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Adapting CAD Education for Visual Inclusivity

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Adapting CAD Education for Visual Inclusivity

Abstract

A unique curriculum adaptation of a Computer-Aided Design (CAD) course was developed for visually impaired students. This initiative was undertaken to ensure equitable access and foster an inclusive learning environment. The curriculum was designed to familiarize students with the functionalities and limitations of CAD software and the foundational processes of design, and to facilitate their interaction with other engineers using these tools.

The teaching approach predominantly involves a series of 3D printed models accompanied by detailed text documentation, illustrating the CAD creation process behind these models. A teaching assistant (TA) is assigned to guide students following the adapted curriculum through examples and assignments aligned with the standard class syllabus. Assignments were tailored to include both the study of pre-made 3D printed parts and the oral description of steps for creating similar parts in Siemens NX. This method not only addresses the unique needs of visually impaired students but also provided insights into the effectiveness of tactile and descriptive learning in CAD education.

The broader impact of this work lies in its demonstration of the potential for personalized teaching techniques in engineering education, particularly for students with visual impairments. It underscores the importance of inclusivity in technical fields and paves the way for more accessible and diverse educational environments.

Introduction

At the University of Southern California (USC), AME 308: "Computer Aided Analysis for Aero-Mechanical Design" is a required course in the undergraduate mechanical engineering curriculum. The course introduces students to CAD software and tools, including basic sketching and extrusion; 3D featuring; synchronous modelling; creating assemblies and drawings; finite element analysis (FEA); surfacing; and kinematic analysis. The course also discusses topics in geometric dimensioning and tolerancing (GD&T), which are vital to mechanical design. These techniques are presented to students via Siemens NX, although many of the discussed design principles and techniques are applicable to other CAD software.

In the Spring semester of 2024, a blind student pursuing their bachelor's degree in mechanical engineering enrolled in AME 308. Since CAD software is typically graphics-based, there is little opportunity for the student to directly engage with the software. In anticipation of their enrollment in the required course, the AME department at USC assigned a PhD student as a dedicated teaching assistant to develop course materials that would allow the student to participate in AME 308. The TA was also tasked with creating a set of adapted assignments that are both instructive and allow for a fair evaluation of the student's learning. These assignments and materials were designed to provide an equitable and comprehensive learning experience, accommodating the student's needs while maintaining the course's rigorous standards.

The objective of the project is to provide the student with an intimate understanding of the capabilities and limitations of computer-aided design, as well as the ease or difficulty of executing certain tasks using this type of software. Ultimately, CAD software is not well-designed for visually impaired users, and this project will not necessarily provide the student with the ability to utilize the software directly. Instead, it is expected that the developed course materials and assignments will prepare the student to confidently and effectively collaborate with other professionals in environments where CAD tools are employed.

Existing Support for Use of CAD Software by Visually Impaired Individuals

Since the AME 308 lectures are based on Siemens NX, it was important that any adaptation of the course to enhance visual accessibility be based in NX as well. As of 2019, NX did not have any native support for visually impaired users [1].

As an alternative, OpenSCAD is a free CAD software whose operation is purely script-based. The user provides a text script which the program parses to produce a 3D rendering of a solid. [2] While in principle a visually impaired user could create such a script using a screen reader or braille display, there is no support for them to visualize the created part and troubleshoot the designs without seeing the software's rendering of the script.

This initiative also considered the use of tactile display devices such as the Orbit Graphiti [3], which functions by protruding pins in a 60x40 array to different heights to attempt to recreate an image on-screen. However, its limited resolution was found to be unsuitable for effectively rendering detailed 3D parts. While some research institutions are developing tactile solutions for blind users to interact with CAD objects [4][5], these are not yet widely available. Moreover, integrating such a solution would require a complete overhaul of the existing course structure, exceeding the scope of this project.

Lecture and Assignment Format

During the regular lecture for AME 308, the professor opens Siemens NX on a projected screen and demonstrates design techniques for the class in real time, while describing the process and steps being taken. This remains an effective approach to teaching CAD for visually able students, and so it was not desirable to redesign this lecture format. However, this approach is not accessible to a visually impaired student. As such, in lieu of attending regular lectures, the student spent their lecture period with a designated TA, who explained concepts and vocabulary using modeling clay, waxed twine, and/or a Sensational BlackBoard [6] as tactile aids, depending on the content. For example, when discussing a tangent relation in Siemens NX, the TA would sketch two tangent edges for the student to feel, as in Figure 1.

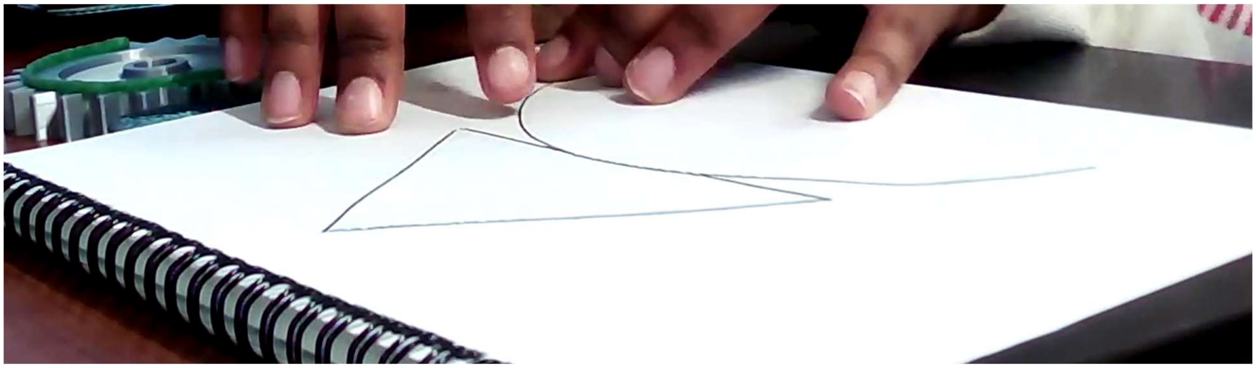

Figure 1: The Sensational BlackBoard enables quick creation of sketches with raised edges, which a visually impaired user can read via touch. Here, the student reviews a sketch demonstrating a tangent relationship between a triangle leg and an arc.

After being fully introduced to key modelling techniques surrounding each major topic covered in the course, the student was presented with an instructive assignment for evaluation. Historically, AME 308 has been an entirely computer-graphics based course, and students were evaluated using computer-graphics based assignments. These assignments would typically involve recreating a specified part, drawing, or simulation in Siemens NX. To translate the information into a visually inclusive format, a series of 3D printed parts were fabricated to provide the student with a tactile visualization of the 3D parts used for assignments, which are otherwise created and rendered in NX.

Topics covered in this course can be divided into 4 categories: (1) design topics, which focus on creating parts or assemblies in Siemens NX and comprise the majority of the course; (2) analysis topics, including execution of FEA and kinematic analyses; (3) creating part drawings; and (4) GD&T. A more thorough discussion of assignments for each topic category will be presented in the following sections.

Assignments for Design Topics

The adapted curriculum is intended to closely follow the regular course lecture schedule. Auto-transcripts of the lectures are taken and made available, so that the student can review the presented material, if desired. To supplement their education, the general approach taken was to create and 3D print, for each design topic, at least two parts that clearly showcase the CAD techniques presented in lecture: an instructive example part and an assignment part. Additionally, for each example part, a text document was created detailing the steps involved in producing the part in Siemens NX. The 3D printed parts were provided to the student, along with the text document to accompany the example part. The student was given an opportunity to review these materials and was then expected to produce for evaluation a verbalized, step-by-step guide to designing the assignment part in Siemens NX, in the same spirit as the accompanying document. The student was allowed to use the waxed twine, modeling clay, and the Sensational BlackBoard to demonstrate their thought process. They were also allowed to request feedback from the TA, depending on the assignment. For example, in CAD software, users can easily see whether their sketches or features are fully defined, or otherwise how many degrees of freedom exist within the model. Similarly, during these design assignments, the student was allowed to ask the TA about the state of their sketch (constrained or not), or to describe any existing degrees of freedom.

This approach reinforces the ideas taught in lecture in a way that is accessible to the student and provides an opportunity for them to exercise CAD techniques without the need to interface directly with the software. Table 1 contains a summarized list of assignments in the adapted curriculum that fall under the topic of design.

Assignment	**Topic(s)**	**Example Part(s)**	**Assignment Part**
1	Sketching	Bell Crank	Anchor Plate
2	3D, mirrored, and patterned features	Gear I-Beam	Flange
4	Synchronous Modelling	Shaft Bracket	Wall Bracket
6	Assemblies	Ladder	Flange and Pipe
8	Surfacing	Flared Pipe	Vase

Table 1: Summary of assignments for design topics. Note that assignments 3, 5, 7, and 9 do not fall under the topic of design and are discussed in later sections.

For Assignment 1, two parts were 3D printed: a bell crank and an anchor plate. Since the topic here is sketching, both parts were designed in such a way as to be creatable by extruding a single 2D sketch. The bell crank served as the example part and was accompanied by a document detailing a 15-step process to design the part in Siemens NX. The student was then required to provide a similar walkthrough explaining how to reproduce the anchor plate. They were evaluated on whether their described method used appropriate modelling tools and achieved a fully constrained part similar in shape to the provided anchor plate (though not necessarily similar in size or relative dimensions).

Assignment 2 introduced the student to many new tools for creating patterned and mirrored features, as well as some 3D featuring tools such as edge blending and hole creation. To demonstrate all of these features, two example parts were created (a gear and an I-Beam) along with instructive documentation, as for bell crank part in Assignment 1. The student was then provided a flange part and asked to describe a process for creating it in NX. They were evaluated again on whether their process produced a fully constrained part resembling the overall shape of the provided flange. For full credit, they were also required to include some use of the hole tool, edge blend tool, and either the patterning or mirroring tool in their described process.

Assignment 4 was focused on synchronous modelling. The student was provided with two 3D printed versions (“original” and “altered”) of two different parts, for a total of four items. Each part came with a document describing a list of differences between the original and altered versions. Braille labels were added to each face of the “original” versions of each part, so that the student could easily follow the described changes in the provided document, and so that they could reference these faces in their work. As in previous assignments, an instructive document describing a process for modifying the example part (a shaft bracket) was included. The student was then expected to describe a process for making the requested alterations to the assignment part (a wall bracket) and was evaluated on whether their process addresses all requested changes using appropriate synchronous modelling tools.

In Assignment 6, the student was introduced to assemblies. Here, the example part was a ladder assembly, which included a total of 9 parts. The assembly was 3D printed and assembled for the student, and extra copies of each unique included part were printed as well for their review. As per precedent, thorough documentation on creating the assembly from the component parts was provided as well. The assigned assembly was comprised of two flanges, two connected pipes, and a series of nuts and bolts holding them together. Again, the components were 3D printed and assembled, and provided to the student along with separately printed copies of each unique part. The student was tasked with providing a process for creating this assembly, given the component part files. They were graded on whether their process imported the correct parts, whether each part was appropriately constrained, and whether they correctly made use of the patterning tool.

The final assignment in the design category addressed surfacing techniques. Here, the example and assigned parts were a flared pipe and a vase, respectively. These parts were quite simple in shape, but designed in a way that would be difficult to imitate without making use of surfacing tools. For this assignment the student was provided not only with the usual example documentation and a 3D printing of each part, but also with a separate 3D printed "reverse engraving" demonstrating an appropriate set of line profiles for creating the flared pipe. The reverse engraving featured a flat plate with lines of material protruded to resemble a 2D image, allowing the student to perceive the 2D line profiles in a tactile manner. Similar reverse engravings were produced for assignments 3 and 7 (see Figure 2 and Figure 4, respectively). The student was expected to describe a process for producing the vase part in NX, and graded on whether their process involves creating a second plane, using multiple (well-constrained) sketches as profiles for the surfacing tool, correctly implementing the surfacing tool, and ultimately whether the process produces a part qualitatively similar to the provided vase.

Assignments for Analysis Topics

To reiterate, the goal of the adapted course is that the student be able to competently communicate with other engineers regarding issues related to CAD. Regarding the simulation portion of the course, some important topics for the student to take away include understanding the need for specifying boundary conditions and loads, the kinds of results one can expect to achieve from analysis, and in the case of FEA simulations, the tradeoff between mesh density and computation time.

Two types of simulations were introduced in this course: finite element analysis and kinematic analysis. One assignment was designed to cover each simulation type. Implementation of simulations in NX requires navigating through many dense menus, which can be intimidating even for visually abled students. As such, for these assignments, the student was not asked to implement a unique simulation. Instead, they were provided detailed instructions on performing a simulation and allowed time to review the instructions at length. For evaluation, they sat with a

TA while the TA slowly walked through the simulation as outlined in the provided instructions, being sure to communicate the process as it unfolds in as much detail as possible. Following the demonstration, the student was required to walk the TA through the same process, starting from a part file, to produce the requested simulation. The TA performed steps as instructed by the student. The student was not expected to correctly dictate every step of the process, but for full credit was required to correctly describe a predetermined shortlist of key steps and discuss what data they might expect from the simulation. Each assignment also included a tactile aid, providing the student with a visualization of the simulation being performed.

Table 2 includes a summary of each analysis assignment.

Assignment	Topic	Simulation
5	FEA	Simply supported beam
9	Kinematic Analysis	Carabiner

Table 2: Summary of assignments for analysis topics.

Assignment 5 introduced the student to an FEA analysis performed on a simply supported beam. For tactile aids, the student was provided with a 3D printed copy of the beam part file, as well as a second copy of the beam after deformation due to the simulated load. These aids were intended to provide some intuition as to the expected results of the simulation. For evaluation, the five key steps that the student was expected to describe in their process were: (1) that the simulation must begin from a part file, (2) creation of a mesh on the part file, (3) correct application of loads, (4) correct application of constraints (boundary conditions), and (5) extraction of data from the simulation. The student was also expected to briefly discuss some of the data points they might be able to achieve from this analysis.

Assignment 9 was a kinematic analysis of a simple carabiner opening and closing its gate. The tactile aids provided for this assignment included two carabiners, one fully assembled and the other deconstructed. The student was graded on whether they could correctly describe the following four steps in implementing the simulation: (1) acknowledgment that the simulation begins from an assembly file, (2) definition of motion bodies, (3) definition of joints, and (4) definition of initial conditions. They were also expected to discuss which parameters of the simulation they might alter, and how this might affect the data obtained from the analysis.

Assignments for Drawing

Only one assignment was created for the topic of technical drawings, which comprise only a small section of the AME 308 syllabus. The goal for this assignment is that the student understands how to clearly represent a part with a drawing. To this end, an example and assignment part (flange and crank, respectively) were designed and 3D printed, as in the design assignments described previously. In addition, a reverse engraving of the flange was 3D printed to provide the student with a tactile "view" of the part from different angles which might be included in a drawing. Images of the 3D printed flange, crank, and reverse engraving are provided in Figure 2:

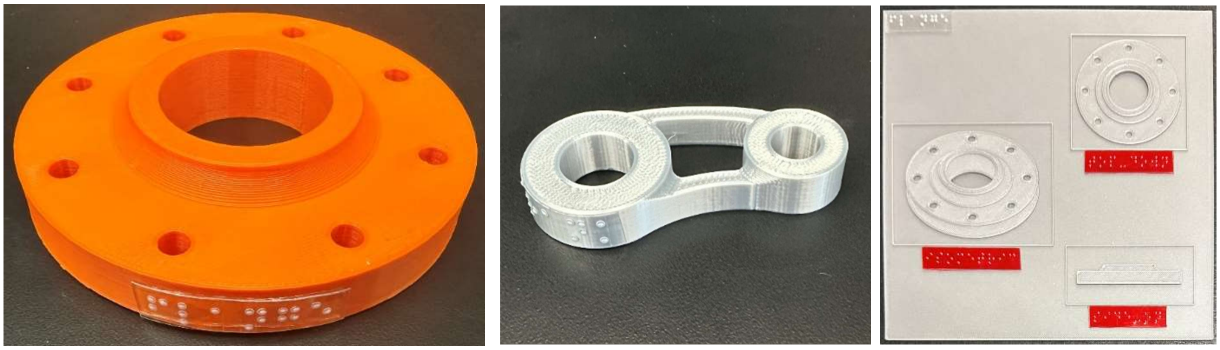

Figure 2: (Left) 3D printed flange, to serve as an example. (Center) 3D printed crank, which serves as the assignment part. (Right) Reverse engraving of the flange, showcasing different viewing angles which might be included in a drawing to showcase various part features.

The student was paired with a TA to walk through the different views on the reverse engraving and describe how each dimension of the 3D printed flange could be clearly showcased through at least one of the engraved viewing angles. Importantly, they discussed how these views and dimensions would be used and labelled in a drawing to fully define the part.

For their assignment, the student was required to describe a set of views and dimension labels that would be relevant in a drawing of the crank part. They were evaluated on whether the drawing they described included appropriate views for showcasing part features, as well as an isometric view to provide an overall impression of the part. They were also expected to describe labels for features that fully define the part and assign each label to a viewing angle from which the labelled feature is clearly visible.

The student found that they were best able to represent the views they chose to include in their drawing with a sketch (using the Sensational Blackboard). They then verbally described where they might place dimension labels on each view. Figure 3 shows the “answer key” drawing (provided to the student only after completion of their assignment), and the students’ hand-drawing of the front and side views.

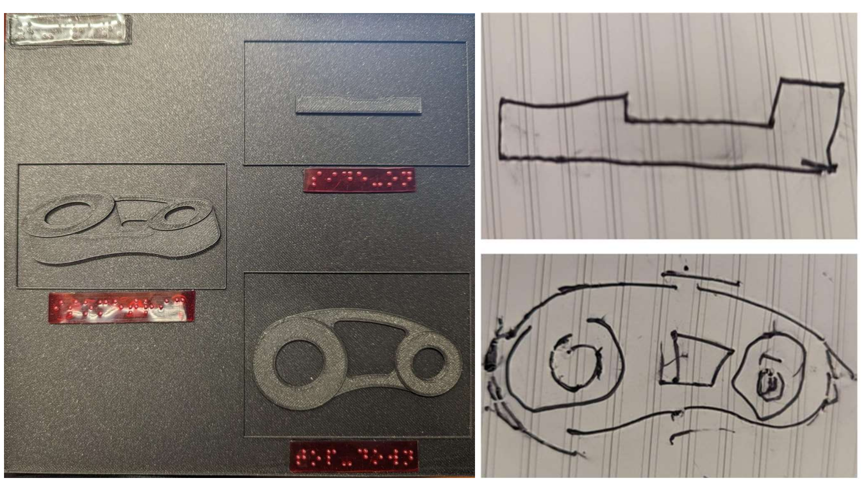

Figure 3: (Left) Reverse engraving of the crank drawing. (Right) Student hand sketch of drawing.

Note that creating the sketch required the student to follow their writing hand with a finger to feel the drawn results, since they cannot otherwise perceive their drawing. This is difficult in practice, especially for small features and for shapes within other shapes. The student verbally communicated the differences they identified between their intentions and the actualized sketch and was not penalized for any discrepancies.

Assignment for GD&T

Relative to the other topics in this course, the topic of geometric dimensioning and tolerancing has the least dependence on visualization of 3D objects. Consequently, most of the principles presented in these lectures require little to no adaptation for visually impaired students. However, several key symbols describing dimensioning/tolerancing parameters are introduced in this section, and it was desirable to communicate these symbols to the student. For this purpose, a reverse engraving containing a library of useful symbols was 3D printed and labelled with braille for the student to review. Images of the reverse engraving are provided in Figure 4.

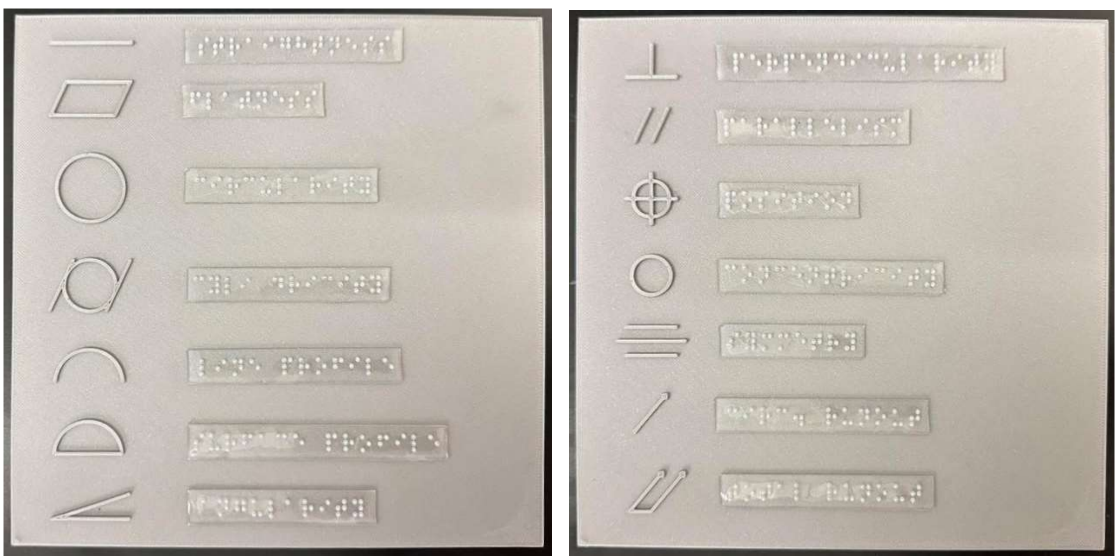

Figure 4: Reverse engraving of several common GD&T symbols.

For evaluation, the student was provided with a more traditional homework set featuring six written questions, including both broad questions such as why one would assign a tighter or looser tolerance to a part, as well as more practical questions testing the student's ability to understand or correctly produce appropriate dimensioning/tolerancing labels on a part drawing.

Challenges and Lessons Learned

One challenge encountered early in the development of this adapted course was the difficulty of perceiving small 3D printed features by touch. An instance of this issue arose in the anchor plate part used for Assignment 1. As shown in Figure 5, the perimeter of this part involved a somewhat obtuse angle, making it difficult for the student to discern whether the corner of this angle was sharp or whether a fillet was present. Other foreseeable examples might include differentiating shallow arcs from straight lines, or elliptical features from circular ones.

Figure 5: The anchor plate from Assignment 1 had a small fillet at the top and bottom edges of the perimeter, which were not noticeable to the student by touch.

Similar issues arose in 3D printed parts whose interior geometries were too small to fit the student's finger. The crank from Assignment 3 is a good example of this: notice in Figure 6 how the corners of the interior cutout have a radius that is too small for the student to easily feel.

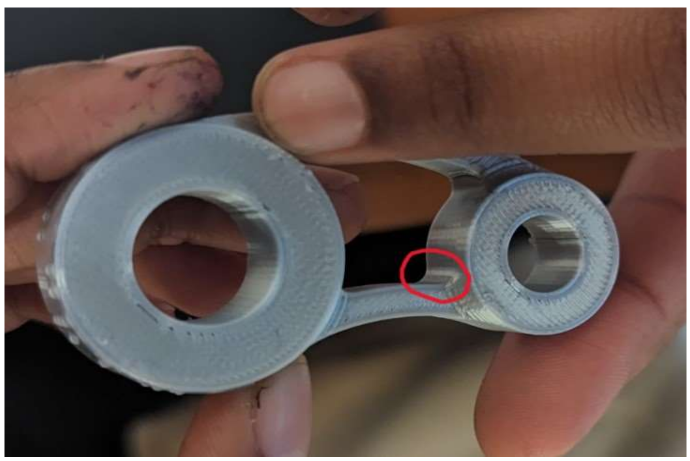

Figure 6: This part has a cutout with rounded curves at the corners with a small radius making it difficult for the student to feel the features of the part for the drawing.

This kind of issue can be easily resolved by 3D printing parts at a larger scale. It must be noted, however, that in cases where designed parts have extremely small features, 3D printing at a sufficiently large scale may not be feasible in practice depending on cost, time, or equipment restraints. Therefore, some care must be taken when designing parts for any future adapted curriculum to ensure that all features are appropriately sized.

Conclusions

This initiative successfully developed an innovative, adapted curriculum to introduce a visually impaired student to the fundamentals of CAD software, with a focus on Siemens NX. The goal of the course was to familiarize the student with the capabilities of this software and the fundamental design workflow involved in modelling parts, executing simulations, or creating drawings. To achieve this goal, the student received one-on-one instruction from a TA, who explained core concepts verbally while using waxed twine, modelling clay, and/or a Sensational

BlackBoard as tactile aids. Practical, instructive assignments also served an important role in the course. These assignments featured a series of 3D printed parts accompanied by detailed text documentation outlining the process for their design in NX. The printed models allowed the student to perceive parts which would otherwise be restricted to a visual interface, and follow the procedure for defining such parts in a CAD environment. The approach was effective, and the student was able to absorb the information presented and describe similar processes for creating new parts using this software. However, in some cases it was found that the printed parts had features too small to identify by touch. In a future iteration of this course, care would be taken to print parts at a larger scale, or otherwise design parts with large, clear features to enhance tactile discernability.

This initiative underscores the broader imperative of inclusivity in STEM education, demonstrating that with innovative approaches, technical courses can become accessible to a more diverse student population. The success of this adapted curriculum not only enhances educational opportunities for visually impaired students, but also sets a precedent for rethinking and redesigning academic programs to embrace a wider spectrum of learning needs and abilities.

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