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GIFTS: Integrating Generative AI into First-Year Engineering Education: From Knowledge Acquisition and Arduino Projects to Defining Accessibility Problems and Solutions

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Introduction: Motivation and Objectives

This Great Ideas for Teaching Students (GIFTS) paper presents two approaches to employing Generative AI (GenAI) in the engineering design process with first-year engineering students at the University of Virginia (UVA). UVA has established a university-wide AI Guides program to explore the implementation of GenAI in teaching practices. This team has gathered information regarding the use and implementation of AI in various academic practices. The results indicate a variety of attitudes and applications of AI in the science and engineering classrooms among both students and faculty. To further the understanding of effective use of GenAI as a tool of both discovery and generating ideas, there is a clear need for more examples of effective applications of AI in engineering education.

Therefore, as the First Year Engineering faculty responsible for developing and implementing the required Engineering Foundations I and II courses that all first-year engineering students, we aim to continue developing innovative ways to more meaningfully integrate AI use and analysis in the engineering classroom. These activities build understanding of and analytical approaches to using GenAI tools such as Copilot in the Engineering Design Process (EDP). Although Copilot was encouraged for this course due to its university licensing, the activities can also be conducted using other GenAI platforms. This GIFTS paper is motivated by the drive to leverage this evolving technology in ways that enhance students learning while fostering a deeper understanding of its benefits and limitations. As AI technology continues to evolve, it is increasingly apparent that we need to develop and share more promising practices that enable faculty and students to navigate various applications effectively. In each activity presented, students integrate technical skills with social and ethical thinking as they explore and evaluate how GenAI can enhance or hinder their engineering design process. These topics are woven into two team-based design challenges to make this meaningful and applicable to students.

Implementation

During the fall semester, Engineering Foundations I is offered across 20 sections, each averaging 37 students, and is taught by seven faculty members. For both projects, students worked in teams of four to five in a classroom setting equipped with basic prototyping tools including woodworking tools, electronics, and 3D printers. In each activity, students are presented with an engineering challenge, then introduced to essential skills and knowledge needed to complete the challenge which effectively frames and embeds engineering foundational skills and content, helping students understand the relevance of these skills and how they connect to the engineering design process.

Activity 1: AI and Arduinos

During the first eight-class session activity, students were introduced to using GenAI as a tool to acquire knowledge and help generate code. During this activity, student teams were presented with a challenge to engineer a mechanism that can go onto a scaled parade float that incorporated an actuator, a sensor, and a team-chosen theme. Students must also individually design a 3D printed piece to go on the parade float and incorporate Arduino UNO R3 and various Arduino electronic components to bring their creativity to life. In addition to developing more effective teamwork and communication skills, this challenge required students to acquire and apply knowledge about CAD, 3D printing, electrical circuits, soldering, and programming.

In this challenge, students first acquired knowledge needed to complete the challenge through both direct instruction and individual and team research. During this research phase, students were not allowed to use any GenAI tool, but they could use any other resources for their research. After the class introduction of the project, along with basic circuits, students individually chose an electrical component such as an ultrasonic sensor or servo. Then, they became their team's "expert" on this component by researching how it works, how to wire it with an Arduino, and by finding or developing a sample code to make the component function correctly. Students then shared their new knowledge with their teammates in order to establish a basic foundational understanding of technology they could use in their designs.

After "becoming an expert", students collaborated to further engineer their final design for this challenge. During this phase of the project, students were introduced to GenAI tools such as Copilot. Because first year engineering students have varied levels of experience with programming, providing a tool such as Copilot allowed the focus of this activity to be less on "learning to program" and more on the other individual skills needed to produce a working mechanism. In this case, a GenAI tool helped generate initial Arduino code and explain how each piece of the code functions. Additionally, this gave students the opportunity to analyze GenAI as a tool to acquire knowledge. Class discussions centered around effective AI prompting, including the differences between entering "good" prompts versus "not so good" prompts and analyzing if the tool is effective at accomplishing the intended goal. For example, if a student wanted to have an ultrasonic sensor sense movement that is 10 cm away and trigger a piezo to play a song and make LEDs light up, the student could seek assistance from a GenAI tool to help develop the code for this. In doing so, students needed to determine if the prompts they generated were clear and specific enough for the AI tool to produce a helpful answer.

During the discussion and implementation of this challenge, students were asked to share what they discovered through this process to develop a better understanding of how to effectively use GenAI and when. Questions included:

1. What prompt did you use in GenAI, and did this achieve your goal?
2. What happened if you changed the prompt to be more or less specific?
3. Do you better understand how to analyze GenAI generated code to see if it will achieve your goal?
4. How did you know if you could or could not "trust" the solutions provided by GenAI?
5. What role does GenAI have in acquiring knowledge or helping in an area you feel less skilled during the engineering design process? And, how did the second part of the project where you were allowed to use GenAI compare to the first part where you were not allowed to use GenAI?

At the end of the challenge, when students presented their final parade float mechanisms, they were also required to reflect and share what they learned about employing GenAI in their design process. More details of the assignment are available in Appendix A.

Activity 2: Problem Statement and Solution Generation

During the second activity, students deepened their understanding of how to utilize and evaluate GenAI responses during the problem definition and ideation phases of the engineering design process. Here, the focus was less on acquiring knowledge, and more on employing GenAI as an editing tool in the initial writing stages and as a tool to pose solutions to a defined problem.

In this activity, student teams were tasked with engineering a device that can be implemented on campus to facilitate sustainable practice or make a daily activity more accessible. This is an eight-week project. At the beginning of the project, students identified obstacles, issues, or inefficiencies that posed sustainability challenges and developed their own problem statements without the aid of any GenAI tools. In the problem statements, students were instructed to include the context of the problem, the specific problem, the current state of doing nothing, and an ideal state, supported by relevant research.

After drafting their own statements, students used GenAI to generate alternative problem statements for comparison. They analyzed whether Copilot could generate a logical, fact-based problem statement for their identified problems. Students evaluated the accuracy of facts by consulting external sources (not GenAI) that would support (or not support) what the AI tool generated. They compared the AI generated problem statements with their own and assessed whether the AI-generated problem statements included the four critical aspects of a good problem statement: context, a specific problem, the current state, and the ideal. At the conclusion of the activity, students reflected on the potential role of GenAI in the engineering design process. More details of the assignment are available in Appendix B. In the subsequent project stages, students were allowed to use GenAI tools for solution ideation by prompting a GenAI tool to generate a five-paragraph solution that meets specific criteria.

Student Assessment and Results

The focus of these activities was not to assess how well students used GenAI, but how they perceived it as a tool in the design process and their ability to articulate relevant ethical considerations regarding its use.

Assessment used for Arduino Activity

During the Arduino activity, students were assessed on their ability to effectively create a 3D component, use the Arduino platform to engineer their final design, and effectively work in a team. Additionally, students self-reflected and self-reported on if they continued to use GenAI to help with their process, and, if so, if they found it effective or ineffective. Similarly, during class discussion, students focused on the importance of using AI in the design process, specifically when generating prompts to help gain knowledge. Through responses to the questions outlined in the activity description, we were able to assess how students perceive and employ GenAI.

From these self-reflections and class discussions, it was clear students developed a foundation for analyzing the efficacy of using GenAI in their process. Through practice, students developed clearer prompts and determined how and when to use this as a tool to help gain understanding in this area.

Assessment used for Problem Definition and Solution Generation

The use of GenAI in the problem statement and solution generation exercises was also assessed through student reports and reflections. Open-ended guided prompts encouraged students to reflect on efficacy and role of AI in the design process by analyzing the responses created by their GenAI tool. Specifically, students examined clarity in argument, factual support, and compared completeness of an argument or problem statement to what GenAI generated. These specific prompts are included in Appendix B.

End-of-Semester Report and Reflection

Students were also asked to reflect at the end of the semester on how they developed their understanding of using GenAI in the engineering design process. In their reflections, students described what tools they used, and when they used them in the design process, as well as their overall perspectives on the advantages and limitations of Generative AI.

Overall, students reported positively on the use of GenAI tools in the design process. The most common use was for brainstorming ideas. Many students also found AI tools helpful for refining technical descriptions and debugging Arduino scripts, particularly in the context of coding. They recognized that AI tools saved them time when exploring technical skills.

While students appreciated the advantages of GenAI tools, they also cautioned about their limitations. For example, students discussed the importance of crafting accurate prompts, noting that the quality of the prompt significantly influenced the usefulness of the response. They also recognized that GenAI at times provided misleading or incorrect information, and that its responses typically lacked ethical and practical considerations important to the design process.

Conclusions

Through the intentional gradual practice and implementation of the use of GenAI tools, students developed a strong foundation in understanding the capabilities and limitations of these technologies. Discussions and student written work demonstrated that students are actively engaged in assessing if and when to apply AI in the engineering design process. This structured approach allowed them to integrate AI tools effectively into their design projects, enabling them to enhance creativity and explore innovative solutions. Beyond mere utilization, students demonstrated the ability to critically analyze AI-generated outputs, evaluating their accuracy, relevance, and ethical implications that they will hopefully generalize to future courses and practices.

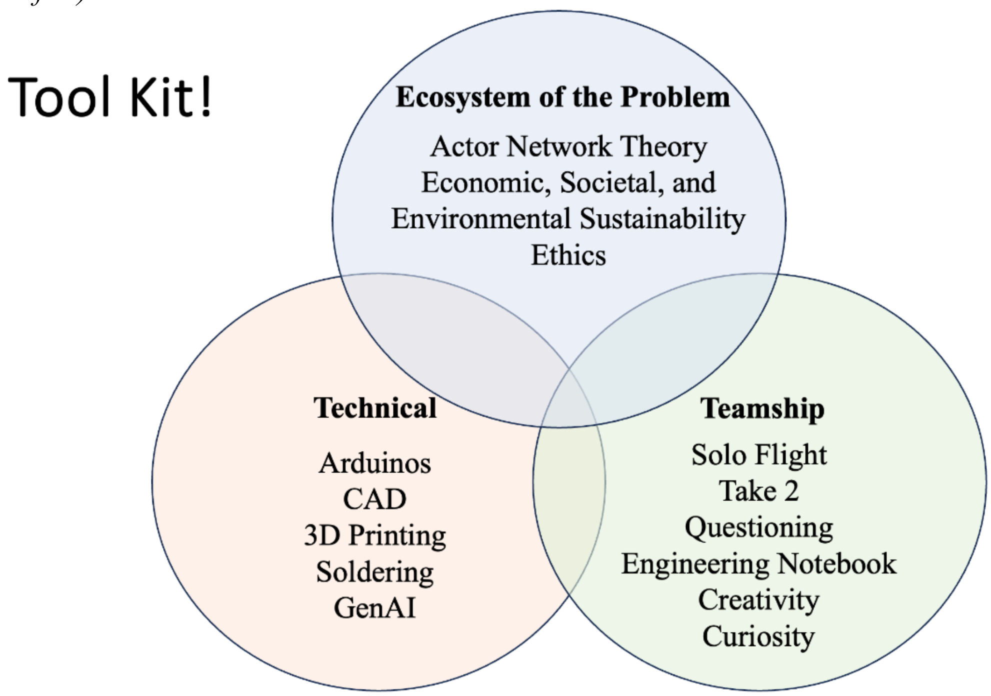
Appendices:

1. Appendix A: Arduino Challenge
2. Appendix B: Problem Statement and Generative AI Assignment

Appendix A: Arduino Challenge

Goal:

With your design team, use the tools diagrammed below to engineer a mechanism to go on a parade float that is activated by a sensor and causes an actuator to do something in a way that makes the float more entertaining and fun. *(No, you are not designing the entire float, just a part of it.)*



Requirements and Expectations:

1. Incorporate at least **one working sensor**
2. Incorporate at least **one working actuator**
3. Include a **correctly soldered** component
4. Document all work and ideas in your team **Engineering Notebook**
5. Have **4 unique 3D printed parts** (see below for limitations and constraints)
6. Include cardboard or other material as the base of your float.
7. Through the process, incorporate discussions around "**Challenge Essential Questions**" relevant to this challenge to inform your design process and decisions:
    a. How are you addressing economic, societal, and/or environmental sustainability challenges in the design process and any potential tradeoffs?
    b. Problem framework: Who are the primary technical, social, natural, conceptual, and economic actors and how do they affect your process?
    c. How are you incorporating principles of Universal Design through the process?

    d. What are the ethical considerations and implications that you will (or did) consider when generating a solutions?
    e. How do you work effectively as a team member and what tools will you use to help your team be productive?
    f. How are you planning to effectively document and communicate the merits of your design and process to relevant stakeholders?
8. Demonstrate **curiosity, creativity, and teamwork** as you collaborate with your team.

Limitations and Constraints:

Float:

1. All parts must fit in your project box.

3D Printing:

1. Each person on the team must design one unique part to be printed (and it cannot be housing for your Arduino or breadboard; it must tie into the theme of your float).
2. You may get inspiration and start with a file from another source, but you *must prove you have significantly modified the part to fit your float theme or goal.* For example, you cannot take a file from Thingiverse and scale it down; you must show you have altered it in some way to make it what you actually want.
3. All 4 parts must fit on a single print bed (250 mm x 250 mm x 250 mm is the max print cube, so plan and space accordingly); all 4 parts for your team will be printed at the same time. (For teams of 3, you will print 3 parts.)
4. You may only print with 15% infill or less.
5. If your total print time exceeds 2.5 hours, we will ask you to change your design (or scale it down).
6. Your instructor will go through the printing protocol in class; make sure to follow it.

Arduino Components:

1. You may only use one of each of these (but you do not need to use all of these):
    a. Ultrasonic sensor
    b. Buzzer
    c. Force sensor
    d. Breadboard
2. You need instructor permission to use more than one of these:
    a. Servo
    b. Flex sensor
3. You may use as many of these as you want (if your design supports it):
    a. LEDs
    b. Resistors
    c. Buttons
4. IMPORTANT: you will be sharing an Arduino Unos R3 with other classes, so your design needs to be easily plugged into and unplugged from the Arduino board. An easy way to do this: take a picture of the circuits you make each class, then you can rebuild them at the start of the next class.

Generative AI Use:

1. For the first part of the project where you “become the expert”, you are not allowed to use any GenAI tool in your research.
2. For the second part of the project, once you have shared what you have learned with your team, you may use Copilot for the project. Remember to evaluate and analyze:
    e. What prompt did you use in GenAI, and did this achieve your goal?
    f. What happened if you changed the prompt to be more or less specific?
    g. Do you better understand how to analyze GenAI generated code to see if it will achieve your goal?
    h. How did you know if you could or could not “trust” the solutions provided by GenAI?
    i. What role does GenAI have in acquiring knowledge or helping in an area you feel less skilled during the engineering design process? And, how did the second part of the project where you were allowed to use GenAI compare to the first part where you were not allowed to use GenAI?

Appendix B: Problem Statement and Generative AI Assignment

Goals:
- Evaluate viable problem statement for your defined sustainability problem
- Analyze if Copilot can generate a logical, fact-based problem statement to your posed problem
- Determine what role Copilot may play in the engineering design process

Background:
We all know tools like Copilot can generate information and interesting arguments when given a prompt. The real question is: do you trust what Copilot or other tools generates? It is your responsibility to actively challenge, question, and analyze arguments AI generates in response to your prompts. This activity is aimed at intentionally making you think about:
- Problem statement of your proposed sustainability problem
- Using tools like Copilot to gain and analyze information
- Determining accuracy of facts included in arguments generated by an AI tool like Copilot
- Analyzing the efficacy and logic presented in response to your prompt

What to Do:
1) Open Copilot
2) Ask Copilot to generate a problem statement for your sustainability problem.
3) Open a word doc and title it "Copilot problem statement to _____" (fill in the blank with the title of your problem)
4) Retype your prompt at the top of your document in **bold** font
5) After running Copilot, copy and paste what Copilot generates into this document and make the font **blue** (yes, this is the only time you can copy and paste from this website)
6) Read through what was generated and answer the following in your document:
- Highlight "facts" that were generated supporting the argument
- For each "fact" presented, find one outside source (not from GenAI tools) that would support this fact. You may not ask Copilot to cite its sources; you must find resources that support (or not support) what Copilot wrote. In **green**, write the source and identify if the source does or does not support the fact and why. (Put this at the end of the copied answer.)

7) Re-read the argument. In **purple**, answer the following in complete sentences in your document:
- Does this argument make sense?
- Do the "facts" support the argument?
- Was there even an argument made, or does it leave the reader with more questions than answers?
- Does it **provide context, present a specific problem, articulate the current and ideal state of the problem** (the four aspects of a good problem statement)?
- How would you compare the AI generated problem statement with the problem statement you developed?
- Based on this activity, what role do you think Generative AI could play in the engineering design process? Explain.