Building Locker Mini-Worlds: A CAD Course with a Semester-Long Project

Abstract: Computer-aided design (CAD) education requires extensive practice for students to grasp 3D spatial thinking effectively. In this paper, we present the design and implementation of a CAD curriculum within the Creative Technology and Design undergraduate program at the ATLAS Institute, University of Colorado Boulder. The curriculum aims to cultivate students' proficiency in 3D spatial thinking through a semester-long project focused on constructing miniature worlds within lockers. Through this project-based approach, students engage in hands-on learning, applying CAD techniques while fostering collaboration and creativity.

The curriculum design integrates Project-Based Learning and Collaborative Learning methodologies, providing students with autonomy and encouraging teamwork. Weekly design assignments and milestones guide students through the project's development, enabling iterative design and continuous feedback. This pedagogical approach emphasizes practical application and reinforces theoretical concepts.

Student learning outcomes indicate increased engagement and proficiency in CAD software, with all the students completing their mini-world projects. The curriculum effectively enhances students' CAD skills and engineering design capabilities. We also discuss the challenges that students face with this curriculum.

Our curriculum offers a comprehensive learning experience, integrating theoretical knowledge with practical application. By emphasizing hands-on learning and collaborative projects, the curriculum prepares students for real-world engineering challenges. We conclude this paper with recommendations for educators based on lessons learned from the implementation, aiming to further enhance the effectiveness of CAD education.

INTRODUCTION

In the pursuit of developing students' engineering, design, and critical thinking skills, the Creative Technology and Design undergraduate program at the ATLAS Institute, University of Colorado Boulder emphasizes a hands-on approach to learning. Central to this approach is the FORM course, a mandatory course typically undertaken during students' sophomore or junior years. This course focuses on equipping students with essential 3D modeling, printing, and rapid prototyping skills through the use of Computer-Aided Design (CAD) software. The overarching goal of the FORM curriculum is to foster students' ability to think and work proficiently within three-dimensional space.

In this paper, we discuss the experiences and insights gained from the implementation of a collaborative mini-world project within the FORM course. Throughout the semester, students are tasked with constructing miniature worlds within the lockers. This project helps students translate theoretical concepts and technical skills into the real world, while nurturing collaboration and encouraging their creative potential. Our curriculum is designed to meet the diverse backgrounds and skill sets of students within our department, underscoring the importance of foundational 3D modeling and spatial thinking skills. To enhance student engagement and efficacy in mastering CAD techniques and engineering design principles, we use a pedagogical approach rooted in Project-Based Learning and Collaborative Learning. By embarking on a semester-long project centered around the construction of mini-worlds, students are empowered to take ownership of their learning, while collaborative endeavors instill vital communication and teamwork skills.

In the subsequent sections, we discuss the design and implementation of the FORM curriculum. Through an exploration of student learning outcomes, challenges encountered, and reflections on the curriculum, we conclude this paper with insights for the design and implementation of similar courses in the future.

BACKGROUND

Topics Covered in the FORM Curriculum

The use of 3D technologies in education has been steadily increasing, driven by advancements in technology and a growing recognition of the importance of digital literacy. The introduction of computer-aided design (CAD) has made 3D design more convenient, leading many engineering-related degree programs to include a CAD course [1]. In our department, we have developed the FORM curriculum to teach students the fundamentals of 3D modeling, animation, and printing from both conceptual and practical perspectives.

The application scenarios of CAD technologies are different in different disciplines, and thus the focus of the courses is different. In our department, students' backgrounds range from interface design to product design. Although there are different needs for CAD skills, as the first CAD-related course for students, the main focus of FORM is to teach students basic 3D modeling and spatial thinking skills. To this end, we taught students to use CAD from a design methodology perspective [1]. More specifically, the FORM curriculum covers the following CAD design methodologies:

- Design Philosophy: students will learn both top-down and bottom-up designs
- Parametric Modeling: Students will learn constraint-based modeling
- Feature-based Modeling: Students will learn to model with features
- Creative Design: Students will learn how to build on existing models

In addition to teaching CAD-related skills, the FORM curriculum also covers different engineering design concepts. Previous researchers have suggested that the most important learning goal of CAD education is to teach students that design is a process [4]. We need to teach students not only how to use CAD software, but also to understand the whole process of designing and developing with CAD. To this end, the FORM curriculum also includes the following specific topics:

- Product Data Management: Students will learn how to manage their documentation
- Reverse Engineering: students will learn to model based on existing physical objects
- Prototyping and Manufacturing Methods: Students will learn about different fabrication methods, including common prototyping methods and industrial manufacturing methods.
- Design for X: Students will learn how to design for different scenarios, including Design for Assembly, Design for Manufacturing, and Design for Accessibility and Safety.

Pedagogical Approach

To better engage students with these CAD techniques and engineering design concepts, the FORM curriculum guides students through the consistent development of one project throughout the semester. The pedagogical approach used in the FORM course is a combination of Project-Based Learning and Collaborative Learning.

Project-Based Learning is a student-centered learning approach that is based on constructivist principles [3]. The freedom and challenge that students experience in developing projects result in a high level of engagement [6]. Based on this pedagogical approach, we designed the FORM curriculum to center around a semester-long project: building a mini-world in a locker. Student engagement in this project challenges them to apply the knowledge and skills they have learned in the lectures. With this project, we intended to foster student autonomy, as they have the freedom to explore their ideas within the framework of the project. The course also includes weekly feedback and midterm milestones. This provides students with the opportunity to solve problems through iterative design, continue to develop the project, and receive constant feedback as they develop the project.

Collaborative Learning involves students working together in groups to solve problems and complete tasks. This educational approach helps to increase students' self-esteem, reduces their anxiety about coursework, and encourages active engagement in the learning process [5]. In the FORM course, students work in groups to develop projects throughout the semester. This collaboration encourages communication and teamwork among students. It also encourages students to share their expertise with each other. In addition to the project, we also set up student workshops where students are encouraged to share skills they learned from their projects.

Design and Implementation of the FORM Curriculum

Course Structure

FORM is a 3-credit required course that runs for a standard 15-week semester. Students are expected to attend 150 minutes of class and 5 hours of out-of-class work time per week. The FORM course is designed to include a 75-minute lecture and a 75-minute lab per week. Lectures focused on different topics each week. The first 13 weeks of lectures are provided by the lecturer (Author 1) except for one guest lecturer, and the last 2 weeks of lectures include workshops organized by the students. The weekly labs are organized by both the lecturer (Author 1) and the learning assistants (LAs). During labs, students are expected to complete a lab assignment to practice what they have learned in class. These assignments are sent out at the beginning of the lab session and students are expected to complete these assignments independently. Students are expected to complete a total of 13 lab assignments, which count as 40% of their final grade.

In addition to the lab assignments, students are required to complete the Skill Demonstration independently, which counts as 10% of their final grade. This requires them to complete two of the three tasks by week 13:

- Pass the LinkedIn Skill Assessment for Autodesk Fusion 360
- Get one Autodesk certification
- Preparing a Fusion 360 workshop for a topic not covered in the lectures

As the only project in the FORM curriculum, students are asked to work in groups and build mini-worlds in their lockers. This project counts for 50% of their final grade. Students are free to choose the theme of the mini-world they wish to build, and they are expected to submit a project proposal by week 4 in groups. Students are also expected to submit individual designs each week based on the weekly lecture topic, prompt, and theme of their mini-worlds. These designs will be applied directly to their project. Finally, students are expected to submit a final report at the end of the semester, including all design documents and drawings.

Student Background and Group Formation

A total of 40 students enrolled in the FORM course during the semester discussed in this paper. These students' backgrounds range from UI/UX design, product design, game design, and more. The majority of these students (n=38) were in the 2nd or 3rd year of their undergraduate program. Some students (n=15) had prior CAD experience, including using CAD software such as SOLIDWORKS and Fusion 360. We chose Fusion 360 as the CAD software to use since most of the students use Apple computers.

During the first week, we tested the students on their spatial abilities. The test consisted of 28 questions on 6 topics: Identical Figures, Keyholes, Top-Front-End, Hole Punching, Cube Counting, and Pattern Folding. A total of 19 students were found to have good spatial ability (scores of 16 and above), with the majority of these students (n=13) having prior CAD experience; 5 students were noted as possibly needing help with spatial thinking (scores of 10 and below).

We had a total of three lab sessions at different periods, two of which had 14 students and the other had 11 students. Students were asked to team up with others in the same lab session. Since

most of the students knew each other, we encouraged them to form their own groups. Students ended up forming 10 three-person groups and 5 two-person groups.

Mini-World Project

Each group was provided with a locker unit at the beginning of the semester. Each locker unit measures approximately 12 inches wide, 14 inches deep, and 23 inches high. These lockers are located in the common hallway and students fill out their group information on the locker door. During the last week of the semester, these lockers were opened to the public and voted on to choose the most popular mini-worlds.

Students can choose their own theme for their mini-world projects. During the first week of class, we showed students different examples of mini-world projects for schools, libraries, and houses that we found on the internet. We also encouraged students to look for more examples for inspiration. Some basic rules include students should not damage the lockers in any way (e.g., removing the hook inside the lockers), and all building must occur inside the lockers (that is, students need to make sure the locker doors can be closed at all times). Meanwhile, students are expected to build as many or more levels/stories as the number of people in their group (e.g., a group of three would need to complete a mini-world with three or more stories).

STUDENT LEARNING OUTCOMES

Student Engagement

We assessed student engagement primarily through student self-reporting, as suggested by [2]. Based on the results, all students considered themselves actively involved in the course as well as in the development of their projects. We organized peer evaluations within student groups at mid-semester, and one student pointed out that their group mates were not contributing enough to the mini-world project. This improved in the second half of the semester and all students were satisfied with the engagement of their group members.

In addition, we also consider rating and observation as indicators for assessing student engagement [2]. Students are expected to participate in lectures and labs, but attendance is not credited to the student's grade. Most students had no absences during the semester; 6 students were absent for 5 or more lectures and 1 student was absent for 2 or more labs. The average final grade for all students was 93.53% with an A grade. Most of the students who were frequently absent from lectures (n=4) ended up with grades of B- and below. Most students (n=37) completed their weekly design assignments on time except 3 students who missed more than 2 assignments. Many students also shared their experiences with other students who did not participate in the FORM course that semester. Some students also posted their development process on social platforms, such as YouTube and TikTok, during their building process.

Overall, we have been successful in FORM curriculum design in terms of student engagement. Through a semester-long project, we were able to keep students actively engaged. In comparison to other project-based CAD courses, students self-reported that they had a better sense of the timeline for project development. The longer teamwork period also enabled them to work more collaboratively. By the end of the semester, all students were proficient in modeling with Fusion 360. The majority of students (n=38) passed the LinkedIn Skill Assessment for Autodesk Fusion

360 and added the badge to their homepage. Most students (n=30) prepared workshops of 30 minutes or more to share the additional skills they gained in the development of their projects.

Student Work And Achievements

All students completed their locker mini-world projects. At the end of the semester, the projects were presented publicly and all visitors were invited to vote for the projects. Out of all the student projects, visitors have selected the most popular mini-world *Slice Of Earth* (Figure 1 left), the most complex design *Dante's Inferno* (Figure 1 middle), and the most interesting design *Field of Stars* (Figure 1 right). These projects were also kept in our department for one more semester for additional visits.

Figure 1: Slice Of Earth (left), Dante's Inferno (middle), and Field of Stars (right)

CHALLENGES AND REFLECTION

We gained insights from this semester-long project on the challenges and opportunities faced by CAD education. While the design of our curriculum was successful, we observed different challenges faced by our students during implementation. Commitment to a long-term project was the biggest issue faced by the students. Not all students' final mini-worlds maintained the same theme as their proposals. One group of students quickly revised their plans after submitting their proposals, which they claimed was due to realizing they did not have enough time to complete their original designs. Another group of students completely revised their theme by midterm, stating that they realized that their previous theme was overlapping with another group.

In addition, we noticed that students were extremely enthusiastic about the projects at the beginning of the semester, but the lack of skills may have led to their frustration. For the first couple of weeks, many students were not able to complete the designs they wanted due to the

limitations of the CAD skills they were taught. Some students with prior CAD experience had a distinct advantage in project development prior to this point, which put them in a natural position to be team leaders. However, this also led to some students reporting their concerns about not being able to build as soon as they wanted to. While the project-based curriculum fostered creativity and collaboration among students, it also highlighted the importance of project management and technical proficiency. These challenges faced by students also indicate that we, as educators, need to plan for scheduling especially in guiding students through the projects.

Overall we consider this FORM curriculum design to be a success. Students learned CAD-relevant skills and engineering design concepts in the course and were able to apply them practically through the mini-world project. From the implementation of the course, we have summarized the following tips for future reference in similar courses:

- Identify student learning objectives along with the course schedule. When designing semester-long projects, these learning objectives should match the skill levels of the students and the timeframe of the course.
- Consider the current knowledge and skill levels of the students. This means that we need to ensure that students have access to the necessary technical support and resources (from lecturers and learning assistants). Personalized support is needed especially when students have different prior experiences with CAD software.
- Provide frequent feedback and assessment. When designing this semester-long project, we need to consider how to provide frequent evaluations of students' progress. In this curriculum design, we do this in the form of weekly assignment evaluations, midterm self-evaluations, and peer review with group discussions to identify issues promptly and to provide guidance and support.
- Provide opportunities to share and demonstrate. Have the students present their projects and share their experiences and insights from the development process with others. This is a great activity to boost students' confidence and also to motivate other students, especially those who will be taking this course in the future.

CONCLUSION

Our curriculum centered on a one-semester mini-world project, which successfully achieved the learning goals of the Creative Technology and Design undergraduate program at the ATLAS Institute, University of Colorado Boulder. Through a blend of Project-Based Learning and Collaborative Learning methodologies, students have learned essential CAD skills while also polishing their engineering design proficiency. Our curriculum's emphasis on practical application, coupled with iterative design and constant feedback, has fostered student engagement and autonomy. Students have demonstrated proficiency in CAD software, evidenced by the successful completion of their mini-world projects and certifications obtained. Moreover, the collaborative nature of the project has facilitated the development of communication and teamwork skills, vital for success in the professional sphere.

Challenges encountered during implementation have provided valuable insights for the future development of the curriculum for similar courses. The recommendations we derived from this implementation offer guidance for educators seeking to enhance CAD education. Identifying clear learning objectives, providing support to students, and providing opportunities for sharing and demonstration are crucial aspects to consider in such curriculum design.

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