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# Assessing Engineering Sketching Skills on Object Assembly Tasks


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## Abstract

Sketching is a valuable skill in engineering for representing information, developing design ideas, and communicating technical and abstract information. It is an important means of developing spatial abilities which are predictive of success in STEM fields. While existing spatial ability tests are predictive of engineering visualization skills, they do not allow students to develop drawing skills through spatial exercises. The Object Assembly Sketching test examines sketching skills with object assembly tasks using mental imagery and mental rotation. This study focuses on the development and pilot testing of a new sketching skills test using object assembly exercises. We piloted the test in two sections of an undergraduate mechanical engineering design course. Inter-rater reliability of two raters scoring students sketches on eight criteria was acceptable across exercises, but low across criteria. Students scored highest on Representation Accuracy, Scale, and Symmetry, and exhibited complex understanding of perspective sketching. We intend to revise the rubric to score for aesthetics and make instructions more precise.


## Introduction

Engineering simulation and modeling increasingly relies on digital tools in design processes. Virtual design is used for the conceptual space to connect designers in virtual studios, share feedback across teams [1] and engage in reflective conversation with individuals and shared representations of problems and designs through digital information [2]. Virtual prototyping allows designers to represent their ideas in the three-dimensional virtual space for testing its function and communicating design characteristics [3]. Many new applications, such as virtual and augmented reality, are used in lean manufacturing where digital tools are able to reduce waste and improve efficiency through flexible interactions with information before, during, and after production [4]. These design tools need spatial ability to navigate them and they help to develop spatial abilities at the same time.

For students to successfully apply these tools in the design world, interacting with virtual design tools requires a degree of spatial ability to perceive and interact with three-dimensional information, as well as confidence in those abilities [5]. Strong spatial abilities are predictive of success in engineering on problem-solving and visualization [6] as well as long-term outcomes such as pursuing STEM degrees and careers [7]. Digital design tools support creating and interacting with complex engineering visualizations with immersion in virtual and augmented reality [8]. Design-ing with three-dimensional graphics software enables students with multiple sources of evidence to perceive relationships among design variables as they interact in real-time, while promoting idea fluency [9]. However, these visualization tools are limited in their support of the full design process, including idea development.

Learning to sketch is an important skill in engineering design education for creativity, communication, and visual problem solving [10]. Sketching is a valuable skill in engineering design for representing information, developing design ideas, and communicating technical and abstract information [11]. While the tools for navigating virtual design spaces can support spatial skill development [12], manual sketching supports key design activities that computer tools do not. As a precursor to computer-based visualization skills, manual sketching is an important means of developing spatial abilities. Students may overlook important conceptual design and become over-committed to a single idea too early when using computer-aided desgin (CAD) exclusively [13, 14] or become caught up in the aesthetics of a design without attending to its feasibility [15]. In an interview of professional educators using CAD by Veisz et al. [16], experts agreed that CAD is not ideal for idea generation due to limitations of a mismatch between idea complexity and tool knowledge, the use of draft ideas, and time commitment.

There is a need to evaluate sketching skills apart from computer-based design, in order to authentically assess sketching practices in engineering designers. Students who are confident sketchers will have many advantages in design, and have more opportunities to develop essential spatial abilities. In this study, we develop and conduct pilot studies of a new instrument for assessing sketching skills in undergraduate engineering design students, in the context of spatial ability tasks in object assembly. The purpose of this study is to investigate engineering student performance on eight fundamental sketching skills, through a series of spatial exercises which test 1- and 2-point perspective sketching. Our goal is to take steps towards a classroom tool which engineering and design instructors can use in conjunction with visualization and graphics education to promote and assess freehand sketching

## Literature Review

A number of tests have been used in engineering education research to assess spatial ability and predict learning and achievement in engineering education. We define mental imagery in the context of our study, and review spatial ability tests in engineering education which inform our current study.

### A. Mental Imagery

Mental imagery broadly describes the ability to internally conceptualize and crystallize an image. Images are created and maintained in working memory in order to solve problems, visualize information, and perform mental operations. This process occurs in the mind's eye, especially in situations where a physical stimulus is not immediately perceived or present [17]. Mental imagery involves a tradeoff when visualizing complex images, because deeper processing of many features requires more time, producing a delay in producing high-quality images [18]. Mental imagery quality is characterized by an image's vividness, clarity, controllability, and transformation [19]. As a working memory strategy, mental imagery supports a high degree of information processing strategies, such as elaboration. The necessity for precise mental imagery impacts the visually scanned area and the response time when drawing from memory [20].

Mental imagery relies on spatial orientation for comprehension of how objects are arranged and manipulated in space, and spatial relations for problem-solving ability with these objects [19] During design idea generation, Tedjosaputro et al. [21] investigated the link between mental imagery and sketching in novice designers, and found that mental imagery was influential in thinking through design problems and reframing, and sketching demonstrated the connection between internal and external representation. Spatial orientation and mental rotation are closely related to mental imagery, as they involve perceiving objects in space and manipulating internal representations. Anderson [22] explores factors that influence the imperfect replication of external representations from internal images by evaluating key experimental demonstrations of mental rotation, image size and complexity effects on processing capacity, and the view of mental images as pictures.

### B. Spatial Ability Tests

Mental rotation tests such as the foundational instrument by Vanderberg and Kuse [23] rotate irregular shapes on an axis by a number of degrees, and students select the correct rotation from multiple options after mentally performing the same operation. These tests have been well integrated in engineering design drawing research. For example, Kadam [24] found mental rotation training with freshman engineers improved their transfer to new mental rotation tasks and engineering drawing skills for orthographic views of irregular part drawings. Erkoc et al. [25] found improvements in students' mental rotation scores following classroom instruction in isometric hand drawing 3-dimensional models and constructing their drawings with modeling software.

The Revised Purdue Spatial Visualization Test: Rotations (PSVT:R) shows symmetrical and asymmetrical objects from multiple isometric perspectives. Students select the image from multiple choices that is a consistent view with the rotations performed. Maeda et al. [26] conducted extensive validity research on the PSVT:R instrument to show its factor structure, item difficulty, and correlation with ACT and SAT scores and high school GPA. Difficult items require a combination of 90 degree and 180 degree rotations of the image around more than one axis, often on using complex shapes [26]. The PSVT:R is frequently used as an outcome measure for spatial ability interventions in engineering and design education such as modeling assembly drawings [27], middle school science and math participation [10], and engineering design creativity [28].

Engineering students learn orthographic projection as a way of visualizing engineering structures and machines. Assembly drawings are a feature of digital drawing and modeling software to create 2- and 3-dimensional images. The Engineering Graphics Concept Inventory (EGCI) was proposed by Study, Nozaki, & Sorby [29] to assess knowledge of concepts including visualizing and mapping in 2 and 3 dimensions, sectional views, object representation methods, projection theory, and solid object constraints. The EGCI instrument included open-ended questions for students to draw their responses. Isometric drawing exercises have also been used to simultaneously assess drawing ability and spatial ability in STEM education research. For example, Van Den Einde et al. [30] developed a sketch recognition mobile app to teach digital isometric drawing, and saw improvements on sketching ability and spatial visualization skills.

### C. Object Assembly

Object assembly as a spatial ability can be found in the Wechsler Preschool and Primary Scale of Intelligence (WPPSI)'s Object Assembly subtest [31]. In this test, a picture is divided into pieces like a puzzle, and children must assemble them correctly to reconstruct the image. In the same instrument, the Block Design subtest instructs children to rotate and arrange diagonally-divided white and red 3-dimensional blocks to replicate specific patterns on the upturned block faces. Other mental operations tests include Mental Folding [20, 32], where flat sides are mentally folded into a 3-dimensional shape, and Mental Cutting (MCT) [32] which requires mentally dividing irregular shapes with a plane and identifying the resulting cross-section. In all tests, students perform internal operations on an image they are given, and choose from several options the correct picture of a final product which matches their estimation of what the new shape will look like.

The Test of Spatial Assembly (TOSA) developed by Verdine et al. [33] examines preschoolers' ability to construct block shapes that match six given examples. Shapes were assessed on the number of blocks they contained, block lengths, vertical location, rotation, and translation. While the purpose of this test is to make inferences of children's spatial, mathematical, and language development, the tasks relied on mental imagery and translating observed examples into tangible models using blocks.

In a test of designers' perceptions of 3-dimensional shapes from virtual interactions, Schnabel & Kvan [34] tested participants on their ability to accurately build irregular shapes, with the goal of reconstructing an assembled cube from irregular after viewing it in virtual reality. A control group constructed the cubes from 2-dimensional pictures. The assembled cube was graded on its parts matching the virtual cube by having all shapes in the correct color, volume, and position. The study not only demonstrated the influence of shape complexity on accurate retrieval of internal representations, but also highlighted the benefit 3-dimensional virtual reality over 2-dimensional views in perceiving shape volume.

While these tests are linked to many engineering visualization skills, spatial ability research and its link to engineering drawing often uses them as intervention outcome measures or indicators of success with a specific technology, without directly assessing sketching ability. Of the spatial tests which are widely used, few are clearly connected with drawing or allow students to respond via sketching. Therefore, the goal of this instrument is to directly link the two practices by assessing sketching skills with spatial ability tasks.

### D. Research Questions

This assessment is intended to give first-year mechanical engineering design students practice on 3-dimensional perspective sketching skills through a series of object assembly exercises. The learning objectives of these exercises are:

- Draw lines and shapes with control, accuracy, and precision
- Draw simple and complex shapes in correct perspective
- Translate 2-dimensional orthographic object views into a 3-dimensional image
- Assemble elements made of simple shapes into a composite 3-dimensional image

Our study is guided by the following research questions: *What are engineering students' sketching skills on object assembly exercises as assessed by our instrument?*, and *What is the performance of the Object Assembly Test and rubric as measured by inter-rater reliability of sketching grades?*

## Methods

### A. Instrument Development

The Object Assembly Sketching test was developed for evaluating undergraduate engineering students' performance on freehand 3-dimensional sketching. The instrument consists of three exercises where students are given a set of shapes. Their task is to draw an assembled shape in correct 3-dimensional perspective. In the first and second exercises, students view three shapes and the orthographic projections of a composite object made up of the three shapes, and are asked to draw the composite shape in perspective. Exercise 1 uses a cylinder, a cube, and a rectangular prism, and asks students to draw in 1-point perspective with one vanishing point in the corner of the paper. Exercise 2 uses four rectangular prisms, and asks students to draw in 2-point perspective with vanishing points on either side of the paper. In Exercise 3, students view three irregular rectangular prisms and are asked to assemble them into a new object, rotating or flipping the shapes as necessary. The full instrument can be seen in the Appendix. While Exercises 1 and 2 show orthographic views to help students learn how to perceive and draw assembled objects, Exercise 3 does not include orthographic views in order to permit unique answers and challenge students with more difficult mental imagery and mental rotation.

A grading rubric was developed to score sketching performance on each task. The rubric contains eight grading criteria: Representation Accuracy, Line Straightness, Precision, Line Smoothness, Scale, Symmetry, Converging Lines, and Proportion. Table 1 shows the definitions of the criteria.

Table 1: Rubric Criteria Definitions

| | |
|---|---|
| **Representation Accuracy** | The picture result replicates sketch exercise instructions |
| **Line Straightness** | Ability to connect points with minimal drawn distance |
| **Precision** | Ability to converge lines at a point, and not before or after |
| **Line Smoothness** | Ability to draw lines with fluidity without shakiness or inconsistent weight |
| **Scale** | Ability to draw at a given height, width, and depth based on the line of sight |
| **Symmetry** | Ability to reflect a shape identically on both sides of a central axis |
| **Converging Lines** | Ability to follow vanishing point(s) guidelines when drawing in perspective |
| **Proportion** | Ability to accurately represent height, width, and depth for all sketch elements relative to each other |

Each criterion is scored on a 3-point scale as Emerging, Developing, and Proficient. Representation Accuracy was scored as "Sketch follows all instructions in the exercise, including any creative personalization," "Sketch follows some instructions in the exercise but not others: using given shapes OR using correct perspective," and "Sketch does not follow exercise instructions about using given shapes and using correct perspective" (see Appendix). The other criteria were scored as "All," "More than half," or "Fewer than half" lines or sketch elements exhibit this characteristic. Scores were not summed into a total score, because performance on each criterion was hypothesized to be independent of others. Because the rating scale is nominal, we assume equal distance on the sketching skill measurement scale we established, allowing us to infer that differences between proximal grading categories are equal.

We solicited feedback from five faculty, instructors, and graduate students who are experts in the field of mechanical engineering, design, and assessment. Experts provided feedback on how clear or unclear the instructions were for each exercise, how well the exercises let them practice the sketching skills from the rubric, and if they would add or remove any sketching skills from the rubric. Experts recommended more specific definitions of 1- and 2-point perspective to students who are not familiar with the techniques, and suggested that an original criteria of Line Weight be changed as it may not strongly predict drawing skill. They also suggested the three grading levels be less ambiguous. Based on expert feedback, one exercise was revised, the rubric language was clarified, and instructions specifically addressed tools and perspective drawing. Line Weight was replaced with Line Smoothness, and grading levels were quantified with clear cutoffs.

### B. Participants

Participants were recruited from two undergraduate sections of a mechanical engineering design course with 45 students per section. A total of 72 students from the two sections participated in the study and completed surveys and the Object Assembly Sketching Test. The demographics of students are summarized in Table 2. Note that all the participants did not reveal their demographic details.

Table 2: Demographics of Participants

| Demographic | *n* |
|---|---|
| **Gender** | |
| Male | 52 |
| Female | 13 |
| **First Generation Status** | |
| First Generation | 12 |
| Non-First Generation | 59 |
| **Ethnicity** | |
| Hispanic | 9 |
| Non-Hispanic | 61 |
| **Race** White or Caucasian | 39 |
| Black or African American | 5 |
| Asian | 20 |

Out of the 72 students, 42 of them never had any form of drawing training or experience including courses or recreational activities. 26 of them had previous drawing training; most of their experiences were either from middle school or high school except for a few who had drawing experience from college. In addition, 42 students were in their first year at the university, 27 students were in their second year, 1 student was in the third year and 1 student fourth year respectively. Note that the list might include transfer students, hence the exact classification based on credit hours is not known.

## C. Data Collection

We piloted the instrument in two sections of an undergraduate mechanical engineering design course at a large Southern university in the United States. The two course sections were taught by the same instructor. Participation was voluntary and students could choose to exit the study at any time. After reading and signing consent forms to participate, students first received a pre-survey asking their background with sketching and their knowledge of two-point perspective. Students then completed the Object Assembly Sketching test. Finally, students received a post-survey asking them to provide their demographics. This study was a part of a larger project developing and testing intelligent tutoring software in undergraduate engineering design classrooms, and this instrument was administered in classrooms where the software was being implemented. We collected a total of 216 sketches, with 3 exercises from each participant.

## D. Data Analysis

We scored student responses with the rubric developed, first together with two raters and then independently with one. We report mean scores for all grading criteria and exercises, as well as by sketching experience. We calculated inter-rater reliability with Krippendorff's $\alpha$ [35] between two raters who applied the rubric for this test.

# Results

## A. Descriptive Statistics

Figure 1 shows the mean grades on each grading criteria for the three object assembly sketching exercises. Grades followed the same pattern across all three exercises, meaning each student generally achieved consistent grades across the three tasks. Students scored highest on average in Representation Accuracy ($\bar{x}$ = 2.85, 2.88, 2.81), Scale ($\bar{x}$ = 2.81, 2.92, 2.88), and Symmetry ($\bar{x}$ = 2.80, 2.89, 2.63).

Mean scores on each grading criteria by self-reported background were very similar across all types of experience. Some students learned sketching in formal settings such as art classes throughout elementary, middle, and high school, while some practiced for recreation, engineering clubs, and classes. Others applied their skills in design technology, engineering graphics, and robotics projects. All groups for Exercises 1 and 2 had mean scores ranging from 2.13 to 2.88. Exercise 3 scores had a somewhat wider range from 1.50 to 2.50. Overall average scores across the three exercises had very small differences, between 2.17 and 2.53.

## B. Inter-Rater Reliability

Two raters reviewed rubric criteria definitions and independently scored 45 sketches from fifteen students, discussing their ratings to understand differences. As a reliability coefficient between raters, Krippendorff's $\alpha$ is an effective statistic for calculating any sample size where raters apply a coding scheme to data at any level of measurement [35]. In our case, the raters scored sketches using an interval measurement system with no missing data. We calculate Krippendorff's $\alpha$ by first constructing a reliability matrix from all scores from the two raters. Coincidences of agreement

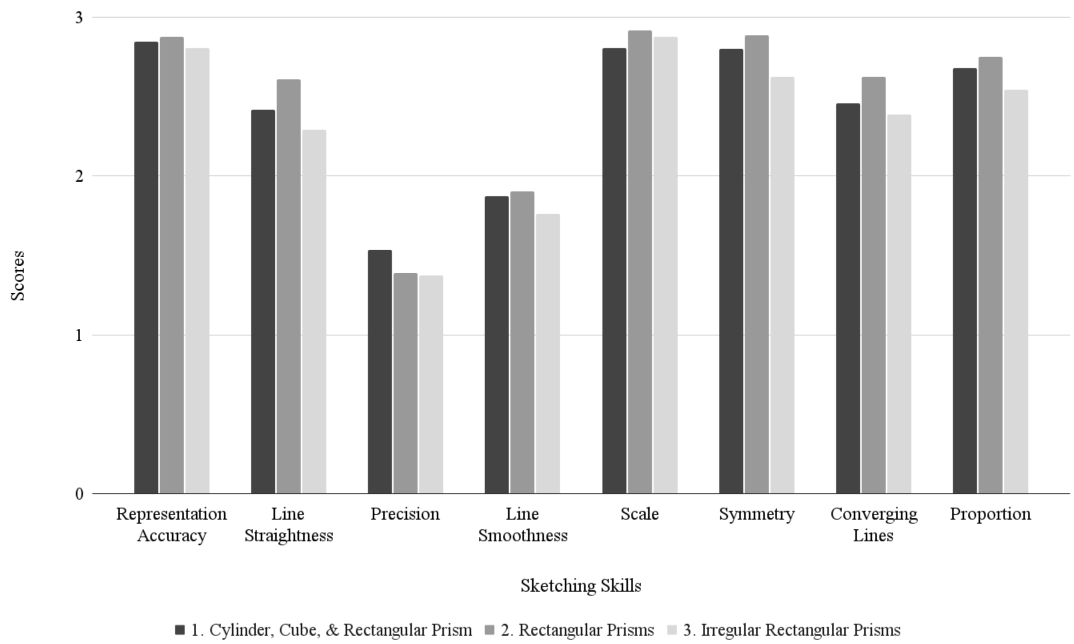


Figure 1: Average sketching scores on object assembly exercises.

are then tabulated and $\alpha$ reliability is calculated with the following formula:

$$\frac{(n-1)\sum_c o_{cc} - \sum_c n_c(n_c-1)}{n(n-1) - \sum_c n_c(n_c-1)} \tag{1}$$

where the numerator is the percent of observed agreement in all graded units, and the denominator is the percent of agreement that can be achieved by chance [35]. We calculated reliability in R with the package *kripp.alpha*. Values range from -1 to 1, with -1 indicating perfect disagreement, 0 that agreement is random, and 1 perfect agreement. Our inter-rater reliability for grading criteria and exercises is shown in Table 5.

Table 3: Inter-Rater Reliability by Grading Criteria and Exercise

| **Rubric Criteria** | $\alpha$ | **Exercise** | $\alpha$ |
|---|---|---|---|
| Representation Accuracy | 0.348 | 1. Cylinder, Cube, & Rectangular Prism | 0.423 |
| Line Straightness | 0.232 | 2. Rectangular Prisms | 0.582 |
| Precision | -0.0878 | 3. Irregular Rectangular Prisms | 0.383 |
| Line Smoothness | 0.277 | | |
| Scale | 0.189 | | |
| Symmetry | -0.116 | | |
| Converging Lines | 0.367 | | |
| Proportion | -0.0167 | | |

We calculated IRR overall for each exercise and reliability for grading criteria was highest for Converging Lines (0.367) and Representation Accuracy (0.348). Reliability was lowest in Symmetry

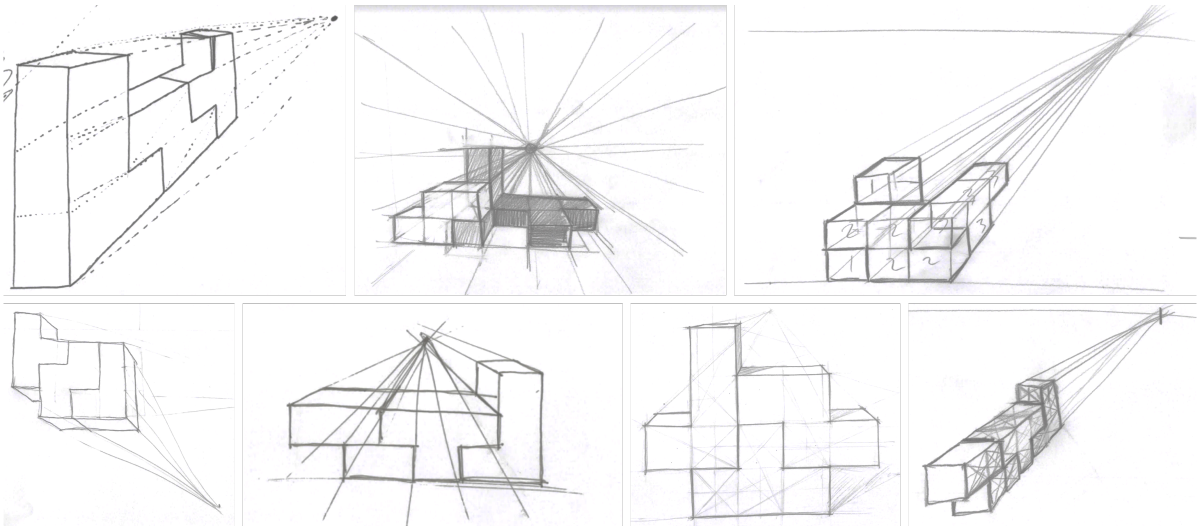

Figure 2: Exercise 3 object assembly examples.

(-0.116), Precision (-0.878), and Proportion (-0.0167), with Scale and Line Smoothness somewhat higher than random agreement. Reliability for exercises was highest for Exercise 2 (0.582). In Exercise 1, agreement was highest for Representation Accuracy (73%) and Scale (67%) and lowest for Line Smoothness (33%). In Exercise 2, agreement was highest for Symmetry (87%) and lowest for Line Straightness, Precision, and Line Smoothness (47%). In Exercise 3, agreement was highest for Scale (93%) and lowest for Line Smoothness (27%) and Proportion (47%).

### C. Sketching Strategies

Students used a variety of strategies to sketch the object assembly exercises. When sketching in perspective, vanishing lines were not always included, even when correct perspective was used. Vanishing lines also did not guarantee that a sketch would follow them correctly, and some students were able to draw in perspective without vanishing lines. Some students sketched orthographic views before attempting to sketch in three dimensions. Others used a mini grid of assembled irregular shapes before the full 3-dimensional sketch or labeled each shape before assembling them. Most students sketched with pencil and a few used pen. Many students sketched guidelines but erased them before outlining their final sketch, or traced over rough sketches with heavier solid lines. Some students chose to represent hidden lines as dotted. Many students included aesthetics in their sketches such as as shading, hash marks, and shadows.

Figure 2 shows examples of students responses to Exercise 3, assembling an object using three irregular rectangular prisms. Many students demonstrated creativity and a complex understanding of one-point perspective on this exercise by sketching with depth and interlocking parts, rather than stacking shapes alone.

## Discussion

Our results We found ways in which instrument metrics overlapped and influenced each other. Scale and proportion can be understood as similar but separate qualities of sketch dimensions.

Scale describes each shape's relative size to the others in the sketch, and whether they all follow the same measurement system. Proportion describes each shape's specific height, width, and length. If scale is followed, it becomes easier to determine whether shapes have followed correct proportion. Similarly, line straightness and precision impact other metrics on the grading rubric. Line straightness is related to the direction of the line and how efficiently students connect points, while precision describes connections and corners. Because proportion and symmetry depend on line straightness and precision, the overall shape and size of the object will be affected if students are unable to draw straight lines or have them meet at corners.

There are many aspects of aesthetics and complex perspective which the rubric can be modified to capture based on our results. Many students showed unique expression of 1- and 2-point perspective in their assembled drawings, such as interlocking parts with depth beyond stacking the irregular shapes. While a high number of students struggled with line smoothness, sketchy lines may suggest more artistic approaches over precise ones with clean lines. Many complex uses of 1- and 2-point perspective were drawn with rough lines. Future iterations of this instrument should continue allowing for artistic interpretations of exercises, and include additional rubric metrics that account for complex object assembly and have it contribute to students' grades.

Finally, inter-rater reliability for grading criteria across all exercises was low. Further calibration and discussion of rubric definitions is necessary to improve ratings. Some metrics are consistently lower than others across all exercises, suggesting that disagreement may arise from how these criteria are measured or observed. A limitation of Krippendorff's $\alpha$ is a paradox of a low coefficient when probability of agreement is high [36]. In addition, our sample size was relatively small, which may impact reliability statistics by increasing the percentage of disagreement.

### Limitations

A limitation of this study is students' unfamiliarity with the grading rubric. Data collection procedures were established before integrating the Object Assembly test into classroom instruction, preventing us from briefing the students. It is best practices in fair assessment to give students full information about an assignment, including grading procedures and criteria, in order to help them understand its purpose and expectations. While test administration instructions encouraged students to look carefully at the given shapes and visualize how they should be assembled before drawing, they were not given specific details about line smoothness and straightness technique, or shape proportion and scale. Students were not aware that their sketches would be graded using the rubric criteria and did not see the rubric as part of the exercises. Specific explanation could prevent students' frustration and improve alignment of the rubric in the future.

A second limitation of this study is that rubric language may still be too vague. For example, Exercise 2 has an even number of shapes, which makes it difficult scoring more or less than half of elements. Since one shape on Exercise 3 is not symmetrical, the Symmetry metric can be scored as both, one, or neither of the remaining two sketch elements. In addition, our higher-rated categories of Converging Lines and Representation Accuracy commonly were scored as 3 or 1, with little nuance. This lack of clarity is reflected in the low inter-rater reliability scores for grades on a sample of sketches. Further rubric improvement could increase reliability of the proposed scoring system. While experts and raters agreed that metrics adequately covered sketching skills for the object assembly tasks, it may be useful to conduct focus group studies from the student test-taker population to understand their perception of the grading system.

## Conclusions and Future Directions

In this study, we developed and piloted a new sketching skills assessment instrument for object assembly tasks. This instrument combines sketching assessment with spatial ability assessment, by evaluating students' mental imagery and mental rotation abilities when combining shapes into assembled objects and visualizing the result. This instrument can be used in a variety of engineering design learning contexts where spatial abilities are taught, especially where practicing sketching skills can be beneficial.

We intend to further define object assembly as a spatial ability by exploring the skills necessary to perform test exercises. In addition to mental rotation and mental imagery, the exercises could use more advanced spatial skills such as perception of 3-dimensional space, awareness of hidden lines and shapes, and understanding of interactions between shape sides in order to assemble complex solids. We also plan to continue making changes to the sketch grading rubric language. Precision will be more sensitively graded to capture cases when students only have one open or overdrawn corner, or when there are multiple ways to draw a corner. Additional clarification to the rubric, while making it flexible for a variety of sketching contexts, is the goal of future development.

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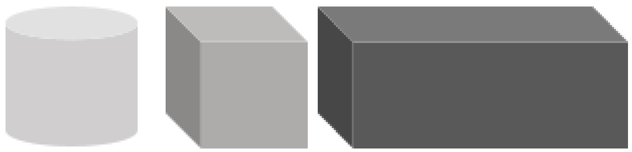
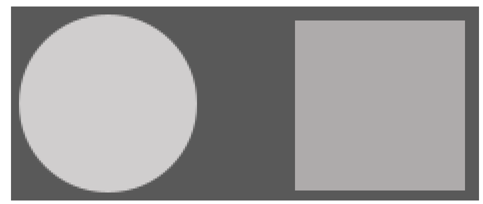
These exercises are intended to test your sketching skill on 3-dimensional object assembly. For each exercise, you should use the orthographic views provided to imagine what the final picture will look like after combining the 3-dimensional shapes into one object. Your sketch should be the of the final assembled object after performing this action mentally.

You may use either a pencil or a pen to sketch your answers. You may use a ruler to draw the horizon line and vanishing lines, but your response should be freehand sketched.

Look carefully at the cylinder, cube, and rectangular prism below. The top and side views show a composite picture made up of these three shapes. Using the top and side views shown, sketch the picture **in 1-point perspective** using one vanishing point.

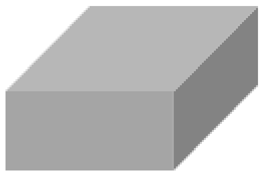


**Top View**

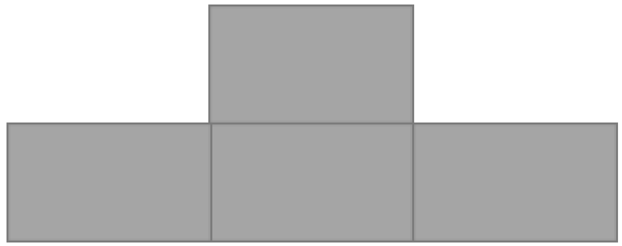


**Front View**

Look carefully at the rectangular prism below. The top and side views show a composite picture made of four rectangular prisms. Using the top and side views shown, sketch the picture in **2-point perspective** using two vanishing points on either side of the paper.

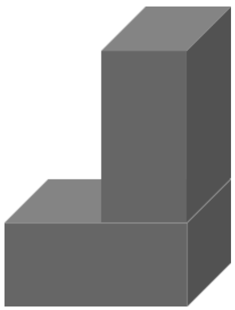


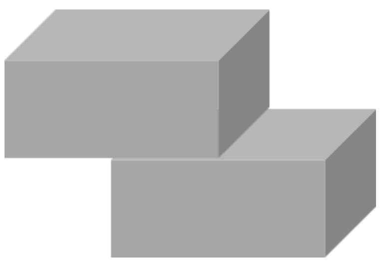
**Side View**



**Top View**

Look carefully at the three shapes below. Using these shapes, construct a 3-dimensional composition of shapes that combines the three shapes into a single object. Try to visualize the composition of shapes before drawing. You may rotate or flip the shapes before combining them. Sketch your assembled shape in **1-point perspective** with one vanishing point.





| Criteria | Emerging (1) | Developing (2) | Proficient (3) |
|---|---|---|---|
| **Representation Accuracy** - The picture result replicates what the student intended to sketch. | Sketch does not follow exercise instructions about using given shapes and using correct perspective | Sketch follows some instructions in the exercise but not others: using given shapes OR using correct perspective | Sketch follows all instructions in the exercise, including any creative personalization |
| **Line Straightness** - Ability to connect points with minimal drawn distance. | Fewer than half of lines have straight direction between points | More than half of lines have straight direction between points, OR have some deviation | All lines have straight direction between points without excessive deviation |
| **Precision** - Ability to converge lines at a point, and not before or after. | Fewer than half of lines do not meet at points | More than half of lines do not meet at points | All lines in sketch meet at points |
| **Line Smoothness** - Ability to draw lines with fluidity without shakiness or inconsistent weight. | Fewer than half of sketch elements are drawn with smooth lines | More than half of sketch elements are drawn with smooth lines | All sketch elements are drawn with smooth lines |
| **Scale** - Ability to draw at a given height, width, and depth based on the line of sight relative to each other. | Fewer than half of sketch elements have consistent scale from multiple views | More than half of sketch elements are consistent from multiple views | All sketch elements follow scale from multiple views |
| **Symmetry** - Ability to reflect a shape identically on both sides of a central axis. | Fewer than half (zero) of shapes with central axis have more than one equal side | More than half (one) of shapes with central axis have at least one than one unequal side | All (both) shapes with central axis have equal sides |
| **Converging Lines** - Ability to follow vanishing point(s) guidelines when drawing in perspective. | Fewer than half of shapes are drawn with lines converging towards vanishing point(s) | More than half of shapes are drawn with lines converging towards vanishing point(s) | All lines in all shapes converge towards vanishing point(s) |
| **Proportion** - Ability to accurately represent height, width, and depth for individual sketch elements. | Fewer than half of elements follow correct proportion in height, width, or depth | More than half of elements follow correct proportion in height, width, or depth | All sketch elements (height, width, and depth) follow correct proportion |