Improving Clarity of Engineering Drawings Through Introduction of Manufacturing Processes in a First-Year CAD Design Course

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Abstract

This research paper investigates how students' understanding of manufacturing processes influences the clarity and quality of their engineering drawings. The ability to effectively communicate design intent via engineering drawings is a critical skill for successful engineers. Engineering students are often introduced to engineering graphics early in their coursework, but exposure to manufacturing processes typically occurs later in the curriculum. With this sequencing of topics, students are able to generate drawings that portray geometry, but they are unprepared to anticipate the informational needs of machinists and makers, resulting in drawings that are often cluttered or incomplete. At Washington State University, a new activity was incorporated in the first-year Computer-Aided Design course, providing students with a brief introduction to manufacturing processes to supplement their training on engineering drawings. The intervention involved adding a brief lecture on manufacturing processes, a manufacturing drawings guide, a guest talk from a local machinist, and an assignment where students created drawings and manufacturing plans for parts from a jack stand assembly after reverse engineering the parts using measurement tools. These new activities were implemented in the Fall 2025 semester in sections 2 and 3 of the class while the first section—taught by the same instructor as section 2—did not participate in the intervention and served as a control group. The outcomes were assessed by evaluating student drawings from the jack stand parts to compare clarity of dimensions/views, notes on material/finish, tolerances, and general neatness. A pre- and post-assessment survey was also given to all three class sections to observe changes in students' confidence and understanding of manufacturing processes. The inclusion of the new activities, compared to the control group, resulted in improved neatness/clarity of drawings and more thorough drawing notes. In addition to improving drawing quality, this approach aimed to broaden students' perspective from focusing solely on drawing creation to intentionally communicating design intent with an awareness of their audience and the implications of their documentation.

Introduction

Effective communication of design intent between engineers and manufacturers is essential for efficient product development [1]. Hence, much effort has been devoted to improving these communication lines through standardization of engineering drawings and geometric dimensioning and tolerancing systems over the last decades [2]. For early engineering students, however, the process of learning these techniques for effectively communicating their designs with manufacturers is challenging for several reasons. First, students have little to no exposure to quality engineering drawings, which limits example-based learning due to lack of quality examples to follow [3]. Second, typical engineering course sequencing requires students to learn engineering graphics before learning about manufacturing processes; without understanding manufacturing processes, students lack the foundation to construct knowledge and struggle to know what information is needed to manufacture the parts they design [4], [5]. Third, without having used manufacturing equipment themselves, students have low empathy for machinists and other tradesmen [6]. Fourth, students have not made enough parts to have experienced and learned from the consequences of incomplete drawings such as manufacturing errors and delays or excessive back-and-forth communication needed to clarify ambiguities [7]. As a result of these challenges, students often leave their first engineering graphics course knowing the CAD tools needed to create drawings but with little context for what information should be included for the part to actually be made. Other authors in this field have pointed out that proficiency in CAD software can sometimes hinder creative thought, thus students must be trained to think critically about their work, resisting the temptation to mindlessly generate models and drawings without awareness of their audience and design implications [8], [9].

Methods in the literature to support student learning in engineering drawings have included augmented reality to assist students in visualization of projected views [10] and a heavy focus on general training in spatial visualization [11]. While these approaches focus on improving students' ability to translate 3D shapes into 2-dimensional drawings (and vice versa) which is necessary for producing drawings, few have attempted to address knowledge gaps on the manufacturing side that affect engineering drawing outputs. Several universities have begun implementing 3D printing in introductory CAD courses [12], but typically without training on other manufacturing processes. Instructors at Western Washington University have explored using Lean Manufacturing Principles to improve CAD instruction, but this approach was focused on improving efficiency of course delivery rather than trainings students on manufacturing [13]. At Washington State University (WSU), authors explored using video content to provide training on manufacturing in a CAD design course, which showed promise but was not fully implemented due to COVID-19 interruptions [5], [14]. Common findings from these studies suggest that project-based learning, hands-on approaches, and collaborative learning environments provide the best training ground for learning to produce accurate, complete drawings [8].

At WSU, an attempt was made to briefly introduce manufacturing processes in the first-year CAD design course to provide students with the necessary context to understand what information need be included in their drawings for their parts to be manufacturable. The goal was for students to know the difference between, for example, what is needed on a drawing for a 3D printed part vs. a part that would be turned on a lathe. Thus, students could focus on including relevant details while excluding unnecessary information to reduce clutter and improve clarity in their drawings.

Methods

The introductory CAD design course at WSU is the first mechanical engineering course offered to students. The course focuses primarily on part modeling, engineering drawings, and assemblies, with more advanced topics covered briefly towards the end. Recently, effort has been made to augment the CAD concepts in this course with hands-on activities to improve student interest and promote hands-on skills such as 3D printing, part inspection, and reverse engineering [15]. Among these activities, there is an existing assignment that requires students to reverse engineer the jack stand assembly shown in Figure 1, using calipers and radius gauges, images, and 3D scans to create an accurate CAD model of a physical assembly provided to them in the class. The intervention described in this work leveraged this reverse engineering assignment as a logical place for introducing manufacturing processes. The intervention involved adding a 30-minute manufacturing lecture, providing students with a manufacturing drawings guide, and including a guest lecture from a local machinist. Teaching this new content in the context of an existing assignment instead of adding a new assignment allowed the intervention to be easily implemented without adding a significant amount of coursework that would require cutting course content elsewhere to make room.

Figure 1. Jack Stand Assembly and Individual Parts Used for Reverse Engineering and New Manufacturing Training.

As shown in Table 1, three sections of the course were offered in the Fall 2025 semester with Sections 1 and 2 being taught by instructor A and Section 3 being taught by instructor B. Sections 2 and 3 received the interventions described below while Section 1 did not receive the interventions and served as a control group for this quasi-experimental study. Overall, the intervention groups received an extra 60 minutes of instruction compared to the control group, although this additional lecture time was focused primarily on manufacturing processes and communication strategies, rather than providing additional teaching directly on how to make quality drawings. Meanwhile, the control group used this time to practice creating hand drawings—an activity that was removed for the intervention groups to make room for the new manufacturing content.

The new 30-minute manufacturing lecture introduced students to some common manufacturing processes, specifically:

- 3D printing
- Injection molding
- Laser cutting
- Waterjet cutting
- Lathe turning
- Manual milling
- CNC milling

- Sand casting
- Welding
- Sheet metal forming
- Stamping (press forming)

The lecture slides included diagrams of the manufacturing equipment, videos illustrating the processes, and information on what materials and parts are best suited to each method. This was added at the beginning of the reverse engineering assignment for Sections 2 and 3, encouraging students to think about how each part of the jack stand assembly might have been made.

Table 1. Topics/Activities Provided to Each Class Section with Differences Shown in Italics.

Class Section	Instructor	Teaching Topics	Materials Provided	Activities
1 (control)	A	• 20-minute lecture on reverse engineering and how to use measurement tools	• Jack stand parts • Measurement tools	• Create part models for jack stand parts using reverse engineering • *Create hand drawings for jack stand parts* • Create CAD drawings for jack stand parts* • Manufacturing quiz*
2 (intervention)	A	• 20-minute lecture on reverse engineering and how to use measurement tools • *30-minute manufacturing lecture* • *30-minute guest talk from local machinist*	• Jack stand parts • Measurement tools • *Manufacturing drawings guide*	• Create part models for jack stand parts using reverse engineering • Create CAD drawings for jack stand parts* • Manufacturing quiz*
3 (intervention)	B	• 20-minute lecture on reverse engineering and how to use measurement tools • *30-minute manufacturing lecture* • *30-minute guest talk from local machinist*	• Jack stand parts • Measurement tools • *Manufacturing drawings guide*	• Create part models for jack stand parts using reverse engineering • Create CAD drawings for jack stand parts* • Manufacturing quiz*

* Assignments used to assess effectiveness of interventions

Another component to the intervention was providing students in Sections 2 and 3 with a new manufacturing drawings guide—a handout detailing what information should be provided to machinists/makers for different manufacturing processes. For each manufacturing method, the handout listed:

- Typical materials and tolerance ranges
- What files machinists need (e.g. PDF drawing and DXF file)
- Drawing requirements
    - Whether full dimensions are needed or only overall dimensions and critical features
    - Notes on post-processing, build direction, etc.
    - Any specific view types (e.g. 2D flat pattern)
- Sample drawing

Offering this guide to the students helped them learn what information is needed for different types of manufacturing processes and provided quality drawing examples to learn from. This handout was developed by the instructors and reviewed by local machinists to ensure accuracy.

The last component of the intervention involved hosting a guest speaker from a local engineering company in Sections 2 and 3 of the class. The guest speaker identified for this purpose was a machinist with more than 20 years of experience who had progressed to a management role over the entire metals department at the company. He spoke with the class for 30 minutes, sharing best practices and emphasizing the importance of clear drawings and early/frequent communication with machinists. This opportunity for students to interact with a machinist and hear his perspective was intended to help students understand machinist's needs and the ways engineers can support positive and efficient working relationships with machinists.

Section 1—the control group—did not receive the new manufacturing lecture, guest lecture from local machinist, or manufacturing drawings guide but completed the same activities and assessments as the other sections, in addition to a hand drawings assignment which was removed for the intervention groups. Summative assessments, including exams and the final project, did not require knowledge from the intervention lectures. As such, students in the control group were not academically disadvantaged by not receiving the intervention.

Assessments

The goal of these interventions was to improve the clarity of students' engineering drawings, increase understanding of manufacturing methods, and enhance communication with machinists. Assessments used to evaluate these outcomes included comparison of performance between class sections on the jack stand part drawings assignment immediately following the intervention and a pre- and post-quiz on manufacturing processes given before and after the intervention.

After learning about manufacturing processes and associated drawing guidelines, students were tasked with creating drawings for four of the jack stand parts, specifically with the aim of including everything that would be needed to actually manufacture the parts using four different manufacturing processes. This same assignment was given to all three class sections, including Section 1 which did not receive the interventions. The drawings resulting from this assignment were assessed using the rubric shown in Table 2 which enabled comparison of various drawing attributes between Section 1 (control) vs. Sections 2 and 3 which received the intervention.

Table 2. Jack Stand Part Drawing Rubric.

Rubric Category	**Criteria**	**Scoring Metrics**
Dimensioning & Geometry Representation	1. Included isometric view	2=yes 0=no
	2. Included section view	2=yes 0=no
	3. Enough views to understand part	2=yes 1=kind of 0=no
	4. Included overall part dimensions	2=yes, all three 1=only two of three

		0=one or less
	5. Dimensioned critical features	2=dimensioned hole diameter 0=did not dimension hole diameter
Neatness	6. No crossing dimension lines	2=none 1=one crossing 0=more than 1
	7. No dimensions inside part outlines	2=none 1=one inside 0=more than 1
	8. Clean sheet layout	2=clean 1=slightly crowded or messy 0=views too small or close together
	9. Used R and ϕ symbols correctly	2=no errors 1=one error 0=more than one error
Manufacturing Information	10. Listed material	2=listed some type of plastic 0=did not list or listed wrong material
	11. Listed manufacturing method	2=listed injection molding 0=did not list or listed wrong method
	12. Included general tolerance note	2=listed tolerance between .002" to .005" 1=listed, but not reasonable value 0=did not list tolerance

The other assessment used to evaluate this work was a simple, 8-question quiz on manufacturing processes, which was provided to all class sections both before and after the intervention. Section 1 did not receive any intervention between the pre- and post-quiz. Only paired responses were evaluated, so if a student took the pre-quiz but skipped the post-quiz (or vise versa), his results were discarded to avoid skewed results. The quiz questions and format are shown in Table 3.

Table 3. Manufacturing Quiz Question Details.

Question Category	**Quiz Question**	**Correct Answer**	**Question Type**
How part was made	1. What manufacturing method do you think was used to make this part? [photo of complex plastic injection molded part]	Injection molding	Multiple choice
	2. What manufacturing method do you think was used to make this part? [photo of thin flat metal part with intricate patterns cut out]	Waterjet or laser cutting	Multiple choice
	3. What manufacturing method do you think was used to make these parts? [photo of several round metal parts with circular symmetry]	Lathe	Multiple choice
Recommended mfg. method	4. What manufacturing method would you recommend for producing large quantities (1,000) of this part? [photo of plastic injection molded part]	Injection molding	Multiple choice
	5. What manufacturing method would you recommend for producing these parts out of aluminum? [photo of T-shaped flat metal parts with detailed hole pattern]	Waterjet or laser cutting	Multiple choice

What info is needed for mfg.	6. If you were submitting this part to a machinist to be made by CNC milling, what information would you need to provide? [photo of CAD model for complex part]	• Fully-dimensioned PDF drawing with tolerances on critical dimensions • .STEP\, .IGES\, .SLDPRT\, or other format of 3D part model • Material selection	Select multiple answers
	7. If you were submitting this part to a machinist to be 3D printed, what information would you need to provide? [photo of CAD model for complex part]	• PDF drawing with overall dimensions and critical dimensions only • .STEP\, .IGES\, .SLDPRT\, .STL\, or other format of 3D part model • Material selection • Material infill density	Select multiple answers
Confidence rating	8. How confident do you feel in your ability to communicate your designs to a machinist for manufacturing?		1-5 Likert scale

Results

As shown in Figure 2, results from the jack stand part drawings assignment showed that Sections 2 and 3 scored higher than Section 1 (control) in every category except for sheet layout. The statistical significance and effect size of these improvements were calculated using the Mann-Whitney U-test to compare scores in each criterion between the control group (Section 1) vs. intervention group (Sections 2 and 3). These results are shown in Table 4, where the statistical evaluation identified nine out of the twelve criteria as having statistically significant improvements with the intervention with $p < 0.05$. Similar trends were observed in the two intervention groups (Sections 2 and 3); therefore, their results were combined in Figure 2 for clarity, while section-specific scores are detailed in Table 4. This study aimed to evaluate the effectiveness of the new teaching content, not to compare minor differences between instructors.

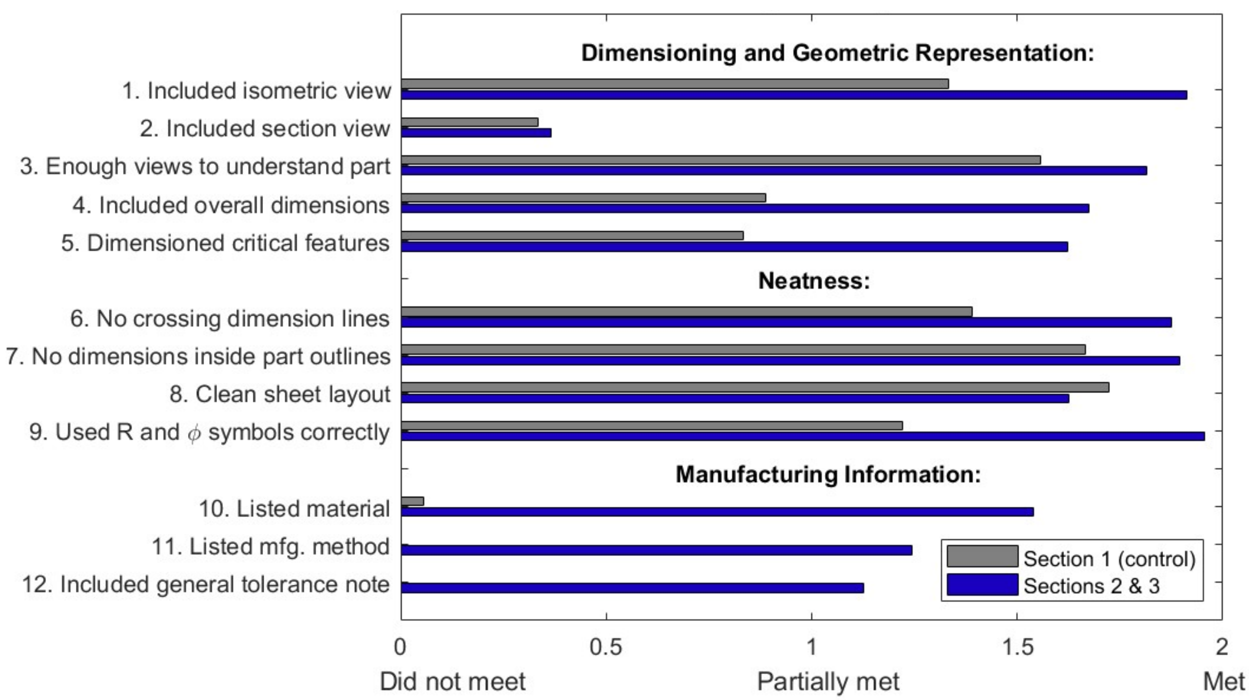

Figure 2. Jack Stand Part Drawing Score Comparison.

Students who received the additional manufacturing training were significantly more likely to include an isometric view, include enough views to understand the part, include overall part dimensions, and dimension critical features on their drawings. These improvements suggest that the manufacturing training caused students to better portray the geometry and dimensions of the parts. In this category, the only insignificant change with the intervention was the number of students who included a section view. It is likely that students need more training on how and when to use section views.

In the neatness category, students who received the intervention were significantly more likely to avoid crossing dimension lines and use the radius and diameter symbols correctly, although changes in number of dimensions inside part outlines and cleanness of sheet layout were insignificant between the two groups.

Unsurprisingly, the category pertaining to manufacturing information saw the most significant improvements with students who received the manufacturing training significantly more likely to list the material, manufacturing method, and general tolerance note on their drawings. This shows that students who received the manufacturing training intervention thought more carefully about the additional information—beyond part dimensions/geometry—that would be needed to manufacture the parts.

Table 4. Scores from Jack Stand Part Drawings Assignment.

Criteria	**Sec. 1 Average Score (n = 18)**	**Sec. 2 Average Score (n = 23)**	**Sec. 3 Average Score (n = 25)**	**Average Improvement with Intervention**	**Statistical Significance (p-value)**	**Effect Size (r_rb)**
1. Included isometric view	1.33	1.83	2.00	0.58	0.0014	0.2917
2. Included section view	0.33	0.17	0.56	0.03	0.8547	0.0208
3. Enough views to understand part	1.56	1.87	1.76	0.26	0.0410	0.2350
4. Included overall part dimensions	0.89	1.83	1.52	0.78	0.0003	0.5116
5. Dimensioned critical features	0.83	1.57	1.68	0.79	0.0006	0.4479
6. No crossing dimension lines	1.39	1.87	1.88	0.49	0.0010	0.3565
7. No dimensions inside part outlines	1.67	1.87	1.92	0.23	0.3341	0.0938
8. Clean sheet layout	1.72	1.61	1.64	-0.10	0.9083	-0.0150
9. Used R and ϕ symbols correctly	1.22	1.91	2.00	0.73	0.0000	0.5278
10. Listed material	0.06	1.48	1.60	1.48	0.0000	0.7581
11. Listed manufacturing method	0.00	1.13	1.36	1.25	0.0000	0.6250
12. Included general tolerance note	0.00	1.13	1.12	1.13	0.0000	0.5833

The manufacturing pre- and post-quiz provided insights into students' understanding of manufacturing processes by assessing their ability to identify how parts were made, recommend manufacturing methods for different part types, and know what information machinists would need for different manufacturing processes. The final question also captured students' self-perceived confidence in their ability to communicate their designs to a machinist. As shown in Figure 3, students who received the intervention between their pre- and post-quiz showed more improvement between attempts than the control group in all four categories. Again, the statistical significance and effect size of these changes, shown in Table 5, were calculated using the Mann-Whitney U-test to compare the change between pre- and post-quiz scores from the control group (Section 1) vs. the intervention group (Sections 2 and 3).

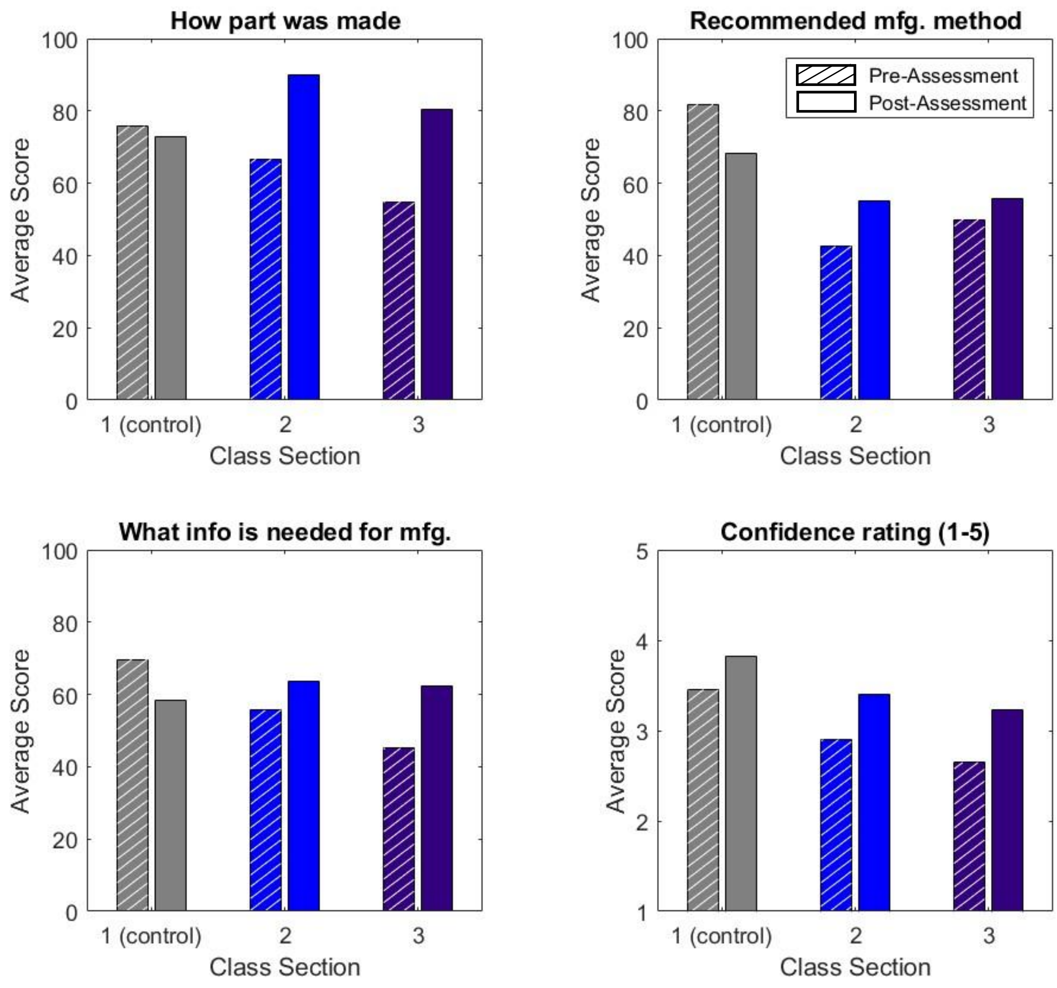

Figure 3. Manufacturing Pre- and Post-Quiz Results Comparison.

The categories that saw significant improvement ($p < 0.05$) with the intervention compared to the control were students' ability to identify how parts were made and their understanding of what information would be needed for different manufacturing processes. Students' ability to recommend a manufacturing method for different part types improved with the intervention, but not significantly. Students' confidence in their ability to communicate their designs to machinists improved with the intervention, but also improved almost equally in the group that received no intervention between the pre- and post-quiz. This suggests that this increased confidence may have resulted more from the sense of familiarity with the quiz questions on the second attempt than from actual confidence gained from the manufacturing training.

Table 5. Manufacturing Pre- and Post-Quiz Results.

Question Category	**Section 1 Avg. Score (n = 11)**		**Section 2 Avg. Score (n = 20)**		**Section 3 Avg. Score (n = 17)**		**Avg. Change w/o Inter-vention (Sec. 1)**	**Avg. Change w/ Inter-vention (Sec. 2&3)**	**Stat. Sig. (p-val)**	**Effect Size (r_rb)**
	Pre-	**Post-**	**Pre-**	**Post-**	**Pre-**	**Post-**				
How part was made (%)	75.76	72.73	66.67	90.00	54.90	80.39	-3.03	24.32	0.0187	0.2211
Recomm-ended mfg. method (%)	81.82	68.18	42.50	55.00	50.00	55.88	-13.64	9.46	0.0857	0.1941
What info is needed for mfg. (%)	69.70	58.33	55.63	63.54	45.10	62.50	-11.36	12.27	0.0205	0.3249
Confidence rating (1-5)	3.45	3.82	2.90	3.40	2.65	3.24	0.36	0.54	0.7747	0.0565

Conclusion

This paper explored an approach to improving the clarity of engineering drawings produced by early engineering students by providing them with an introduction to manufacturing processes, a manufacturing drawings guide, and a guest lecture from a local machinist. Students who received these interventions demonstrated statistically significant improvements in their drawing neatness, clarity of part geometry and dimensions, and thoroughness of manufacturing notes compared to students in the control group who did not receive the interventions. In addition to these improvements in their part drawings, students who received the manufacturing training also demonstrated an improved ability to identify how different parts were made and increased understanding of what information they would need to provide to a machinist for different manufacturing processes. Despite requiring less than two additional hours of instruction, this intervention shifted students' perspectives from viewing designs as isolated CAD models to understanding them as manufacturable parts, strengthening their awareness of audience needs in engineering drawings. In the future, this activity may be expanded to include a machine shop tour or hands-on practice with simplified manufacturing processes to promote deeper understanding of the processes presented and the information needed by machinists.

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