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A Student Classification and Characterization Model of Generative AI Use in First-Year Engineering Design

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Complete Paper: A Student Classification and Characterization Model of Generative AI Use in First-Year Engineering Design

Abstract

This paper presents a student classification and characterization model of generative AI usage within a first-year engineering design course at a mid-sized university. The study explores how a collection of custom-built generative AI chatbots shaped unique student learning trajectories. It focuses on four distinct learner categories: Self-Reliant, Pioneering, Overwhelmed, and Engaged learners. This paper also highlights case studies representative of student experiences from each category that expands on the model and its implications in higher education learning environments. The findings emphasize that learning is not a static process; students' interactions with AI tools evolve over time, influenced by their initial attitudes and skills. The implications of this paper extend to curriculum design, pedagogical approaches, and the broader integration of generative AI tools in higher education.

Introduction

The rapid advancement of generative artificial intelligence has revolutionized various industries, including education. As generative AI tools such as ChatGPT, Claude, and Gemini become increasingly accessible, educators are exploring their potential to transform teaching and learning processes [1]. Generative AI tools continue to grow dynamically facilitating innovation, supporting inquiry-based learning, fostering creativity and personalizing education. Its usages in the classroom span diversely from acting as learning aids in STEM discussion [2] to preparatory tools in a flipped classroom [3]. Adaptive learning systems powered by AI have garnered the ability to analyze student performance in real time and tailor content to individual needs, thereby enhancing the learning experience. AI-driven platforms, such as intelligent tutoring systems, provide immediate feedback, helping students improve their skills and understanding at their own pace. Hence, generative AI is changing the way students are interacting and engaging with the classroom. It is calling for a re-assessment of learning tools and re-evaluation of what learning means and how students are learning.

This paper presents a classification model of how custom tailored generative AI chatbots influence student learning experiences in the first-year engineering environment. More specifically, this work explores the changing learning trajectories of first-year introduction to engineering students based on the real-time support from the chatbots for programming, ideation, documentation and debugging amongst other uses. This paper attempts to analyze the data generated by student and chatbot interactions, pre and post class surveys analyzing the data to understand how generative AI tools can reshape traditional pedagogical models, promoting both individualized learning and collaborative innovation with the potential to empower learners.

Class Description

In a 30 student first-year engineering design course (Fall 2023) at a mid-sized private university in the northeastern United States, students were encouraged to "use AI as much as possible" while engaging in hands-on engineering design projects using LEGO Education SPIKE Prime robotics kits. This 15 week innovative course structure, as detailed in the work by Dr.Ethan Danahy and colleagues in their paper “Supporting Students’ Educational Robotics Experiences through Generative AI Chatbots” [4], was designed to integrate AI into the learning process. The course goals included teaching foundational engineering principles, promoting design thinking, and encouraging students to explore generative AI tools for coding and project development. The custom generative AI chatbot, built on Google Cloud Architecture and leveraging OpenAI’s ChatGPT API, was developed to assist with image generation, webpage documentation, a python IDE (integrated development environment) for robot interactions, code generation, and general other prompt usage. Five types of bots were made fully and freely available to the students: GeneralBot, SyllabusBot, WebDeveloperBot, PrimeBot, and BuildBot [4].

Data Sources

To better understand how to build the classification model and categorise the learning experiences of students, this paper has two primary data sources: (1) conversations tracked via the custom chatbot platform and (2) student responses from both pre- and post-course surveys. Of the 30 total students enrolled, 23 consented for use of their data in IRB approved research.

The custom chatbot platform recorded real-time interactions as students used the bots to seek help with programming, debugging, ideation, and documentation tasks. Through the duration of the one-semester course over 3,000 messages were exchanged [4] amongst a variety of message types, from idea refining, code generation, troubleshooting errors, or general conversation about the class. The conversation content, style, length and intensity was also tracked.

Complementing this, the pre- and post-survey questions (Appendix) captured changes in student perceptions, attitudes, and self-reported skills related to generative AI, coding, robotics, and engineering tasks. Self-reported likert scale responses of coding ability and robotic skill were also collected. This was triangulated by asking implicit questions about student coding ability. More specifically student responses to questions such as “If you do have prior programming experience: when you "get stuck" and need help, what online resource(s) would you use to figure out how to move forward?” helped assess their prior coding knowledge. For instance, generalized responses that referred to use of a search engine or asking others for help were indicative of lesser prior knowledge in comparison to student responses that referred to Stack Overflow, open source databases, code libraries, or rubber ducky style debugging techniques. This allowed for a more accurate understanding of student ability prior to the class. Moreover,

normative questions were also asked to understand students' initial and eventual opinion of generative AI usage and their prior experiences.

These combined data sources allowed for a holistic view of student progress throughout the semester, highlighting both the challenges they faced and the strategies they developed to overcome them.

Classification Model

Using data from chatbot conversations, pre- and post-surveys, and qualitative coding in NVivo 14, a classification model was developed. It aims to categorize students based on their prior technical experience and willingness to engage with generative AI tools. This matrix provides a clear framework describing four types of learners and their interactions with generative AI and how these interactions shape their learning experiences.

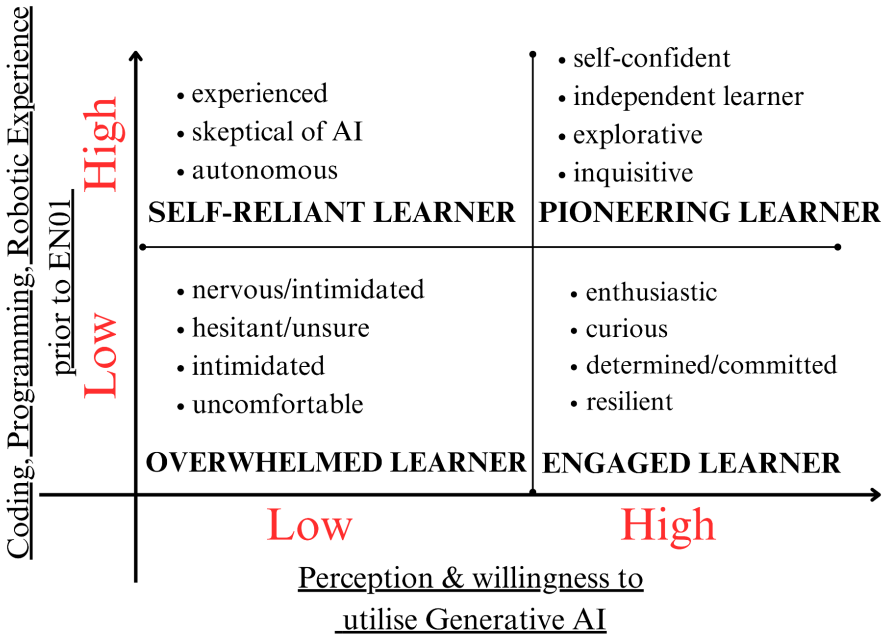

Figure 1. Student Classification and Characterisation Model

Figure 1 depicts the model that categorizes students based on two key axes: (1) their perception and willingness to utilize generative AI and (2) their prior experience with coding, programming, and robotics. The x-axis represents students' attitudes toward using AI, ranging from low willingness, characterized by reluctance or skepticism, to high willingness, marked by enthusiasm and openness to leveraging AI tools for learning and problem-solving. The y-axis captures students' technical background and experience prior to the course, spanning from low experience, reflecting minimal exposure to programming and robotics, to high experience, indicating strong foundational knowledge and confidence in these areas from beforehand.

From these axes, four distinct categories of learners emerged: Self Reliant, Pioneering, Overwhelmed and Engaged learner. The first category, Self-Reliant Learners, includes students with high prior technical experience but low willingness to engage with AI. These students are described as autonomous and confident in their coding and robotic abilities, preferring to rely on their own skills rather than embracing generative AI as a resource. This category refers to students who prefer to use the chatbots sparingly, relying primarily on personal expertise.

The second category, Pioneering Learners, comprises students with both high prior robotic and coding experience and high willingness to explore and work with generative AI tools. These learners are curious and experimental, often pushing the boundaries of what these generative AI tools can achieve by using it for debugging, ideation, and creative problem-solving. This category can be described as a student who chooses to extensively interact with the chatbots to refine designs and enhance their projects, ideas and process.

The third category, Overwhelmed Learners, includes students with low prior technical experience and low willingness to use generative AI. These learners often feel hesitant or intimidated by these tools and might rely heavily on teaching assistants and avoid engaging with the chatbot due to discomfort or confusion.

Finally, Engaged Learners are characterized by low prior technical experience but a high willingness to embrace and understand generative AI tools. These students demonstrate enthusiasm and determination, actively engaging with the chatbots to bridge their skill gaps and enhance their learning. It would be characteristic of such a student to iteratively interact with the chatbot to debug code or generate ideas, building confidence as they progress.

These categories were developed through a systematic analysis of the data sources. Chatbot logs provided insights into how students interacted with generative AI tools through the course and how that changed. The surveys captured shifts in perceptions and self-reported skills over the semester. By identifying patterns and themes in the data, this model offers a comprehensive view of the categories of student learning experiences.

Student Experiences

The student classification model of Generative AI usage is applied to the course to develop four detailed tracked accounts of student learning experiences. Each case study showcases the change—or lack thereof—of the student as a learner over the duration of the course, shedding light on the interplay between their initial learning approaches, interactions with the chatbot, and eventual outcomes and changes.The ‘case studies’ capture unique trajectories and these narratives help to contextualize the broader findings of how generative AI tools shape individual learning experiences. These example students were selected from the larger collective because their learning journeys offered compelling and diverse representations of how learners engaged with the chatbots and class material.

Student 1: Self Reliant to Pioneering Learner

Pre-Semester Context: Student 1 began the course as a self-reliant learner, characterized by a high level of experience with coding, programming, and robotics prior to the course with a self reported ranking of 4 (out of 5). They displayed autonomy and confidence in their abilities but were also skeptical of the potential of generative AI tools. They described themselves as a "self-taught coder" and suggested that while they understood the potential of generative AI, they were "very skeptical" about its role in education.

Initial Engagement: At the beginning of the semester, Student 1's interactions with the chatbot were limited in both frequency and depth. They primarily approached it as a supplementary resource, occasionally testing its capabilities by re-checking their own code but maintaining a cautious and skeptical attitude. This aligned with their perception that they were capable of solving problems independently without relying heavily on the chatbots.

Mid-Semester Interactions: Over the course of the semester, Student 1 began to engage more meaningfully. A noticeable turning point was their focus on asking "process-oriented" questions, such as "how" and "why," rather than simply seeking solutions and asking the chatbot for a direct solution. This shift demonstrated a growing curiosity. The length of their conversations with the chatbot increased threefold, conversation lengths went from only 2 to about 6 or 7 messages at a time, indicating a deeper level of exploration and engagement.

Post-Semester Reflection: By the end of the semester, Student 1 had transitioned into a pioneering learner. In their post-survey responses, they described how their skepticism had evolved into a proactive approach. They highlighted the value of using generative AI to "support your goals extensively," showcasing a newfound appreciation for the tool's ability to complement and enhance their learning. This shift was further evidenced by their expressed interest in learning how different external AI tools, such as DALL-E (a ChatGPT-based image generator), worked beyond the immediate course context.

Student 2: Overwhelmed to Engaged Learner

Pre-Semester Context: Student 2 entered the course as an overwhelmed learner, characterized by limited prior experience with coding, a self-reported score of 2. In their pre-survey, they described themselves as "nervous" and hesitant to use AI tools, expressing a strong adherence to "sticking to the professor's guidelines" and felt that "skill tasks should not use AI."

Initial Engagement with the Chatbot Tool: Student 2 approached the chatbot with minimal interaction in the beginning, often using it only when explicitly directed by assignments. Their queries were short and primarily aimed at clarifying specific instructions in the syllabus bot.

Their early interactions reflected discomfort and reluctance to rely on AI, preferring to depend on traditional methods and external support of the TAs.

Mid-Semester Interactions: A significant shift occurred when Student 2 began to experiment with the chatbot as a learning aid rather than solely an information source. They started asking the chatbot to explain concepts they didn't understand, using prompts like "explain this term" or "how does this work?". They began to more actively use the Build Bot and WebDeveloper Bot, marking their growing comfort with the variety of tools. Student 2 began to consistently provide context for their problems showing more engaged prompts.

Post-Semester Reflection: By the end, Student 2 had transitioned into an engaged learner. In their post-survey, they highlighted how AI brought "perspective" to their learning experience and shared that they were "curious to learn how different bots work". This shift from hesitation to curiosity underscored their newfound confidence in using such tools even without a drastic increase in technical skills.

Student 3: Engaged to Pioneering Leaner

Pre-Semester Context: Student 3 began the course as an engaged learner, demonstrating enthusiasm and curiosity about learning and generative AI tools. They described ChatGPT as a "supplemental resource" in their pre-survey and were eager to use it to explore topics beyond the scope of the assignments. Their prior experiences in coding were moderate, and they showed resilience and determination to work through the course.

Initial Engagement: Early in the semester, Student 3 utilized the chatbot extensively, engaging in conversations with 14 or more messages each. One notable example was when they asked the bot to "give me a lesson on a random topic," showcasing their explorative nature. These interactions reflected their eagerness to learn.

Mid-Semester Interactions: As the semester progressed, Student 3 became increasingly inquisitive and process-oriented. They spent time analyzing the outputs generated by the chatbot, stating, "I studied the code the bot wrote and saw how it worked." Their engagement moved beyond simply accepting solutions; instead, they actively sought to understand the underlying mechanisms. This curiosity and effort to dissect the AI-generated solutions demonstrated their transition toward a more autonomous and reflective learning approach.

Post-Semester Reflection: By the end of the semester, Student 3 evolved into a pioneering learner. They expressed newfound confidence, stating, "I felt like I understood how the code was executing, and I loved that." Their ability to integrate the generated solutions into their broader understanding of concepts underscored their growth into an independent and explorative learner.

Student 4: Overwhelmed Learner Stays Overwhelmed

Pre-Semester Context: Student 4 entered the course as an overwhelmed learner, with no prior experience in coding or robotics. Their pre-survey reflected a lack of familiarity with generative AI tools, and they even left the "experience" section blank.

Initial Engagement: Early in the semester, Student 4's interactions with the chatbot were sporadic and surface-level. They primarily used the chatbot to complete assignments, often asking it to directly "write the code from the assignment." This approach indicated a reluctance to engage deeply with the tool, as they seemed more focused on completing tasks than on understanding concepts.

Mid-Semester Interactions: Despite some exposure to the chatbot, Student 4 showed little change in their engagement style. They often relied heavily on teaching assistants (TAs) for help rather than leveraging the chatbot as a learning resource as they re-iterate in both surveys. Additionally, they demonstrated a pattern of attempting to "hack the system" by asking the bot for direct solutions rather than exploring the learning process. This resistance to engage with the chatbot reflected a lack of motivation to experiment or learn.

Post-Semester Reflection: At the end of the semester, Student 4 remained an overwhelmed learner. In their post-survey, they framed the use of AI as a dichotomy of "AI versus student" rather than an integrated learning tool. This suggested a continued perception of generative AI as a challenge to overcome rather than a resource to utilize.

Reflections

Each student learning journey was hence independent and different. Each student trajectory brings to light ideas to consider. Student 1 and Student 3's journeys highlight the ability and potential of such tools when provided in a structured manner to engage with. Their progression highlights the importance of fostering an environment where learners feel empowered to experiment and inquire. Student 2's change from a nervous to confident attitude depicts the value of such tools in enabling active participation and growth in new environments like first-year engineering. Lastly, Student 4's journey emphasizes that not all learners may fully adapt to or embrace generative AI tools immediately. Their lack of progression highlights the need for additional support, more direction and or targeted interventions. It is imperative to recognise that each student experience was unique which transfers to the rest of the 30 students as well. It is hence difficult to pool together a larger overarching and conclusive summary of class patterns as each student is different.

Implications and Conclusion

The model and student experience examples highlight that learning is not a static process—students changed the way they engaged with material and tools throughout the course. This recognizes the dynamic nature of learning and the importance of fostering a flexible,

adaptive, and engaging environment to support diverse student needs. While it is common to assume that learners approach material in a uniform way, it is critical to acknowledge that learners do not start or end in the same place, which has profound implications for how educators approach classroom instruction and support. Students come into the classroom with varying levels of prior knowledge, confidence, and familiarity with tools or concepts, and these differences shape how they engage with the material. Moreover, acknowledging that learners do not end in the same place is equally critical, each learner approaches and engages with the class at their own pace in their own ability and capacity. Hence, a one-size-fits-all approach to teaching fails to address the nuanced needs of a diverse group of learners.

The paper also raises important questions about the way in which generative AI tools are introduced and utilized in educational contexts. In this course, students were encouraged to experiment with the custom chatbot without formal introduction or instruction. Would their learning outcomes differ if the instructor provided structured tutorials or more scaffolded guidance? This suggests potential for further exploration into how instructional methods shape generative AI adoption and use amongst students.

It's also important to acknowledge that the survey data was entirely self-reported, which may introduce a degree of social desirability bias. Students may have reported more or less favorable perceptions or engagement with the tool than they actually experienced. While this paper only explores the details of four student experiences out of 30, the need to explore additional student journeys is recognised to increase external validity.

Finally, this study took place in Fall 2023 when generative AI was still relatively new and the use of a custom chatbot made it easier to track the majority of student interactions with generative AI. At that time, with fewer alternative tools available, it is reasonable to assume the set of generative AI chatbots provided by the instructor were the main tools used. However, with the growth and accessibility of generative AI tools since, it has become increasingly difficult to replicate such studies and track extensively what resources students are using. It is important to acknowledge how drastically fast advancements in generative AI tools are currently and will be in the near future. This raises critical questions about how to study and understand student engagement with generative AI tools in an era of widespread access and exploration of diverse technologies.

This paper hence highlights the complexity of student interactions with generative AI tools and underscores the importance of recognizing the diversity of student experiences and how these change over time. Learners do not begin or conclude their journeys in the same place, and this variability calls for innovative strategies in educational design and support. While this model helps represent learners' needs more specifically, it is merely a starting point in identifying individual learning compared to traditional pedagogy. It calls on educators to understand and build towards new support systems with the evolving landscape of generative AI in education.

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Appendix

Pre-Course Survey Questions
How much LEGO building experience do you have?
Please list any prior robotics experience (LEGO or otherwise) you have.
How much programming/coding experience (any language) do you have?
Please list any programming languages you've used in the past (and if appropriate, the context or depth).
If you do have prior programming experience: when you "get stuck" and need help, what online resource(s) would you use to figure out how to move forward?
What are you most EXCITED about learning (or interested in) this semester?
What are you most EXCITED about learning (or interested in) this semester?
What are you most EXCITED about learning (or interested in) this semester?
Have you used AI before? If so, provide some examples.
What are your general opinions about AI?
Consider the following industries and give your predictions as to how much each will change/be impacted in the future as a result of the impact of Artificial Intelligence: [Technology and Engineering]
Consider the following industries and give your predictions as to how much each will change/be impacted in the future as a result of the impact of Artificial Intelligence: [Education]
Thinking about Education (and YOUR education specifically), write a few sentences about when you think it IS OK to use AI (generative AI systems like ChatGPT) in education.
Thinking about Education/your education: write a few sentences about when you think it is NOT OK to use AI in education.

Post-Course Survey Questions
How much programming/coding experience (any language) do you have?
Which of the following characterizes your coding in this class (select ALL that apply; add other if not listed) With help from the TAs (Teaching Assistants), With help from other student(s) in the class, I used ChatGPT to iteratively generate my code, I manually modified/customized the code initially generated by ChatGPT, I wrote the code myself without help from AI
Reflecting back on your assignments, can you describe a moment in which AI assisted/helped in your classwork. Provide an example and the details of the experience.

Reflecting back on your assignments, can you describe a moment that you spent time trying to use AI but didn't find it beneficial or helpful. Provide an example and the details of the experience.
When you "got stuck" and needed help with coding, what other online resource(s) (other than ChatGPT/generative AI) did you use to figure out how to move forward?
What are your general opinions about AI?
Consider the following industries and give your predictions as to how much each will change/be impacted in the future as a result of the impact of Artificial Intelligence: [Education]
Consider the following industries and give your predictions as to how much each will change/be impacted in the future as a result of the impact of Artificial Intelligence: [Technology and Engineering]
Thinking about Education (and YOUR education specifically), write a few sentences about when you think it IS OK to use AI (generative AI systems like ChatGPT) in education.
Thinking about Education/your education: write a few sentences about when you think it is NOT OK to use AI in education.
How do you think professionals will use AI to benefit their work in the field you are interested in? E.g., if you are thinking about majoring in engineering, how would you as an engineer use AI to benefit your work?
How did this course impact your view of using AI, in both your learning and the field you are interested in pursuing later?
Anything else you want to share?