THE INTERSECTION OF AI AND BLOOM'S TAXONOMY IN DESIGN EDUCATION: A ROBOTIC DESIGN CASE STUDY

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ABSTRACT
Generative Artificial Intelligence (GAI) tools are getting involved in the learning process of new generations, and these tools can make a change in product design education, which can be used in different design phases. This study examines their integration through a student project at Linköping University, focusing on the creation of an autonomous robot. From its observation and reports, it is analysed how these tools influence the different design phases and their application, and how students with different skill levels adapt to AI integration. This case study presents not only the practical use of GAI in design but also its impact on educational paradigms, particularly in how it gets involved and reshapes the traditional learning hierarchy outlined by Bloom's Taxonomy. Our findings indicate that GAI tools not only improve efficiency in the design iteration but also introduce a possible shift in learning approaches when it comes to new skills, which may make students skip the learning of base knowledge. GAI has the potential to promote an inverse learning sequence in which students participate in practical application and creation before fully understanding theoretical foundations. This shift implies a re-evaluation of educational frameworks to ensure that while embracing the benefits of GAI, critical thinking and foundational knowledge are not excluded. A balanced approach to teaching that incorporates GAI tools while preserving fundamental engineering and design concepts might be a desirable future.

Keywords: Designing with artificial intelligence, GAI processes, design and product development, CDIO 3.0, design engineering education

1 INTRODUCTION
Education in design and product development is facing immediate change as a result of the text-to-creation revolution or the more popular name Generative Artificial Intelligence (GAI). GAI refers to using prompts to create a creative output by entering sentences or words, for example, "classic car, E-type, Bugatti Chiron" and a photorealistic image is generated nearly instantly. This revolution started in late 2021 and has evolved exponentially. Another type of GAI is Large Language Models (LLM). LLM has a longer history stemming from the middle of the 1960ies when Joseph Weizenbaum developed the first chatbot ELIZA at MIT and became known to the public when OpenAI introduced ChatGPT in 2022 [1]. Today, GAI tools can generate executable code, create layouts for designs, perfect design renderings of simple sketches, and 3D printable models directly from graphic images. In design and product development, this means that the step from idea to concept, which previously required extensive experience with various computer programs and several hours to do, can be carried out in a few seconds. Nowadays, engineering students in design and product development can rapidly explore a large number of possible ideas, create new concepts, and explore the design space by generating and developing variations. Repetitive design tasks can also be automated. This means that the time spent in the early product development phases such as the Planning Phase 0 and Concept Development Phase 1, [2] can be used more efficiently. Design judgement and decision-making processes [3] may also be affected using GAI tools. It may place higher demands on design engineers and product developers due to more choices and more opportunities and increase the number of bad proposals. Pedagogic discussions on how to educate students in GAI for design and engineering and what to teach will be ever more paramount in the near future. Curriculums will need to change; courses need to be updated and new ones created.

This paper explores how students' learning outcomes are influenced by the use of GAI tools in the course Advanced Product Development given by Linköping University in the fall of 2023. Bloom's taxonomy [4] is utilised as a framework to analyse and discuss the findings.

2 THEORETICAL FRAMEWORKS

Bloom's Taxonomy, created by Benjamin Bloom in 1956, is a foundational educational framework that classifies cognitive skills required for learning into a hierarchy from basic to complex [4]. t progresses from lower-order thinking skills (LOTS), which include "Remembering" and "Understanding," to higher-order thinking skills (HOTS) such as "Applying," "Analysing," "Evaluating," and "Creating" [5]. This framework is essential for designing curricula and assessments that meet diverse cognitive demands.

At the "Remembering" level, students recall facts and basic concepts. "Understanding" involves explaining ideas or concepts by organizing and summarizing information. "Applying" sees learners using knowledge in new situations. In "Analysing," students break down information into components to examine and understand its structure. "Evaluating" involves judging based on criteria to critique ideas or materials. The highest level, "Creating," requires synthesising information to form new patterns or structures, representing the most complex cognitive tasks [6].

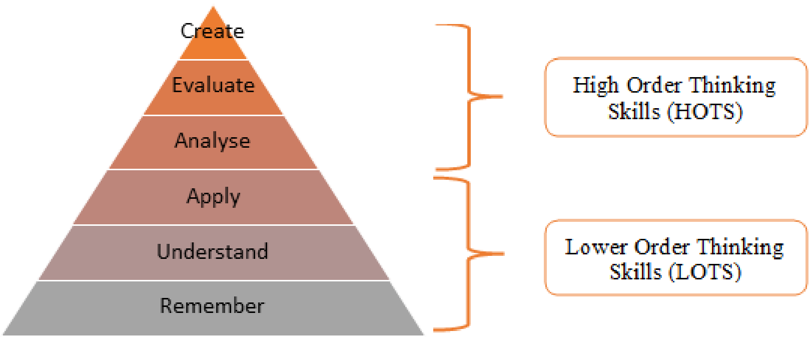

Figure 1. Bloom´s Taxonomy [5]

The integration of Generative AI (GAI) adds complexity to Bloom's Taxonomy, suggesting that traditional educational models and the application of the taxonomy might need re-evaluation[7].GAI tools enhance learning by providing access to extensive information, personalized pathways, instant feedback, and expanded creative options. This challenges the traditional progression of cognitive skill development and calls for a revision of learning experiences to leverage GAI's dynamic capabilities.

3 COURSE DESCRIPTION OF ADVANCED PRODUCT DEVELOPMENT

The advanced product development course is a mandatory twelve ECTS (European Credit Transfer and Accumulation System) credits master's student project course at Linköping University, Sweden, that runs during the autumn semester and ends before Christmas with an exhibition. The course projects must have both industry and scientific relevance, several of which stem from ongoing research projects. Each project team receive their project brief from either a company, a research group, or a governmental organisation. Pedagogically, the course follows the CDIO 3.0 [8] framework which stands for Conceiving–Designing–Implementing–Operating. The core principle of the pedagogic framework is that engineering education is more than technical knowledge and skills, it is part of a larger context that encompasses "product, process, system, and service lifecycle development and deployment" [8].

The course mandates that students work in teams to solve an open-ended brief. They are expected to take responsibility for the progression of the project and learning outcome. The project teams are mixed from three different engineering educations to create multidisciplinary teams [9, 10]. Students apply for the projects making the teams highly motivated and increasing the rate of success in the projects.

The intended learning outcomes for the course include mastering the identification, selection, and application of theory and knowledge areas tailored to specific problems. Students will plan, implement, and research an industry-related product development project, and systematically integrate knowledge acquired during their studies to solve real product development challenges. Additionally, they will apply

methods and knowledge from design and product development, create, analyse, and evaluate technical solutions, and utilize relevant literature to the project.
This article examines one of the student projects in the course Advanced Product Development and analyses how the new technology of GAI influences their design and learning process.

4 CASE STUDY: STUDENT PROJECT FUTURE OF AUTOMATION SKETCH TO-3D PRINTED ROBOTICS

The research methodology in this article follows Miles et al. [11] process of qualitative data analysis. As in line with Yin's [12] recommendations when doing exploratory research where the goal is to understand 'why' and 'how' things have happened and explore contextual phenomena.
Case description: A global material handling company tasked students with a project to explore automation, robotics, GAI, design, 3D printing, and computational linguistics. This initiative aims to transform product design and development, emphasizing the application of emerging technologies for future uses. The project's goal is to leverage various AI tools and processes to design new functions, components, and modules for an autonomous robot, culminating in a proof-of-concept model.
Participants: The student team consisted of five students from two different educations, all students identified themselves as male and were 24 years of age. They study their ninth semester in a five-year civil engineering program (master level). All had selected the project as their primary choice.
Data collection: The authors monitored the student's progress through weekly meetings, collecting their project reports, reflections, and final presentations. Notes were taken during a mandatory seminar where students discussed their methods and processes. The students' exhibition materials, proof-of-concept robots, and posters were also photographed.
Data analysis and Conclusion drawing: The collected material was analysed in two ways; first through a grounded theory [13] approach where cues and themes were coded, and analysed and new conclusions were drawn on how the students described their design process and how it was influenced by their application of new GAI tools. The second approach was to analyse the student's learning outcomes utilising Bloom's Taxonomy [6], understanding learning patterns in the design steps.

5 STUDENTS DESIGN PROCESS APPLYING GAI

In the process of designing a robotic as an educational design challenge, the integration of Generative Artificial Intelligence tools has modified the way students approach the development of new design challenges in this context. This section outlines the design steps and GAI tools employed by students to design a robot, emphasizing an iterative process. From an initial idea to the final stages of optimization, GAI tools have been instrumental in guiding students or supporting them through the phases of the design process. In the next figure, the steps supported by GAI in this case study are shown.

Figure 2. Depicts the students' overall design process in the project

The utilization of Generative AI (GAI) technologies in different phases of the design process significantly enhanced creativity, visual representation, depth, modelling, prototyping, and optimization. In the brainstorming phase, OpenAI's GPT and Bing's DALL-E generated numerous initial concepts, fostering an environment for creative exploration and idea refinement. During the visual representation stage, Vizcom aided in sketching and refining designs, with additional support from Adobe Firefly and Photoshop to enhance image details. ZoeDepth contributed by adding depth and enhancing the realism of visual representations. In modelling, tools like Blender and Fusion 360 allowed for precise 3D modelling, while Common Sense Machines (CSM) streamlined the transition from 2D sketches to 3D models. The prototyping phase involved using 3D printing and Arduino components, with guidance from ChatGPT to create functional prototypes and understand electronic functionalities through iterative trials. Lastly, in the optimization phase, Fusion 360's GAI capabilities were utilized to optimize the robot's design for better structural integrity and efficiency. The degree of AI reliance varied among students based on their prior knowledge, affecting their ability to critically evaluate and refine the GAI outputs.

6 ANALYSIS OF BLOOM TAXONOMY IN THIS CASE STUDY

When bringing GAI into classrooms, especially for projects like building robots, it can change the way students get involved in the learning process. Bloom's Taxonomy [6] is a way to think about learning, starting with basic remembering and moving up to creating new things. But when students use GAI, in this case study we observed that the order of those steps might change.

During the semester, two different themes were observed in the student design process. The first is when students use GAI as a helper for tasks, they're already good at. The second is when GAI helps them dive into areas they don't know much about yet. As we look at these situations, we show how GAI might make us think differently about the steps of learning it has always been used. It was observed that sometimes, students jump right into applying and creating with AI's help, even before they fully understand or remember everything about what they're working on. This indicates that educators need to ensure that theories, foundational principles and best practices are not overlooked when GAI tools are involved.

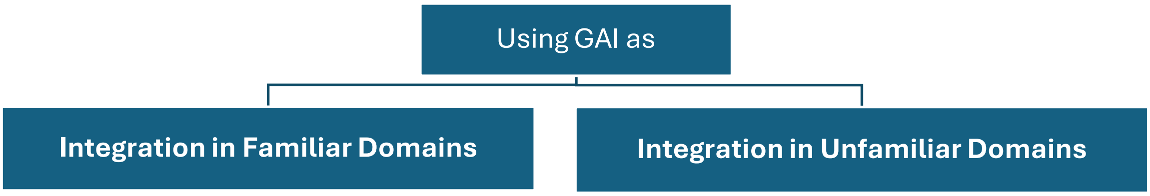

Figure 3. GAI integration themes

AI Integration in Familiar Domains When students applied GAI tools to tasks within their skill set, they adhered to the conventional order of Bloom's Taxonomy (Figure 1). GAI served as a booster, enabling fast prototyping and iteration but did not fundamentally alter the cognitive process. Students began with the remembering stage, recalling prior knowledge. They proceeded to understand the task as sketching, applying their skills using GAI, analysing the outcomes, evaluating the results being able to put into context issues with the perspective of the dimensions thanks to their prior knowledge, and finally creating solutions.

Theme 1: AI Integration in Familiar Domains

1. **Remember**: Students recall their existing knowledge of sketching, CAD, and prototyping. This is the stage where they bring to mind what they already know before engaging with GAI tools.
2. **Understand**: They understand the principles behind the design tasks. For example, they understand that certain design requirements need to be applied to the robot and what makes for a functional and aesthetic prototype.
3. **Apply:** GAI tools come into play here. Students apply their knowledge, using GAI to support and improve the modelling and sketching tasks they are already familiar with. The GAI ease rapid prototyping and iteration, allowing for quick visualization and modification of designs.
4. **Analyse:** With GAI-generated models, students analyse a broader number of alternatives as outcomes to ensure they meet design requirements and specifications. They use their knowledge to analyse the GAI's work, understanding how the design choices affect functionality and user experience.
5. **Evaluate:** Students evaluate the efficacy of using GAI in the process. They can critically assess the quality and efficiency of what was created by GAI integration, comparing it to traditional methods they are used to.
6. **Create:** Lastly students use their knowledge and the GAI's capabilities to create an advanced result. The creative process is interfered with by their understanding of the subject, in combination with the GAI's ability to generate and modify quickly.

GAI Integration in Unfamiliar Domains A shift takes place when students engage with unfamiliar tasks, such as Arduino prototyping. Here, the cognitive process begins with the Apply stage, as they make use of GAI to perform tasks beyond their current understanding, trusting the tool. Following this, they entered the Create phase, using GAI to generate functional code and circuit design suggestions that they put into practice. They might not be able to generate the code by themselves, and they don't understand what it is in the code, but they make use of it. This inversion highlights a learning process that is exploratory and application-driven, leading to an understanding of how basic concepts work by trying out the AI indications and leading us to a remembering face. As they Analysed and Evaluated the functionality of their creations, they gained a deeper understanding of the underlying concepts by comparing what they promoted for, and what they got as a result. In this case, we would see a mix of lower-order thinking skills (LOTS), and higher-order thinking abilities (HOTS). This becomes an iterative process where knowledge is gained through applying unknown knowledge and trusting a GAI tool.

Theme 2: AI Integration in Unfamiliar Domains

1. **Apply**: Students begin by applying GAI tools to generate code and instructions for building an initial part of the robot with Arduino, with which they are not familiar with. They trust GAI to guide them through the coding process leading to a creation step which might or might not result in their initial objective.
2. **Create**: Based on the GAI-generated instructions and code, they create a functioning piece of the robot. The creation here is more exploratory, as they are heading into an area where they have less or no experience.
3. **Remember:** Positioned after the hands-on experience of creating, the act of remembering is now framed by a context of practical engagement. At this stage, students are more likely to internalize the concepts and procedures of Arduino coding, as their thoughts are based on tangible experiences, errors, and achievements. They remember the way of connecting the different components thanks to the GAI guidelines and creation as a result.
4. **Analyse**: Once a part of the robot is created, the student analyses its functionality. They examine the result and see if it aligns with the expected outcome.
5. **Evaluate**: The evaluation phase involves assessing the performance of the robot and the accuracy of the GAI-provided instructions. They consider the efficacy of the solution and identify any gaps in functionality for later on going back to the application phase.
6. **Understand**: Through trial and error and the iterative process of analysing and evaluating, students begin to understand how the Arduino works. The GAI's guidance, combined with practical application, leads to a conceptual understanding of the coding and electronics involved.

7 DISCUSSION AND CONCLUSION

The implementation of GAI tools into the educational design process, particularly in this context of robotic design problems, represents a transformative approach to learning and creativity. The use of GAI tools changed students' approaches to the design challenge given by the case company. These tools did not only aid the creative process, but also functioned as co-creators allowing for a larger exploration of ideas, rapid prototyping, and optimization. The GAI-enhanced iterative design approach enabled the students to efficiently refine their ideas from abstract notions to a proof-of-concept prototype. However, a GAI-driven design learning method raises various considerations. Firstly, we identified that the case students' learning process, as defined by Bloom's Taxonomy [6], got disrupted when GAI tools were introduced. From the comparison of both scenarios previously presented, the students' learning approach in this exploratory project, in some phases, began by directly applying GAI tools and techniques to find knowledge, skipping the basic stages of remembering and learning.

Second, the implementation of GAI requires critical thinking in both learning and design. Although GAI tools aid in various design tasks, they demand a critical analysis of their proposals, acknowledging that these solutions might not always be the most effective or efficient. Rapid results from GAI can be misleading without a solid understanding of the underlying concepts, underscoring the importance of critical thinking and problem-solving skills beyond mere tool usage. This case study highlighted how students applied critical thinking to familiar tasks like sketching, modelling, and optimization when using GAI.

Using GAI requires trust in the technology, especially when applied to unfamiliar areas. However, this trust needs to be balanced with critical analysis. Students should not only use GAI technologies but also critically evaluate and question their outcomes, exploring alternative applications. Educators should offer guidelines to help students assess the relevance, accuracy, and reliability of GAI results, recognizing that while these tools enhance learning and creativity, they are not infallible.

Lastly, this new setting can bring issues about what it means to teach and learn. The problem is not just in finding the right way to implement these technologies, but in understanding the teacher's position in a GAI-enhanced learning setting when it becomes easier to avoid early steps in Bloom's taxonomy (Figure 1), i.e. building a knowledge foundation in a subject. Teachers may need to emphasise more on teaching 'basic principles' in subjects to encourage critical thinking and creativity beyond what GAI can provide in building a strong knowledge foundation. At the same time, in some scenarios the teacher's role might change to facilitator and help through reflections, once the basic concepts are settled, being able to create more personalised and independent learning processes for the students letting them become more self-directed.

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