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Entrepreneurial Mindset and 3D-Modeling: Three Mini-Projects

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Introduction

The Kern Entrepreneurial Engineering Network (KEEN) outlines the 3C's of the entrepreneurial mindset (EM) as curiosity, connections, and creating value. Incorporating EM into curriculum can help students understand the bigger picture, recognize opportunities, and learn from mistakes to create value [1]. Ohio Northern University developed "expanded KEEN student outcomes" (e-KSOs) that translate KEEN's broad student goals into "specific, authentic, and actionable learning objectives." The e-KSOs define outcomes related to curiosity, connections, creating value, communication, collaboration, and character [2]. As such, these e-KSOs could be easily incorporated into course and assignment-specific learning objectives in any engineering discipline.

Computer-aided design (CAD) is a tool for EM projects integrated into design-based courses. Typically, these projects use CAD software to communicate design details [3, 4] or to develop a model suitable for additive manufacturing [5, 6]. However, 3D modeling courses are rarely the vehicle for developing EM. Entrepreneurial mindset could be incorporated into a CAD course through smaller projects that address specific e-KSOs. This strategy would fit will into programs attempting to develop EM across the entire curriculum.

All engineers need the ability to learn new skills independently and teach these new skills to their colleagues. Incorporating EM-related projects into undergraduate courses provide opportunities to develop and practice these abilities. For example, a project first described by Levert [7] aimed to introduce engineering students to dimensioning and tolerancing standards, while addressing eKSO 1l ("Take ownership of, and express interest in topic/expertise/project") and 4d ("Be able to teach and learn from peers."). For this project, the students each researched a dimensioning standard, and presented their findings to teach each other. This project was assigned at the start of the semester as an "ice breaker" that also helped prepare the students for content that would be later addressed [7].

Recent efforts at Ohio Northern University have motivated EM incorporation across the entire curriculum. To this end, three short, mini-projects were incorporated into a 3D modeling elective course to address EM while introducing advanced modeling topics: 1) geometric dimensioning and tolerancing (GD&T) exploration, 2) router cutting with computer-aided manufacturing (CAM), and 3) advanced feature exploration. The purpose of this paper was to describe and evaluate how these projects provided opportunities for the students to control their own learning. Specifically, these three projects were designed to address the e-KSOs described in Table 1.

Table 1: Expanded KEEN Student Outcomes [2] addressed by the three mini-projects.

Category	Expanded KEEN Student Outcome	Project
Curiosity	1l. Take ownership of, and express interest in topic/expertise/project	1, 2, 3
Connections	2a. Understand the ramifications (technical and non-technical) of design decisions	2
	2b. Identify and evaluate sources of information	1
	5e. Integrate/synthesize different kinds of knowledge	1, 2, 3
	2h. Articulate the idea to diverse audiences	1
Communication	4b. Identify and organize information in a format suited to the audience	1, 3
	4d. Produce effective written reports	1, 3
	4e. Produce effective verbal presentations	1
Collaboration	4d. Be able to teach and learn from peers	1

Course Description

The three mini-projects were incorporated into ME 3131: 3D Modeling and Design (3DM) at Ohio Northern University during the Spring ’22 semester. 3DM is a 3 credit-hour technical elective offered to junior and senior mechanical engineering students. The course focused on using SolidWorks for mechanical design applications including modeling, design layout, and geometric dimensioning and tolerancing (GD&T). The course met in a computer lab for 50-minute lectures three days a week. A total of 32 students were enrolled during the Spring ’22 semester. Surveys administered during the first week of the semester revealed that modeling experience ranged from very little to highly experienced.

Table 2: 3DM Course Schedule. Projects were incorporated during weeks 11, 14, and 15.

Week	Content
1	Introduction to SolidWorks: Sketches and Sketch Tools
2	Extrude, Revolve, Reference Geometry
3	Chamfers, Patterns, Hole Wizard
4	Rib, Shell, Loft, Sweep
5	Draft Tool, Exam Review, Exam 1
6	Assemblies
7	Configurations, Design Tables, Equations
8	Orthographic Projections and Dimensioning [By Hand]
9	Sheet Formats, Exam Review, Exam 2
10	Engineering Drawings, Different Views, Assembly Drawings [CAD]
11	Tolerancing, PROJECT 1: GD&T Exploration
12	Defining Tolerances and GD&T in SolidWorks
13	Exam Review, Exam 3, Introduction to CAM
14	PROJECT 2: Router Cutting with CAM
15	PROJECT 3: Advanced Feature Exploration

Project Description

Project 1: GD&T Exploration

This project was adapted from Levert [7] to focus on basic concepts associated with GD&T. To motivate EM, the students were empowered to research the topic on their own, and then teach their peers. Overall, this project took about 3 weeks to complete. During the first week of the project (Week 10), teams were divided into 16 teams of two and each team was assigned different GD&T elements to research (Tab. 3). Each team was required to research and document the following:

1. The precise definition of the element.
2. References were other students could find information on applying the specific element
3. Examples showing the element applied.
4. Three study questions for their classmates. Two of these questions could be multiple choice or short answer. At least one question required the GD&T element to be correctly applied.

Table 3: Research Assignments for GD&T Project

Group	Category	Topic
1	General	Datums and the feature control frame
2		Modifiers in the feature control frame
3	Form	Straightness
4		Flatness
5		Circularity
6		Cylindricity
7	Profile	Profile of a line
8		Profile of a surface
9	Orientation	Angularity
10		Perpendicularity
11		Parallelism
12	Location	Position
13		Concentricity
14		Symmetry
15	Runout	Circular runout
16		Total runout

During the second week of the project (Week 11) the student teams prepared 3- or 4-minute teaching presentations on the GD&T element. The 16 presentations were spread across two, 50-minute lecture meetings. Following each presentation, the student audience members each provided “rocket feedback” by filling out a short Google Forms survey (Appendix 1). To conclude each day, the instructor helped identify the main themes and concepts associated with GD&T and the associated symbols.

During the third week of the project (Week 12), teams submitted a written memo about their GD&T element. These memos were compiled and then distributed to the class as a GD&T reference material for the course. Each team also provided their rocket feedback and wrote a reflection on the following prompts:

- Consider how you taught yourself about the GD&T element. Do you feel confident about your ability to learn independently after graduation?
- Knowing that you would be teaching your peers, did you prepare your presentation differently than a normal presentation?
- Review the feedback from your peers. What did they like about your presentation? What suggestions did they have? If you were to do the presentation again, what would you do differently?

Overall, this project accounted for 10% of the final course grade. The grading breakdown for Project 1 is shown in Table 4.

Table 4: Grading for Project 1

Evaluation	%
Written Memo	40%
Presentation (Instructor Score)	30%
Presentation (Rocket Feedback)	10%
Reflection	20%

Project 2: Router Cutting with CAM

The purpose of this project was to introduce the built-in CAM plugin for SolidWorks. Before this project was assigned, the students completed all 18 video tutorials in the CAM learning path on the MySolidWorks training site [8]. These videos described the steps for setting the cutting parameters, defining the stock material sizes, generating cutting toolpaths, and exporting the operations to G-code. At the start of Week 14, each team of two students was tasked with developing a 3D model to cut on a ShopBot D3624 Desktop MAX router (Fig. 1) [9] using a ¼” cutting bit. The model was required to fit in a 5” square area, but each team was provided a 12” square of ½” MDF particle board to account for multiple cutting attempts.

Figure 1: Models were cut using a ShopBot D364 Desktop MAX router [9].

Each team completed the modeling and toolpath generation during in-class work time (Week 14). A post processer was applied to generate a .SBP file because the ShopBot router utilized OpenSBP syntax. Once the code was generated, each group signed up for a 30-minute timeslot to work with the instructor or class TA. Cutting occurred outside of the normal lecture hours during the final two weeks of the semester. To verify cutting accuracy, the students were required to bring a printed engineering drawing of their model when using the router.

At the conclusion of the project, each team uploaded their part file, the .SBP code, and .pdf of the engineering drawing to an online dropbox. The students also documented the individual contributions of each member to the project's completion. Overall, this project was worth 10% of the final course grade. The project was evaluated in the following categories: 1) number of machining attempts/boards used, 2) design complexity, 3) following directions/uploading deliverables on time, 4) CAM tool path definitions in part file, and 5) individual contribution. Each category was graded as passed or failed, and the overall project grade was determined by the number of categories passed (Tab. 5).

Table 5: Grading for Project 2

# Passed	Score
≤ 1	F (50% or 0%)
2	D (63%)
3	C (75%)
4	B (87%)
5	A (100%)

Project 3: Advanced Feature Exploration

Students are often interested in advanced modeling features that time constraints prevent from being covered during lecture. This project allowed students to pursue an independent study of an advanced SolidWorks feature from the following list: Surfaces, Weldments, Sheet Metal, Pipe Routing, or Mold Design. Working individually, the students were required to complete the associated video tutorials provided on the MySolidWorks training site (Tab. 6). These tutorials were completed during in-class meetings during the last week of the semester.

Table 6: Links to training courses for advanced SolidWorks features

Tool	**Courses**
Surfaces	https://my.solidworks.com/training/path/31/surfaces
Weldments	https://my.solidworks.com/training/path/22/cswpa-weldments-exam-prep-course
Sheet Metal	https://my.solidworks.com/training/path/10/sheet-metal-1
Routing	Tubing: https://my.solidworks.com/training/path/49/routing-tubing Piping: https://my.solidworks.com/training/path/47/routing-piping-1
Mold Design	https://my.solidworks.com/training/path/38/mold-design

After completing the tutorials, each student was required to create a new model or analysis using their chosen feature. For example, a student exploring the surfaces tool might have modeled a football helmet. Students were allowed to find inspiration from online CAD resources or video resources (i.e. YouTube, etc.), but were required to make the model themselves. Finally, each student was required to submit a two-page memo summarizing the following:

1. The purpose, capabilities, and potential applications of the selected tool.
2. The reasons they were interested in learning about the selected tool.
3. The model and/or analysis that was created in SolidWorks.

The students were required to submit their memo, associated part files for their design or analysis, and all the tutorial files on the last Friday of the semester. Overall, this project was worth 10% of the overall course grade, and the grading breakdown for Project 3 is shown in Table 7.

Table 7: Grading Breakdown for Project 3

Evaluation	Pts
Tutorial Files	20
Model Complexity	20
Memo Score	20

Evaluation

Project 1: GD&T Exploration

The GD&T projects were presented across two 50-min lecture periods, with 8 teams presenting each day. Examples from the student presentations are shown in Figure 1. The rocket feedback evaluations revealed that the students mostly agreed or strongly agreed (4.65 ± 0.18) that each presentation was effective in teaching the GD&T material (Appendix 1). Six GD&T questions were developed by the instructor from the student presentations and memos. These questions were then included on the third exam during the semester (Appendix 2). Since the students learned from each other, the test questions only evaluated a basic understanding of GD&T and familiarity with the various symbols. On average, students earned 26.8 ± 3.5 of the 30 possible points available on these questions.

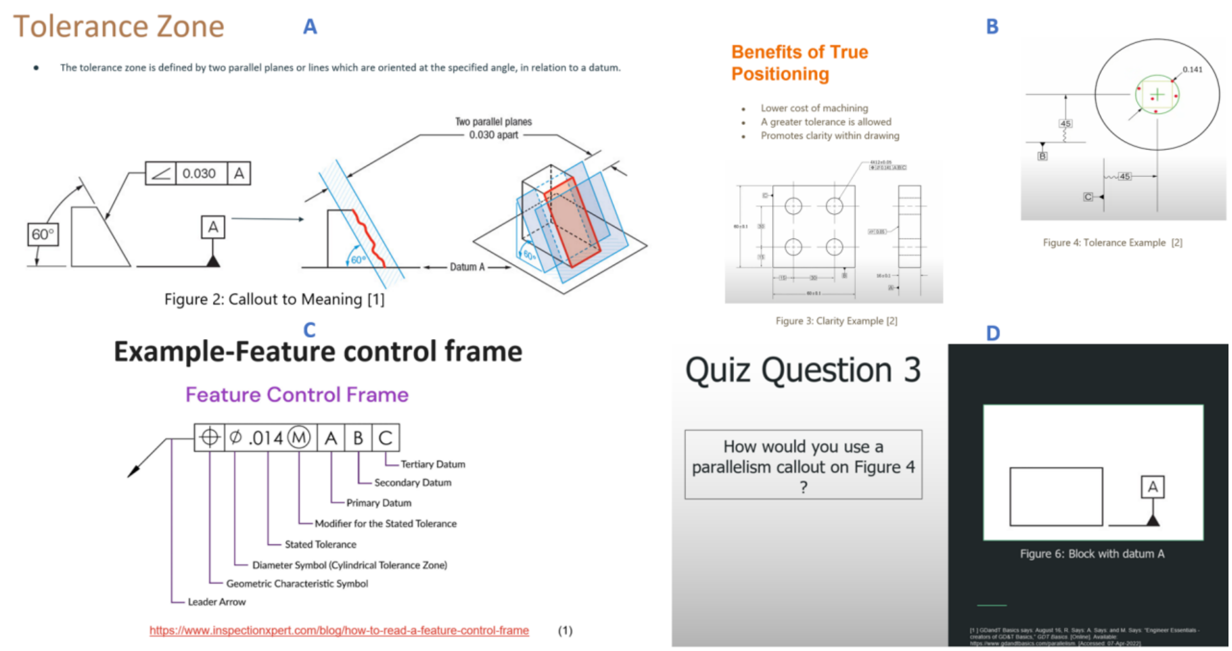

Figure 1: Examples of presentation slides describing (A) the angularity callout, (B) the benefits of using the true positioning callout, (C) the components of the feature control frame, and (D) a student developed review quiz about parallelism.

Project 2: Router Cutting with CAM

At the conclusion of project 2, all teams were able to generate a .SBP code after following the tutorial videos. Of the 16 total teams, 13 were able to cut the entirety of their design out of the MDF board (Fig. 2). Three groups were unable to match their exact geometry for different reasons: 1) failing to define the profile cut, 2) defining the profile cut to an incorrect depth, and 3) trouble defining the coordination system. A total of 11 teams successfully cut their design on their first try, and the other 5 teams were able to complete the cutting during their 2nd attempt. The most common error was setting the machine's zero position at the wrong location before cutting. In fact, exactly half of the teams could not remember where the coordinate center was defined in their model. Anecdotally, students enjoyed the ability to be creative with the modeling in this project.

Figure 2: Example CAM router projects include (A) a dog face, (B) a baby Yoda, and (C) a bass. The bass project (C) is still embedded in the MDF board because the students did not define the profile cut around the boundaries of the model.

Project 3: Advanced Feature Exploration

Overall, the selected feature explorations were spread over the possible topics (Fig. 3), with the most students interested in pursuing surface modeling. No students selected the routing tools for their exploration project. Each student was able to demonstrate the ability to apply their selected feature to model a design of their own choosing, and example models are shown in Figure 4.

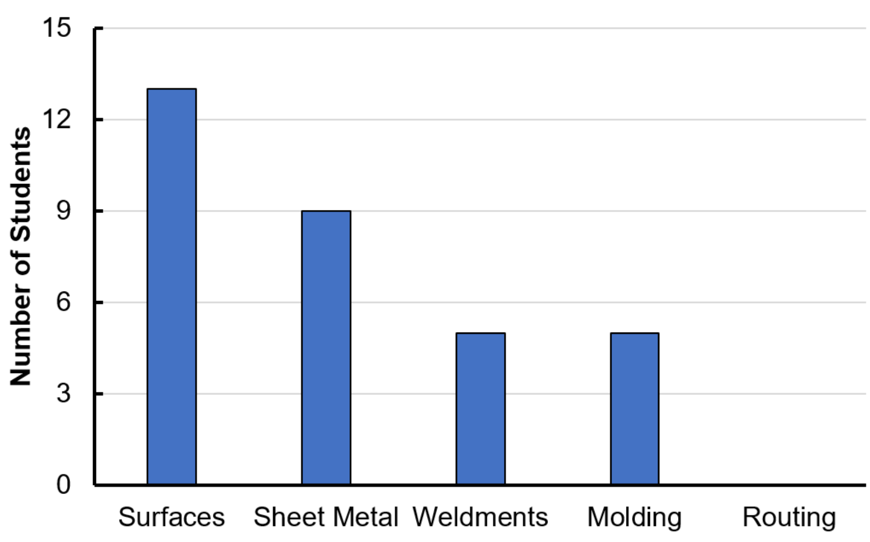

Figure 3: Student feature exploration selections showed a diversity of interests. No students selected the routing courses.

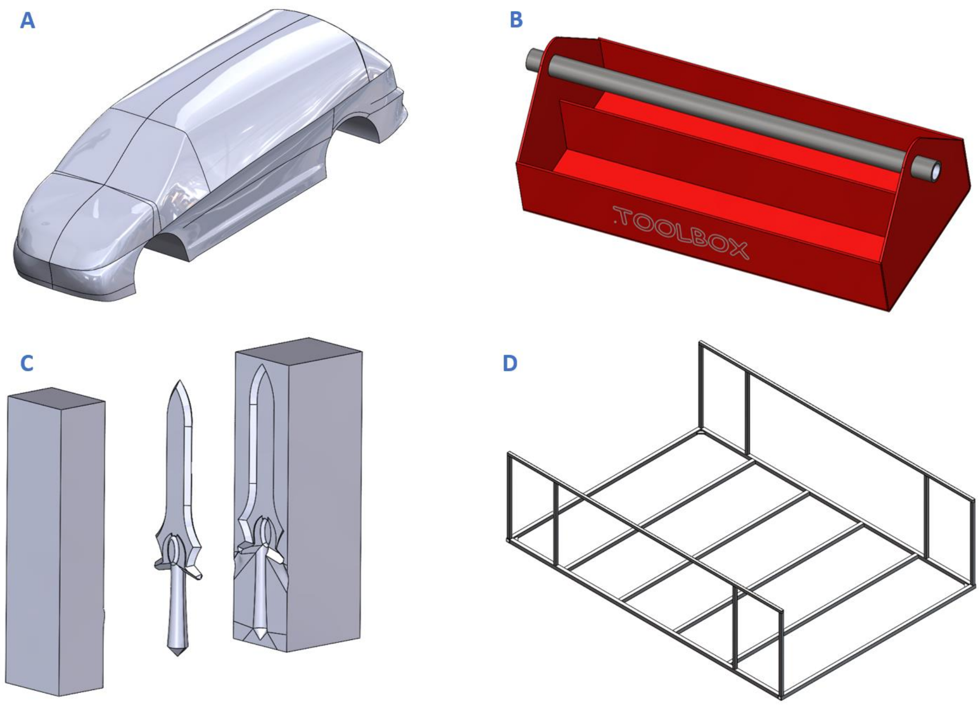

Figure 4: Example student models include a mini-van (A – surfaces), a tool box (B – sheet metal forming), a sword (C – mold design), and a bike trailer frame (D – weldments).

In their submitted memos, the students provided reasons for selecting their feature exploration topic. As expected, the students provided diverse reasons for their selections (Fig. 5). Employment was a strong motivator, and some students even provided examples of parts they had trouble modeling at past internships. Other students mentioned future employment and wanted to learn skills related to specific industries. Some other trends were also observed. For example, students pursuing surface modeling were often attracted by the complexity of the geometries that could be created. These students often mentioned feeling confident with previous course topics and wanted to take on a greater challenge. Students selecting the weldments features were more likely to mention application to their hobbies (i.e. roll cages for race cars, Baja, etc.), whereas students selecting sheet metal modeling were often motivated by a positive experience bending metal in a manufacturing laboratory course.

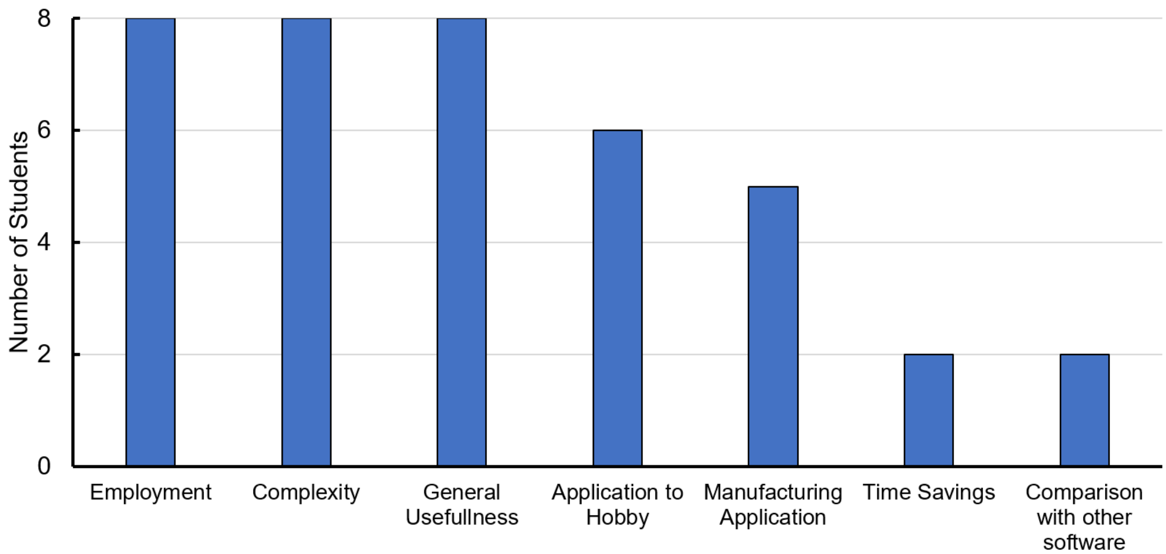

Figure 5: Student selected their exploration topic for a variety of reasons.

Overall Assessment

Student performance was tracked for each project and is shown in Table 8. Additionally, a post-course survey was administered by the instructor on the last day of the semester (Friday of Week 15). The students were asked to rate their competency with the course objectives on a Likert scale where *Strongly Disagree* corresponded to a score of 1 and *Strongly Agree* corresponded to a score of 5. Overall, three of the course objectives were satisfied by the mini-projects and the student responses are shown in Figure 6. Students overwhelming *Agreed* or *Strongly Agreed* to each statement. Three students strongly disagreed to all three statements.

Table 8: Student performance on mini-projects show that students were able to complete projects with an excellent (E) or acceptable (A) score.

Project	Assessment Tool	E*	A	M	U
1. GD&T	Memo Score	8	24	0	0
	Presentation score	19	13	0	0
	Rocket Feedback Score	26	6	0	0
	Personal Reflection	23	8	0	1
2. CAM	Overall Score	28	4	0	0
3. Exploration	Overall Score	27	5	0	0

**Excellent (E): ≥ 90%, Acceptable (A):89-70%, Marginal (69-60%), Unacceptable (<60%)*

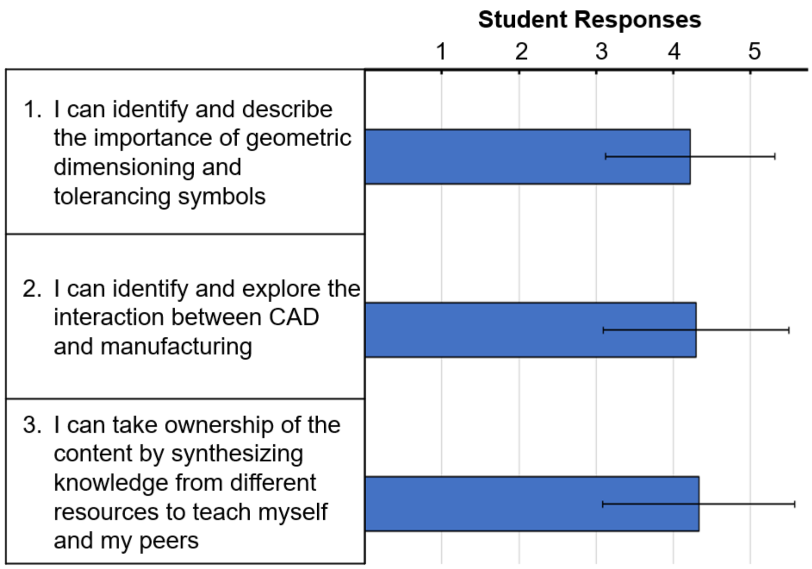

Figure 6: Student responses to questions relating to course objectives were satisfied by the three projects. Scoring: *1 - Strongly Disagree, 2 - Disagree 3 - Unsure, 4 - Agree, 5 - Strongly Agree*.

Discussion

This paper describes the first attempt to integrate and evaluate the effectiveness of three mini-projects in a 3D modeling elective course. Collectively, the projects addressed EM with an emphasis on shifting the primary responsibility of learning to the students. Over the completion of the three projects, the students taught themselves new content (all projects), created resources to teach their peers (project 1; Fig. 1), applied their own creativity to explore the link between CAD and manufacturing (project 2; Fig. 2), and pursued topics of their own interest (project 3; Fig. 3-5). The students responded positively to the projects and overwhelming self-reported competency with their related course objectives (Fig. 6).

Upon graduation, engineers in the workforce need the ability to learn new skills independently and potentially train their colleagues [10, 11]. The GD&T exploration project specifically asked the students to teach their peers a new topic, as GD&T was not previously discussed by the instructor. Strong rocket feedback scores and achievement on exam questions suggested that the GD&T exploration project was an effective method of introducing GD&T to mechanical engineering students. Both the CAM project and feature exploration projects required the students to learn entirely from completing tutorials. At the conclusion of each, the students demonstrated the ability to apply knowledge learned from tutorial videos to a project to their own design (Fig. 2 and 4).

The link between manufacturing and engineering graphics is well established. Even though engineers are not the primary fabricators of the parts they design, manufacturing experience can improve an engineer's ability to design parts that are ready to be fabricated [12, 13]. The CAM project effectively demonstrated this importance because it provided tangible evidence of poor design and modeling choices. During the project, the students were required to consider the limitations of the router and cutting tool size when creating their model geometries. Additionally, the students had to thoughtfully define the coordinate center on their model so it easily identified as the router's zero location before cutting. This seemingly unimportant step in the CAM process was often overlooked by the students. As a result, half of the teams had to redefine their models before cutting. A reflection assignment could be developed for future iterations of this project to help students internalize how modeling decisions affected the speed and accuracy of their fabricated parts.

Previous studies have identified the connection between student motivation and their inherent interest in the topic matter [14, 15]. Unfortunately, time constraints within the traditional semester schedule make it impossible to cover every topic the students are interested in learning. The advanced feature exploration project enabled each student to pursue a topic of their own interest. Students responded positively to freedom and provided insight into why they selected each topic (Fig. 5). Some comments on the post-course survey revealed a desire to pursue more than one topic exploration, suggesting that the project could be extended to include two topics during future iterations of the course. Freedom to explore content and pass assessments at an individual pace is a characteristic of competency-based course assessments [16, 17]. The positive response of students to this independent style of learning further suggests that the 3DM course could be a strong candidate for competency-based assessment. Under such a model, students would set their own weekly learning goals throughout the semester. Highly experienced students could focus more on the advanced skills while less confident students could spend additional time addressing introductory and intermediate skills [16].

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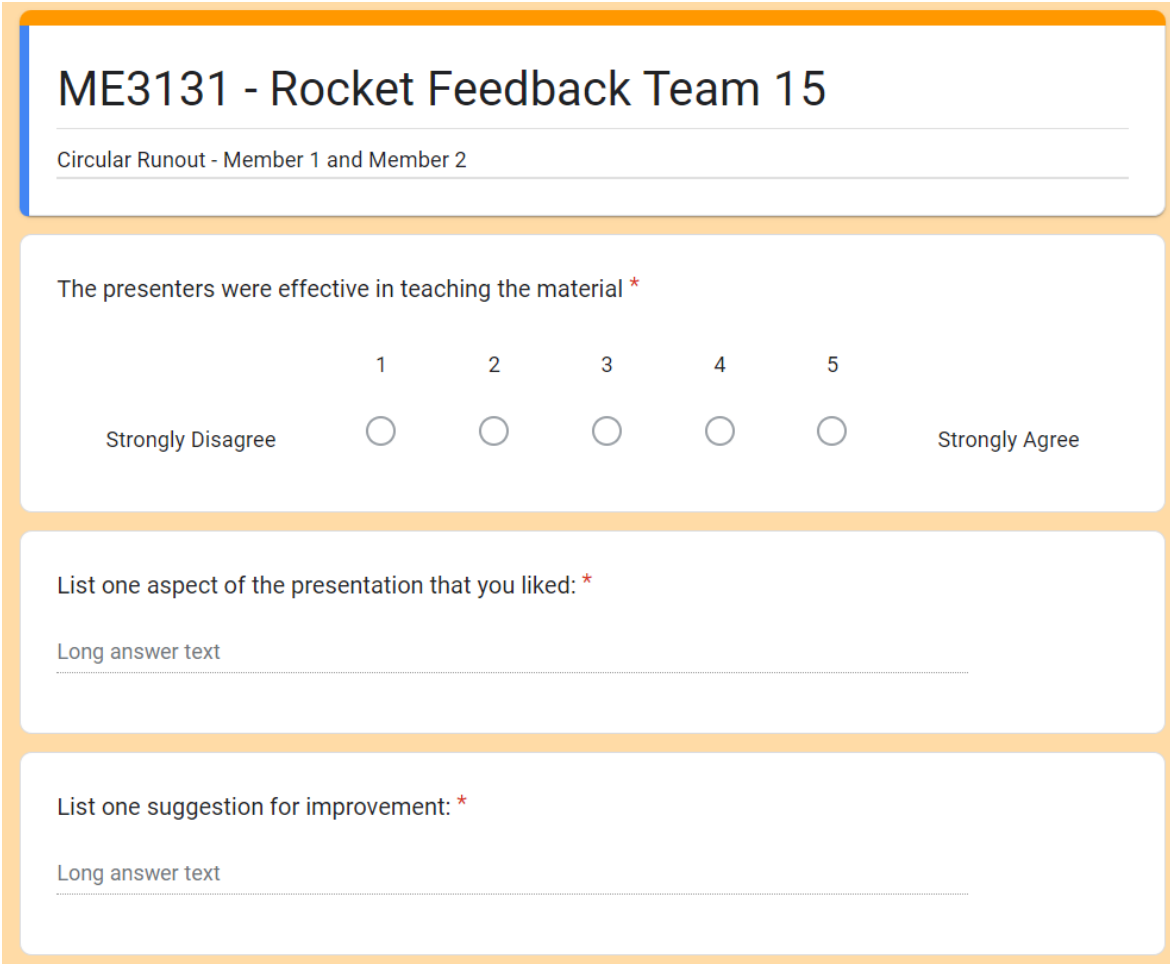
Appendix 1: Example Rocket Feedback Google Form



ME3131 - Rocket Feedback Team 15

Circular Runout - Member 1 and Member 2

The presenters were effective in teaching the material *

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

List one aspect of the presentation that you liked: *

Long answer text

List one suggestion for improvement: *

Long answer text

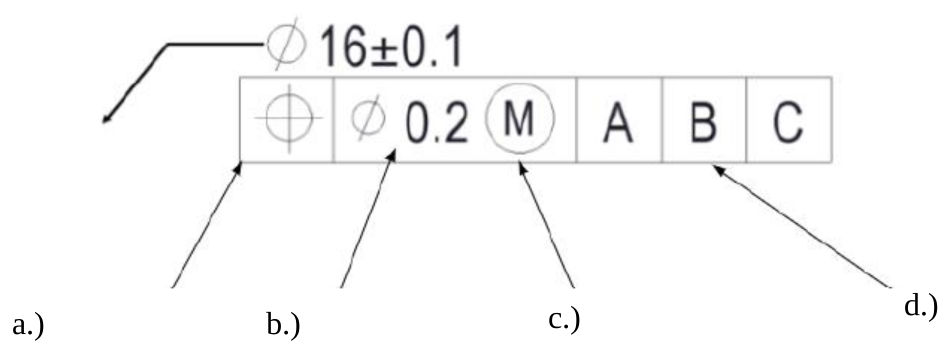
Appendix 2: GD&T Test Questions

1. What are the benefits of using Geometric Dimensioning and Tolerancing (GD&T)? List at least 2. (4 pts)
    a.

    b.

2. Add a .03 in parallel tolerance to the top surface of the block with respect to datum A? (3 pts)

3. Label the components of the feature control frame: (4 pts)



4. Which of the following tolerances depend on a datum? Circle all that apply. (3 pts)
    a. Circularity
    b. Straightness
    c. Perpendicularity
    d. Symmetry

5. From a manufacturing standpoint, why is following dimensioning and tolerancing standards important? List at least two reasons. (4 pts)
    a.

    b.

6. Match the symbols to the correct tolerances. Not all tolerance types are used. (12 pts – 2 pts each)

Tolerance:
A. Straightness
B. Flatness
C. Circularity
D. Cylindricity
E. Profile of a line
F. Profile of a surface
G. Angularity
H. Perpendicularity
I. Parallelism
J. Position
K. Concentricity
L. Symmetry
M. Circular runout
N. Total runout