Expert Feedback on Engineering Sketching Skills for Object Assembly Tasks

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***Abstract*—This Work In Progress research investigates sketching and visualization experts' perspectives on the definitions and alignment of object assembly sketching exercises with experience from their professional practice. Learning to sketch is a key skill for developing strong visualization and spatial reasoning skills, as well as communication, representation, idea generation, and idea fluency during engineering design. However, manual sketching has largely been replaced by computer graphics tools in undergraduate engineering classrooms. The expert feedback of architecture, civil engineering, and mechanical engineering instructors are reported on relative importance of eight sketching skills, as well as grading practices and discipline-specific practices. Experts generally valued shape quality metrics over line quality, and suggested new interpretations of rubric levels and criteria. We discuss recommended changes to the rubric and exercises.**

***Index Terms*—sketching, assessment, interview**

I. Introduction

Sketching is a fundamental skill in engineering design for idea formulation and concept development. It allows designers to develop creativity by generating and refining multiple solution ideas [1]. It facilitates conceptual understanding with translation of information across multiple representations [2]. Sketching is a tool for communication within design teams for planning and conversing about a shared representation [3]. In addition, designers use sketching as a fundamental tool for thinking [4] and enables designers to clarify ideas and engage with information in new ways through reflection [5].

Most instruction on freehand sketching skills has shifted to rely on computer visualization tools for design modeling. This is in part due to industry expectations for proficiency with engineering design software [6]. However, computer software does not support the same types of design thinking as sketching. CAD software allows for representation of exact design details but it does not support changeability of design ideas [7]. While it allows more detailed and powerful visualization and communication, it also may limit students' idea generation and lead to design fixation during problem-solving [8].

Sketching plays a crucial role in multiple engineering disciplines that include Civil engineering, Mechanical engineering, and Architectural engineering. According to the American Society of Civil Engineers (ASCE), communication is a valuable skill in civil engineering [9], [10]. Hand-drawn sketches become helpful at various stages for civil engineers, especially when informal communication in the paper is needed as a quick way to visualize the problem or brainstorm ideas [10]. According to [11], sketching skills play an essential role in the mechanical engineering profession despite the availability of Computer Aided Design tools. Graphical communication skills are crucial for Architectural engineering students as well, and sketching allows them to represent their ideas [12].

Engineers can benefit from learning essential sketching skills as a part of engineering graphics instruction. Assessment is needed to support sketching learning and provide instructors with information needed to give feedback and guide practice. However, assessing sketching is a challenge due to a variety of sketching techniques and approaches, as well as the individualized backgrounds of experts.

Research Questions

The purpose of this study is to investigate experts' definitions of fundamental engineering sketching skills and spatial visualization that can be assessed by a test for classroom use. Our research questions are:

1) How do sketching experts define and rank fundamental sketching skills as assessed by the Object Assembly test?
2) How effective do experts believe the Object Assembly test exercises are for practicing sketching skills?

II. Background

A. Sketching and Spatial Skills Learning

Spatial Visualization skills include the capability of representing and manipulating both Two-Dimensional and Three-Dimensional objects [13]. Studies have shown that it is a skill

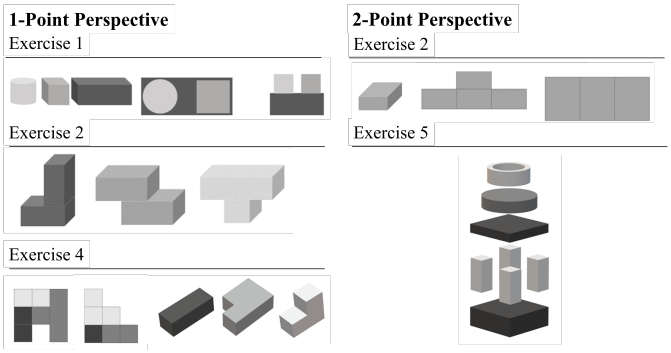

Fig. 1. Object Assembly Test exercises to be sketched in 1-point (left) and 2-point (right) perspective.

TABLE I
SKETCHING SKILLS DEFINITIONS

Representation Accuracy	The picture result replicates what the student intended to sketch based on the requirements.
Precision	Ability to converge lines at points or corners to accurately define shapes.
Scale	Ability to draw shapes at a given height, width, depth relative to each other.
Proportion	Ability to accurately represent height, width, and depth of individual shapes.
Converging Lines	Ability to use vanishing point(s) or horizon line guidelines when drawing in perspective.
Line Straightness	Ability to connect points with minimal drawn distance.
Line Smoothness	Ability to draw lines without shakiness or scratchiness.
Line Weight	Ability to draw lines with consistent thickness.

that can be advanced through training [14]. Freehand sketching instruction is traditionally a part of spatial visualization training [15], and freehand sketching training is instrumental in advancing spatial visualization reasoning of students' [14]. Sketching supports many aspects of design reasoning [1]. Further, improved spatial visualization skills have a broader impact in engineering students' college career and beyond. It has been shown that the grades of engineering students who were proficient in spatial skills where higher in introductory engineering, mathematics, and science courses compared to students with weak spatial skills [14].

B. Object Assembly Test of Sketching

As a tool to practice sketching skills through spatial reasoning exercises, the authors developed a test of object assembly where students sketch combined solids in 1-point and 2-point perspective [16], [17]. The Object Assembly Test of Sketching is a pencil and paper sketching test with five exercises (see Figure 1). Three exercises are sketched in 1-point perspective and two in 2-point perspective. Three exercises provide orthographic views to inform how the 3D assembled object will look. Of the two exercises which do not provide 2D views, one is written as an exploded parts diagram, and one allows students to creatively rotate and assemble shapes into a solid.

A grading rubric assesses performance on four shape quality skills of Representation Accuracy, Precision, Scale, Proportion, and Converging Lines, and four line quality skills of Converging Lines, Line Straightness, Line Smoothness, and Line Weight (see Table 1). The rubric levels are Emerging, Developing, and Proficient. Sketches at Emerging (1) have less than half of all lines or shapes in the sketch follow the skill. Sketches at Developing (2) have half or more than half of lines or shapes meeting the skill definition. Sketches at Proficient (3) have all lines and/or shapes showing the skill as described.

Previous study on the first version Object Assembly Test tested a 3-exercise version in an undergraduate mechanical engineering graphics course, but inter-rater reliability for grades assigned by two raters was not acceptable [16]. Raters achieved higher inter-rater reliability on the instrument with two additional exercises and revised sketching skills criteria in a second study [17]. However, Krippendorff's α varied considerably across exercises and skills. Therefore, we revisited the items and rubric by soliciting expert feedback on their definitions and importance for engineering sketching.

III. METHODS

This instrument is undergoing validation studies and revisions for use in undergraduate and graduate engineering design and engineering graphics classrooms. Validity is a justification for a particular interpretation and use of assessment results that is based on evidence of a test's functioning with specific populations and use cases [18]. In the test development process, an essential step in collecting evidence of content validity is consultation with subject matter experts [19]. Validity evidence for performance assessment should demonstrate alignment between the tasks students are asked to perform and the performance standards representing increasing levels of task difficulty [20]. Expert review contributes to building a validity argument for task-based assessment by evaluating the relative importance of activities for demonstrating skills [19].

This study was part of a larger semi-structured interview project investigating the perceived benefits, necessary skills, and disciplinary value of sketching among instructors of engineering, industrial design, architecture, and visualization. Because sketching for design and engineering is relevant to many fields, we solicited feedback from experts across disciplines to fully represent the content domain. Triangulation is one approach to producing validity evidence in qualitative inquiry by connecting multiple sources of information that reflect convergent themes [21]. As a part of the instructor interviews, we asked instructors to provide feedback on the Object Assembly Test.

A. Participants

Participants in this study were three faculty from a large Southwestern university with expertise in engineering sketching and visualization. Participants were recruited from their self-reported expertise through courses taught and experience. One participant was from Architecture, the second was from Civil Engineering, and the third from Mechanical Engineering.

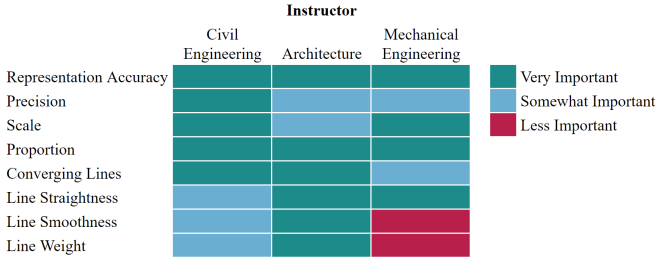

Fig. 2. Relative importance of sketching skills by instructor.

The faculty from Architecture had self-reported connection to the engineering discipline. A recruitment email was sent to each participant explaining the context of our research on engineering sketching instruction and assessment, and asking participants to share their practices and insights. We intentionally invited faculty with diverse backgrounds to fully represent the scope of sketching, assessment, and engineering visualization content knowledge.

B. Interview Protocol

All interviews were conducted via Zoom and structured to last around 45 minutes to an hour, but instructors were free to discuss questions for as long as they wished. One researcher conducted all interviews and cleaned transcripts, and a second researcher analyzed findings from instrument feedback questions. Questions on the Object Assembly Test were asked at the end of each interview. Interview questions were semi-structured to solicit general feedback on which instrument items were or were not important, their views on the rubric skills definitions and importance, and any general thoughts about the value of the instrument in engineering.

IV. Results

As a part of a larger study on instructors' perspectives on the value of teaching and learning sketching in engineering, our findings reflected not only instructors' feedback on improving the Object Assembly Test exercises and rubric, but also its purpose in the engineering practice. Instructor reflections are organized by reflections on most and least important sketching skills, recommended rubric changes, and discipline-specific interpretations of skills.

A. Importance of Sketching Skills

Of the eight sketching skills in the Object Assembly Test rubric, instructors consistently valued Representation Accuracy and Proportion as highly important for assessing sketching skill (see Figure 2).

According to the Civil Engineering instructor, Scale depended on Representation Accuracy, Precision, and Proportion to be successful. This instructor also acknowledged that technical sketching accuracy is limited: *"When we're measuring the real world, we can only do Precision, we can't do Accuracy, because there is inherently built systematic error in our measuring system. So we can only give a precision of how close we think the elevation of this is, or how tall we think this is, because of the inaccuracy of our technology."* The Architecture professor valued Representation Accuracy for translating concepts into reality, as *"you can have a beautiful representation accuracy, or you can have none."*

Skills viewed as somewhat important were described in relative terms. To the Mechanical Engineering and Architecture instructors, Converging Lines was aligned with perspective sketching of the exercises, but the Mechanical Engineering professor acknowledged that perspective sketching is not always used by students. Precision was important to the Mechanical Engineering instructor *"to some extent"* but was also *"willing to be forgiving about precision"*. Similarly, Scale was important to the Architecture instructor only in precise engineering drawings with *"a given height, given width, given depth, that's the problem that engineering always wants to do."* The Architecture instructor interpreted shape quality metrics holistically for supporting design thinking and communication more than technical skill, referring to prototyping and ideation:

> *"Let's analyze a student that does a fantastic job and creates the next business enterprise. They are able to sketch their products quickly, and no problem on the back of a napkin. All right, the prototype for the first iPod ... was nothing more than a block rectangle of Styrofoam with cut pieces that were around ... Was that accurate? No. Was that perfect? No. But it had representation accuracy. Was it precise? Not necessarily. But it had a level of Precision, Scale, Proportion."*

The Civil Engineering instructor described a continuum of line quality corresponding to idea development, as straighter and smoother lines were managed by computers rather than people: *"Straightness of lines and smoothness, we're not using it for hand sketching, then we're [putting it] into a machine, right? And then Proficient, again, we're not back to CAD so it's different."* Line quality metrics of Straightness, Smoothness, and Weight were not consistently important for all instructors. The Architecture instructor agreed that line quality metrics were important, but the Mechanical Engineering instructor only viewed Line Straightness as important but not Smoothness or Weight.

B. Rubric Feedback

Two instructors gave input on the rubric grading scale of Emerging, Developing, and Proficient. The Architecture instructor did not see the middle rubric level of Developing as meaningful or interpretable, and advised against framing rubric skills as a correct-incorrect dichotomy. Rather than have the instructor impose judgment on students' work, the Architecture instructor instead believed that sketching represents individual choices by each student that should be respected:

> *"As long as they're able to defend their choice. What you're doing here is you're taking away their free will, their free choice, and their mode of who they are. ... When you use the word 'correct,' when you*

have the word 'consistent,' when you have the word 'straight,' when you have 'without excessive,' you are dictating something extreme."

The Architecture instructor also felt the need to go beyond the strict process and definitions outlined in the rubric and to allow each student their own process of learning. This instructor emphasized the value of a variety of approaches to assessing the sketching process without a strong focus on correctness.

According to the Civil Engineering instructor, Emerging did not represent lower levels of sketching skill but rather less formality, corresponding to the more rough conceptual sketching phase:

> *"Emerging ... is less accurate in the beginning, and then Straightness, Smoothness, and Line Weight, that becomes more accurate, more important, because it tells us a story. Then, when you're in the design, the development, that means you're making the drawing, all those at the beginning are more important. ... So we're really sketching to grasp the Emerging. We're not hand sketching in Developing or Proficient ... So for sketching the preliminary or the conceptual phase, having Emerging is fine, I would assume, even though everything is not perfect. And then, as they move later to the final drawing stage, all these things matter."*

This instructor interpreted a sketch which develops from Emerging to Proficient as a concept being refined and communicated in increasing detail, where line quality metrics are less important on lower skill levels and become more important as the concept is defined.

C. Discipline-Specific Viewpoints

The Civil Engineering instructor gave detailed insight into the use of sketching as a tool for professional practice. This instructor described the need to sketch for practical communication:

> *"I've been out in the field trying to tell somebody what we have to build, and I have to get everyone around the table, and I've got to draw it, and if I don't draw it well that's a big problem ... I need to know what we're talking about specifically, and then things change ... because it you're talking about we're building a bridge that people die on, no, we've got to do it a lot differently than if you say we're digging a hole to lay a sewer pipe."*

Overall, the Architecture instructor emphasized the importance of sketching to support creativity and open-ended thinking, and acknowledged the limitations of a quantitative assessment for capturing levels of skill:

> *"What students need to compensate for the rigorous nature of absolute, quantitative, perfect everything that is engineering–and there's no doubt about that, because we are engineers, we're not just fluffy artists–what students need to do is focus on its complement for that. Yes, sketching can support traditional engineering, but it should not preclude their expansion into higher levels of thinking and connection with the universe."*

The Mechanical Engineering instructor qualified the importance of Converging Lines for only the exercises in the Object Assembly Test which requires perspective sketching. By referring to the 1- and 2-point perspective exercises, the instructor noted that not all students sketch in perspective.

V. Discussion

Instructors encouraged the researchers to look beyond the technical aspects of sketching to reflect on the meaning behind skills and levels of expertise. High scores on all skills may not fully capture the levels of sketching skill, while low scores may not always indicate poor sketching. Differing weights should be taken into account when measuring skill at each level, as some high scores may not be necessary for observing skilled performance.

Interviews also revealed that most instructors did not consider individual rubric skills independently of each other. Shape quality metrics supported each other most often as instructors ranked Representation Accuracy, Proportion, and Scale highly more often while describing their connections. Relative importance under specific circumstances, such as field sketching or prototyping, suggests that performance assessment can benefit from additional context which accounts for professional practices and goals.

VI. Conclusions and Future Work

This work in progress reports preliminary interview findings from three engineering instructors with experience teaching sketching on the task content and grading methods of the Object Assembly Test. In the process of obtaining expert input on sketching skills definitions and alignment, this study collected valuable insight into instructor's values of sketching based on their disciplinary backgrounds. Results highlight the continued challenge of defining engineering sketching, given both the constraints of technical drawing and the need for communication and idea generation during design.

While our findings of this work in progress represent input from diverse professional backgrounds, they are also limited in scope due to the small sample of instructors who participated. Future work will recruit more experts in engineering fields to further support conclusions about skills and assessment. We also plan to recruit experts in spatial reasoning and visualization to continue evaluating how to appropriately assess visual skill through sketching.

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