Work In Progress: An Object Assembly Test of Sketching in Undergraduate Engineering

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***Abstract*—This Research Work-In-Progress reports the implementation of an Object Assembly Test for sketching skills in an undergraduate mechanical engineering graphics course. Sketching is essential for generating and refining ideas, and for communication among team members. Design thinking is supported through sketching as a means of translating between internal and external representations, and creating shared representations of collaborative thinking. While many spatial tests exist in engineering education, these tests have not directly used sketching or tested sketching skill. The Object Assembly Test is used to evaluate sketching skills on 3-dimensional mental imagery and mental rotation tasks in 1- and 2-point perspective. We describe revisions to the Object Assembly Test skills and grading rubric since its pilot test, and implement the test in an undergraduate mechanical engineering course for further validation. We summarize inter-rater reliability for each sketching exercise and for each grading metric for a sample of sketches, with discussion of score use and interpretation.**

***Index Terms*—sketching, assessment, mental imagery**

I. Introduction

Engineering students who learn to sketch are prepared with essential tools for their professional practice. Sketching equips engineers with representation and communication tools for quickly sharing ideas among team members [1]. Sketching is critical in early stage design processes where engineering designers must generate a variety of ideas, describe design features and functions, and include any necessary annotations conveying technical information [2]. Sketching also informs conceptual thinking during design ideation. Transformations in concept sketches can represent the development of design thinking as students are able to depict design concepts at different levels of complexity [3].

While computer graphics tools are increasingly common for engineering modeling [4], freehand sketching has advantage to computer-based visualization in conceptualizing and modifying designs. Ease of visualization and modifications are tradeoffs for sketching and computer-aided design (CAD) tools where sketching occurs most in early stages and computer modeling is used to represent design solutions [5]. While switching between sketching and CAD allows different goals of developing, realizing, and adapting design concepts [6], students who exclusively use graphics software without developing their sketching abilities are more likely to fixate on a single design idea and become inflexible to changes [7]. For design processes with rapidly changing requirements and expectations, sketching is a key proficiency for brainstorming and adapting ideas. There is a need for high-quality sketching skills assessment in undergraduate engineering education, especially in the context of spatial abilities, to inform best practices in teaching and learning sketching.

II. Literature Review

A. Engineering Drawing and Spatial Ability

Sketching promotes spatial reasoning skills for interacting with complex visual information. Technical engineering drawing requires students to project from 2-dimensional views to 3-dimensional objects, a skill that requires strong spatial abilities regardless of manual or digital medium [8]. Sectional views and orthographic projection are used in engineering drawings to show parts of an object in relation to the whole, requiring students to project a flat surface into a 3-dimensional space to form a solid [9]. This process may involve folding flat sides to mentally assemble a solid, constructing solids that account for hidden edges, and rotating the solid to the correct isometric view [9]. Interventions for improving spatial visualization through engineering drawing have helped beginners perform similarly to experts on spatial tests [10]. Conversely, instruction in mental rotation contributed to students' ability to transfer skills to novel engineering drawing problems [11].

Mental imagery and mental rotation are two key spatial abilities required for students learning 3-dimensional sketching. Mental imagery is the ability to create an internal visual representation of an imaginary object. Working memory maintains these representations to solve problems, visualize information, and perform mental operations [12]. Even when stimuli are not seen, 3-dimensional spatial information can be sensed through tactile tools and perceived to construct an internal representation [13].

Mental rotation is the ability to imagine and predict a new view of a solid after it has been rotated. The Revised Purdue Spatial Visualization Test: Rotations (PSVT:R) has students identify the correct complex rotated irregular shape that is consistent with the original shape [14]. It is often used as an outcome measure for instructional success or as predictors of other engineering achievements [15]. Decisions are based on a person's unique internal perspective when perceiving a solid, often based on incomplete information, limited or deconstructed views, or projections of hypothesized interactions with the solid.

While engineering sketching and spatial ability have been linked through research showing reciprocal impact, few mental folding or rotation tests use sketching as a means of directly measuring spatial ability. Our test uses sketching as a way for students to demonstrate their spatial reasoning, while assessing their perspective sketching skills. The purpose of this research is to evaluate engineering students' performance on object assembly sketching exercises requiring mental imagery and mental rotation.

B. Object Assembly Test of Sketching

The Object Assembly Test was developed in our prior research to assess mental imagery and mental rotation on exercises [16]. The original test has three exercises where students sketch an assembled solid in correct perspective based on shapes they are given. In the first and second exercises, students view the top and front view of a composite object made up of three shapes, and are asked to sketch the assembled shape in perspective. Exercise 1 uses a cylinder, a cube, a rectangular prism, and 1-point perspective. Exercise 2 uses four rectangular prisms and 2-point perspective. Both exercises show front and top views to indicate a correct solution. Exercise 3 uses irregular rectangular prisms and 1-point perspective, but allows students to assemble the objects in any way they choose. We added two new exercises in the current study. One uses irregular rectangular prisms and 1-point perspective, but with front and top views to show a correct solution. This helps scaffold students towards complex assembly with guidelines of how the composite object should look. The second new exercises uses more shapes, including rectangular prisms and cylinders of multiple sizes, to emulate an exploded view of a machine part. While this exercise also has a correct solution, students are expected to follow size and dimensions more strictly and account for hidden shape sides. Figure 1 shows examples of the five completed exercises. Exercises without orthographic views are intended to use more difficult mental imagery and mental rotation, as well as creativity.

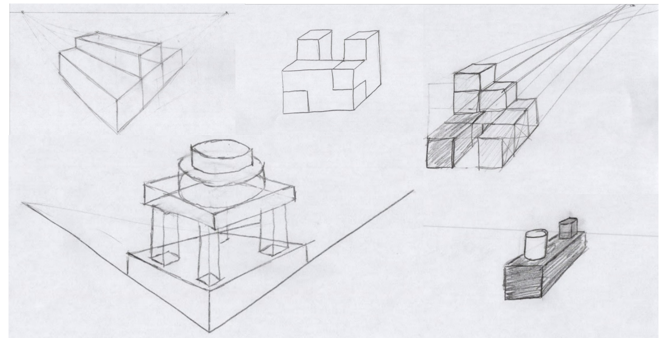

Fig. 1. Object assembly exercises of cylinder, square, and rectangular prism (bottom right), rectangular prisms (top left), irregular shapes with view (top right), irregular shapes without view (top center), and exploded part assembly (bottom left).

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.

The test is graded with a rubric assessing eight sketching skills at the levels of Emerging (1), Developing (2), and Proficient (3) (see Table I). Shape Quality includes Precison, Scale, Proportion, and Converging Lines, graded as *1 - Fewer than half of shapes*, *2 - Half or more than half of shapes*, and *3 - All shapes* demonstrate the skill. Line Quality includes Line Straightness, Line Smoothness, and Line Weight, graded as *1 - Fewer than half of lines*, *Half or more than half of lines*, and *3 - All lines* demonstrate the skill.

The purpose of this study is to continue validating the Object Assembly Test of Sketching for use in undergraduate engineering classrooms to assess sketching skills. This study addresses the research questions: *RQ1: What are the average sketching skills of mechanical engineering undergraduate students as assessed on object assembly perspective sketching exercises?* and *RQ2: What is the inter-rater reliability of the rubric for assessing sketching skills at three levels of ability?*

III. Methods

A. Participants

We recruited students from an undergraduate mechanical engineering graphics and design course at a large Southern university in the United States to participate in our study. This study is part of a larger project that teaches perspective sketching to engineering students through classroom instruction and software-based practice. As a part of this larger project, IRB approval was obtained by the principal investigators at each institution to collect data in undergraduate engineering classrooms and to offer extra credit for research participation. The Object Assembly Test was administered before and after six weeks of classroom lessons and homework on lines, basic 2-dimensional shapes, and 3-dimensional perspective drawing. In a survey following the Object Assembly Test, students also provided their major area of study, gender, age, and race/ethnicity (see Table II). Participation was voluntary and students could withdraw from the study at any time. The test was separate from classroom and homework assignments. Students received extra credit for completing the Object Assembly Test, but were not offered incentives for completing the survey. 40 students completed the Object Assembly Test and 46 students completed the survey. For this work in progress, we randomly sampled 10 students to grade their post-test work and calculate inter-rater reliability between two raters. Students were primarily male and white, equally representing aerospace engineering and mechanical engineering.

B. Data Collection & Analysis

We collected and graded sketched responses to the five Object Assembly Test exercises in this study. Two raters who were researchers from this project revised the rubric and graded a total of 50 sketches from 10 students. First, the raters graded together to discuss criteria and reach consensus. The raters then graded separately followed by discussion to calibrate their grading. Finally, raters graded the entire sample of sketches independently with occasional calibration. We calculated inter-rater reliability using Krippendorff's α coefficient [17]. Krippendorff's α calculates reliability using pairs of agreements between raters, and our sample of 50 sketches produced 200 coded units with no missing values [18]. Krippendorff's α values range from -1 to 1, with α greater than or equal to 0.8 is the target and α greater than or equal to 0.667 allows for somewhat confident conclusions [19].

TABLE II
DEMOGRAPHICS OF PARTICIPANTS

Demographic	*n*
Gender	
Male	9
Not specified	1
Age	
18 yrs	3
19 yrs	6
20 yrs	1
Race	
White/Caucasian	7
Asian	2
Black/African American	1
Ethnicity	
Not Hispanic or Latinx	7
Hispanic or Latinx	3
Major Area of Study	
Aerospace Engineering	5
Mechanical Engineering	5

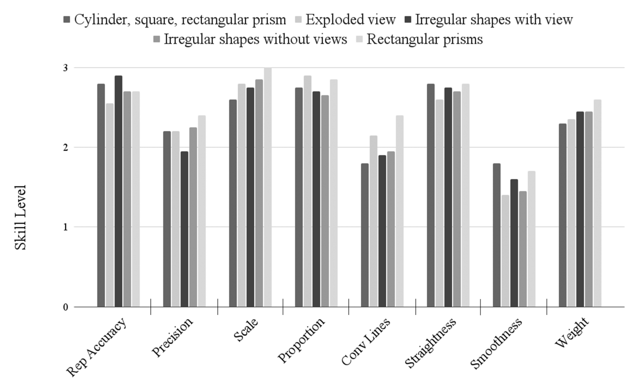

Fig. 2. Average scores for five Object Assembly exercises by sketching skill.

IV. Results

A. Sketching Scores

Average scores for sketching skills on each exercise are shown in Figure 2. Patterns of scores were similar across each exercise for all skills, with generally high scores on Representation Accuracy, Scale, and Proportion. Scores were lowest on Line Smoothness and Converging Lines.

B. Inter-Rater Reliability

We first calculated inter-rater reliability between the two raters across all exercises for each graded sketching skill (see Table III). Agreement was highest for Converging Lines, Scale, and Precision, suggesting that both raters understood the definitions and applied the rubric similarly. Proportion, Line Smoothness, Representation Accuracy, and Line Straightness had low agreement, and Line Weight agreement was below acceptable, indicating rater difficulty reaching agreement.

We then calculated inter-rater reliability across all skills for each of the five exercises in the test (see Table IV). Agreement was consistent and acceptably high across all exercises, with the highest agreement on Exercises 3 and 4, irregular shapes with and without views.

TABLE III
INTER-RATER RELIABILITY BY SKETCHING SKILL

Sketching Skill	α
Converging Lines	0.939
Scale	0.67
Precision	0.651
Proportion	0.567
Line Smoothness	0.567
Representation Accuracy	0.499
Line Straightness	0.407
Line Weight	0.388

TABLE IV
INTER-RATER RELIABILITY BY EXERCISE

Sketching Exercise	α
1. Cylinder, Cube, & Rectangular Prism	0.757
2. Rectangular Prisms	0.722
3. Irregular Shapes With Views	0.778
4. Irregular Shapes Without Views	0.783
5. Exploded Part	0.756

V. DISCUSSION AND LIMITATIONS

On object assembly test exercises, students demonstrated ability to draw complex shapes in 1- and 2-point perspective while performing mental rotations and maintaining assembled objects in working memory using mental imagery. Students' strongest shape quality skills were Scale and Proportion, showing they can accurately represent the form and size of shapes, while lower Precision scores suggest that completing corners to define a shape is still a challenge. Line quality skills were more variable, with strong Line Straightness ability but variable Smoothness and Weight. Many of these skills overlap and interact with each other, requiring future work to better define their co-development during learning. Sketching skills with low agreement between raters also indicates difficulty in judging these skills, suggesting they are challenging for both students and raters to master. Agreement was consistent for all exercises with skills collapsed, showing that variables on shapes, perspective, or assembly complexity did not affect grading reliability.

Unstructured complex assembly tasks pose challenges when students do not have clear objectives what to draw. Even exercises requiring orthographic projects may need creative thinking to reach a solution. Therefore, questions such as the exploded part exercises were limited by having a simple solution, despite not including 2-dimensional views. 2-dimensional views in early exercises act to scaffold student understanding of the assembly process towards confident sketching in free-response exercises. Further test revisions should adapt items to follow the irregular shape exercise format with and without views, so students can demonstrate innovation in assembling complex shapes.

VI. CONCLUSIONS AND FUTURE WORK

This work in progress demonstrates mechanical engineering students' sketching performance on object assembly exercises. Continuation of this study will include grading the remaining sketches from the same course, and implementing the Object Assembly Test in other undergraduate engineering courses for further validation. Outside of mechanical engineering, this test could have applications to other design-based courses such as product design, industrial design, and architecture for supporting development of basic sketching skills. Even when sketching instruction varies across disciplines and courses, the Object Assembly Test can give insight into students mental rotation and mental imagery abilities in the context of learning to sketch. Future work will continue to adapt exercises to better represent a continuum of spatial problem-solving skill. We plan to scaffold learning with 2-dimensional views and correct solutions to allow students practice with complex shapes in perspective, then progress to unstructured tasks that have no correct solution. In this way, students can develop their understanding of perspective and hidden shapes during object assembly, while simultaneously practicing sketching.

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