how AI can summarize vast amounts of information."

> "I find the ability to generate summaries of complex topics really helpful."

> "I incorporate Generative AI into my study to generate summaries of the long and complex topics, creating ideas for making project and helps me review our lessons."

> "I use these tools to summarize lengthy articles and textbooks, highlighting key points. This makes it easier for me to digest essential information."

Another significant code was timesaving, with participants emphasizing how AI tools "saved [them] hours of work" by summarizing research findings, allowing them to focus on higher-order tasks like analysis.

> "Generative AI helped me draft my lab report by quickly summarizing key research findings. It saved me hours of work and allowed me to focus on analysis instead of just gathering information."

The code of organization also appeared strongly, as students mention that AI tools help them stay more organized and efficient when studying, especially during heavy workloads.

> "Using these tools in studying helps me become more organized and efficient especially when I have a lot of lessons to study."

> "It saves me time when I need to review a lot of material quickly, especially before exams."

Similarly, the concept of efficiency emerged as central, with critical codes including writing clarity, content focus, and comprehension support. Students consistently expressed that AI tools enhance their writing efficiency by improving clarity and reducing the time spent on formatting tasks.

> "These tools improve my writing efficiency and clarity, allowing me to focus more on the scientific content rather than formatting."

Another essential code was comprehension support, with students noting the usefulness of AI tools in breaking down challenging information. AI served as an adaptive learning aid, helping students overcome learning obstacles independently, which can foster self-confidence and sustained motivation.

> "In instances where in you find it difficult what you are reading, I use ChatGPT to explain it to me."

Generative AI tools could contribute to college students' motivational engagement by streamlining productivity and supporting effective time management. Key codes were summarization, timesaving, organization, writing clarity, and comprehension support. Students used AI to distill complex topics into concise summaries, which they found valuable for understanding key concepts quickly and effectively. The concept of efficiency also extended to writing clarity, with students expressing that AI tools enhanced their ability to communicate complex ideas succinctly, reducing time spent on formatting and mechanics. Lastly, comprehension support demonstrated how AI aided in breaking down challenging information, acting as an adaptive learning aid that empowered students to overcome learning barriers independently.

Theme 2: Content Generation

Content Generation revealed that Generative AI tools play a vital role in enhancing motivational engagement among college students by offering dynamic, context-rich learning experiences. A prominent code within this theme is real-world connection, as students expressed appreciation for AI's ability to link theoretical knowledge with practical, real-world issues, such as environmental impacts. This connection not only deepened understanding but also made the content more relevant and engaging, developing a greater sense of purpose in their studies.

> "AI tools help me connect theoretical knowledge to real-world environmental issues, enhancing engagement and understanding of the impact of climate change."

> "For practical applications and problem-solving, AI tools are fantastic. They can provide instant feedback and personalized learning experiences."

Another significant code was conceptual integration, where students highlighted the role of AI in bridging various concepts and providing context that clarifies complex relationships, which helps students see the "bigger picture" in their learning.

> "AI's ability to connect different concepts and provide context is amazing. It helps me see the bigger picture and understand how various topics in science relate to each other."

Personalization emerged strongly, with students noting that AI tools adapt to their individual learning styles, providing designed resources or quizzes that align with their pace and preferences. This helped maintain engagement by creating study sessions that are both effective and enjoyable, making students more motivated to continue learning.

> "AI tools that adapt to my learning pace and style, providing tailored resources or quizzes, make my study sessions much more effective."

> "It makes my studying more interactive and enjoyable, helping me to maintain motivated and focused."

Content Generation illustrated how Generative AI tools develop motivational engagement among college students by providing immersive, adaptable learning experiences. A key code in this theme was real-world connection, which enabled students to link theoretical concepts with practical applications, making their studies more relevant and purpose driven. This context-based engagement enriched students' understanding and built a meaningful learning experience that sustained their interest. Conceptual integration, captured the AI tools' role in connecting diverse topics, enabling students to connect complex subjects. Personalization emerged as a strong engagement factor, where AI tools adjust to individual learning paces and styles, creating designed study materials and interactive exercises. This support encouraged enjoyable and efficient learning sessions, increasing students' motivation to engage actively with their coursework and helping them stay focused.

Question 2: To explore students' perceptions of the effectiveness of Generative AI in supporting their academic production and learning outcomes.

This paper revealed that students perceive Generative AI as highly effective in enhancing their academic productivity and learning outcomes, particularly in problem-solving and interactive learning. In problem solving, students appreciate AI's capacity to provide step-by-step solutions, which clarifies underlying principles and helps them understand the concepts. This characteristic also promoted critical thinking by encouraging students to consider multiple solution pathways and analyze different perspectives, which strengthens their analytical skills. Having interactive conversations, adaptive feedback and personalized learning experiences support developed comprehension and strengthen test preparation. Students valued the AI-generated practice questions and interactive feedback, as they simulate real exam conditions and reinforce understanding.

Theme 1: Problem Solving

Students' perceptions regarding the effectiveness of Generative AI tools in supporting academic production highlighted the significance of problem solving as a key theme. A prominent code within this theme was step-by-step solutions, which students find invaluable in clarifying complex concepts. By breaking down problems into manageable steps, students reported an enhanced understanding of underlying principles, leading to more effective learning outcomes.

> "The AI tool provided step-by-step solutions, which helped me understand the underlying principles better. I could see how each step related to the overall problem."

Another important code is improved academic performance, as many participants observed a noticeable increase in their grades attributable to the use of AI tools. This improvement was largely due to the ability of these tools to present multiple perspectives, allowing students to approach problems from various angles. For example, by requesting explanations for code issues, they gain immediate feedback and clarification, which not only aided in problem-solving but also reinforced their learning process.

> "I've seen a noticeable improvement in my grades since I started using AI tools. They allow me to approach problems from different angles."

> "I use ChatGPT when studying for my programming exams. I asked it to explain why the code is not working."

The code of critical thinking enhancement emerged strongly, with students recognizing that Generative AI encourages them to evaluate different solutions and consider different approaches. This process not only developed analytical skills but also boosted their confidence when dealing with challenging problem sets.

> "I believe generative AI can enhance critical thinking by prompting us to evaluate multiple solutions to a problem."

> "It encourages us to consider different perspectives and approaches, which is crucial for developing analytical skills."

> "When working on a complex problem set, I used an AI tool to generate multiple solution strategies. This not only deepened my understanding but also gave me confidence in presenting my answers."

Theme 2: Interactive Conversations

Interactive Conversations revealed that Generative AI tools significantly enhance students' academic production and learning outcomes by facilitating dynamic and engaging learning experiences. A critical code identified in this theme is improved understanding, as students express that AI aids in understanding complex topics and provides instant feedback, enhancing study efficiency. The immediate reinforcement of concepts allowed for an effective learning process, as students can address misconceptions in real time.

> "I believe generative AI has significantly improved my academic performance. It helps me quickly grasp complex topics and reinforces my understanding with instant feedback, which has made studying more efficient."

Another important code was adaptive learning experiences, highlighting the tools' ability to design educational content to individual needs and preferences. This personalization was perceived as a significant advantage, as it develops a relevant and effective study environment, ultimately leading to better academic performance. The effectiveness of these AI tools was further illustrated by the students' reports of increased test scores, attributed to their ability to simulate exam conditions through AI-generated practice questions.

> "Adaptive learning experiences that cater to individual needs and preferences, ultimately improving the overall study process."

> "I've definitely seen a rise in my test scores. The ability to simulate exam conditions with AI-generated practice questions has been part for my preparation."

> "I used ChatGPT to study for my programming exam. I asked it to make codes and explain each line of code. This allowed me to understand patterns in making your code. Results came, I got a perfect score!"

Notably, students explained that engaging with AI-generated viewpoints challenges them to justify their opinions. This interactive conversation not only strengthened their analytical skills but also encouraged deeper investigation into the subject matter, prompting them to question information presented.

> "When I use AI to generate different viewpoints on a topic, it forces me to justify my own opinions. This process really strengthens my analytical skills as I learn to defend my reasoning."

> "It challenges us to question the information presented and encourages deeper investigation into the subject matter."

5. Discussion

In this revolutionary era, AI occupies at the forefront of driving innovation, reshaping the fields of computer science and human interaction. AI tools are distinguished by their ability to reproduce human cognitive functions, including memory, creativity, analysis, and learning, consequently transforming the understanding and engagement with technology[78,79]. The education sector, recognized for the profound recognition related to AI's impact, is currently experiencing a notable evolution driven by the advent of AI technologies[80,81].

Considering the potential use of AI in education, Artemova[82] suggested that Future theoretical investigations need to focus on the intrinsic motivational dimensions of AI use, with the goal of encouraging epistemological demands personal significance, a sense of purpose, and the consideration of choice. This involves developing AI systems and identifying appropriate functions that promote trustworthy self-directed and inquiry-based learning, which can enhance students' autonomy by providing them with the opportunity for personal choice in their learning processes. However, there exists an argument surrounding the potential impact of AI on student learning, particularly regarding its influence on the cultivation of critical thinking and problem-solving abilities[83], as scholars exhibit skepticism and unease regarding the application of AI in educational contexts and evaluation processes[84]. Meanwhile, AI continues to be in the nascent phases of integration within higher education, institutions have not yet formulated extensive frameworks and policies regarding the utilization of AI by students[81].

Considering the need for further assessment of AI use in education, this paper analyzed how generative AI can be linked to students' motivation in self-directed learning, and how this enabled them for effective learning production. The significance of intrinsic motivation component stems from the categorization of interest in a specific subject as well as the epistemological requirements that are regularly addressed in various classic and modern studies in educational psychology[82,85,86]. It is critical to address learners' intrinsic motivation in AI-supported educational processes, since research shows that intrinsic motivation contributes to lifelong learning[87] and overall well-being[88]. This paper was able to identify that the primary motivational factors for student engagement in generative AI use was its capacity for work efficiency and content generation. Science-oriented students, for example, leveraged generative AI for saving time doing tasks, simplifying research works, connecting theoretical knowledge to practical applications, designing solutions for problems, and developing personal assistance.

SDL is an educational strategy in which people actively participate in defining goals, locating resources, and assessing their own progress[89]. Kruger[90] went on to say that technology may be leveraged to create adaptable learning platforms that allow learners to adapt their learning experiences depending on their specific needs and progress. In higher education, students utilized AI as a form of SDL due to its ability to provide personalized and adaptive learning experiences. For example, one student said, "…using these tools in studying helps me become more organized and efficient especially when I have a lot of lessons to study." Another one explained, "…this makes it easier for me to digest essential information." Setlhodi[91] argued that individuals who direct their own learning frequently participate in self-reflection, conduct self-assessments, pursue independent research, and engage in self-paced learning. Narratives from science-oriented students resonate with this perspective, illustrating how generative AI tools facilitate a structured approach to learning, especially through conversations and content generation. By enabling students to break down complex subjects into manageable parts, these tools promote deeper understanding and retention of materials they study.

Primarily, active learning strategies enhance student motivation to attain information[92]. Prior investigations of active learning, concerning student learning outcomes, have predominantly yielded favorable results[93]. In the study by Pahi et al.[94], an innovative active learning approach was implemented that combined teaching assistants with generative AI, specifically ChatGPT, to enhance student feedback during Computer Science courses. The findings indicated that teaching assistants effectively assessed student progress and identified areas of struggle, and ChatGPT contributed by providing clarifying examples and motivational support, leading to improved feedback quality and high student engagement. Similar mechanism was observed when students use generative AI for SDL. For example, one student used ChatGPT "…to explain why the code is not working." One student also used ChatGPT "…to make codes and explain each line of code. This allowed me to understand patterns in making your code. Results came, I got a perfect score!" Generative AI for SDL and active learning further illustrates its effectiveness in promoting autonomy and mastery of complex subjects, like troubleshooting coding issues and gain understanding about programming patterns, which significantly contributed to their academic success.

It appears from the accounts that generally, science-oriented students were positively motivated about the use of AI in education. They manifested motivation in learning academic content at their own pace and demonstrated a proactive engagement in their educational journeys. Autonomy, a fundamental component of SDL[92], reflects the sense of agency, control, and independence with competence like feeling capable, confident, and effective[95]. This context also emerged when using generative AI in learning. For example, one student said that ChatGPT "…forces me to justify my own opinions…[it] really strengthens my analytical skills as I learn to defend my reasoning." Another student said that learning with generative AI "…reinforces my understanding with instant feedback, which has made studying more efficient." College students manifested clear reflection of motivation in learning as generative AI "…encourages deeper investigation into the subject matter" making their learning processes interactive and thought-provoking with only simple prompts. This finding is significant, as early studies on motivation and SDL support similar learning mechanism. Voss and Richards[96] observed that when learners actively engage in their education, their learning process becomes increasingly self-directed. Students exhibiting a high degree of SDL are typically inclined to commit to their education and are eager to understand the knowledge or skills they can gain from the course[19].

The findings might have practical applications to future pedagogical perspectives. As AI technologies become increasingly prevalent, they can serve as powerful tools to develop student engagement, learning motivation, autonomy, and SDL. The positive experiences of science-oriented students utilizing generative AI tools highlight the potential for these technologies to not only enhance academic performance but also to develop critical thinking and problem-solving skills. Educators can leverage these tools to create adaptive learning environments that cater to individual student needs, encouraging personalized learning experiences that promote intrinsic motivation. The integration of generative AI in educational practices presents a paradigm shift that requires educators to rethink traditional pedagogical frameworks.

6. Conclusion

The findings of this study underscore the potential of generative AI tools to enhance students' motivation and learning output, particularly within SDL contexts. Generative AI enhances educational processes by providing personalized and adaptive learning experiences that build intrinsic motivation in students, significantly impacting their academic performance and overall learning experience. Students indicated enhanced understanding of complex concepts, as AI techniques enabled the disaggregation of difficult concepts into more digestible elements. Consequently, AI serves as a transformational influence in education, redefining instructional methodologies and improving student performance. Students reported a greater understanding of complex topics, as AI facilitated the breakdown of challenging concepts into more manageable parts. This transformative role of AI in education not only redefines traditional teaching approaches but also supports improved student outcomes.

Teachers should consider incorporating generative AI tools into their teaching strategies to enhance student motivation and facilitate SDL. This integration can lead to the development of adaptive learning environments that accommodate diverse student needs, thus promoting personalized learning experiences. Academic institutions must recognize the potential of AI in developing critical thinking and problem-solving skills, encouraging the adoption of AI-based pedagogical frameworks that empower students to take responsibility for their learning journeys. Training and support for educators in effectively utilizing these technologies are crucial for maximizing their benefits in educational settings. The findings suggested that a paradigm shift in teaching methodologies is necessary to fully leverage the potential of generative AI in higher education.

Despite the promising findings, this study has several limitations that warrant consideration. The sample primarily consisted of science-oriented students, which may limit the generalizability of the results to other disciplines or educational contexts. Further research involving a more diverse participant pool is needed to explore the impact of generative AI across various fields of study. The study relied on self-reported data, which may introduce biases related to students' perceptions of AI tools and their motivations. Future studies could benefit from incorporating objective measures of learning outcomes and motivation to validate these findings. Finally, as AI technology continues to evolve rapidly, ongoing assessment of its effects on student learning and motivation is essential to inform best practices and adapt educational strategies accordingly.

Conflict of interest

The authors declare no conflict of interest.

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