Rethinking Spatial Visualization Assessments: Centering Recognized Prior Knowledge in 2D/3D Curriculum Development

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Introduction

In this work-in-progress paper, we discuss the development of designing relevant engineering courses for spatial visualization skill development, and to support 2D/3D modeling and prototyping. As engineering classrooms become more diverse in student population, we advocate for the restructuring of assessments such that assessments are used to value and leverage the prior knowledge of students and to better teach new and complex topics.

As researchers and engineers, we rely on our previous experiences and skills as scaffolding to support us in the challenges we face ahead. In engineering education, students complete introductory courses and establish a foundational understanding before exploring the more niche topics or entering a mastery level in an area. DeBoer Lab has a co-constructed design-based engineering curriculum called the Localized Engineering in Displacement, or LED, which scaffolds its curriculum similarly: The LED program aims to recognize learners' relevant local knowledge to utilize as assets for engineering design and community problem-solving. The program's student body consists of varying geographical demographics of different age groups. They have limited access to educational technologies, and widely varying prior formal and informal learning experiences. The 2D/3D modeling modules (which feed into the prototyping modules in the curriculum) are in need of more localized content to better support student learning where the material is situated with culturally relevant design tools. This serves to situate the sociocultural experiences of the students directly in their learning to better support understanding in engineering principles and aid motivation.

The intent of our paper is to contribute to the scholarship on spatial visualization in engineering education, specifically for international contexts. However, we found that literature on spatial visualization in education continues to use assessments designed by western researchers in the 1900s. Research has shown that applying western educational practices and assessments is detrimental for the learning outcomes of students from diverse backgrounds and cultures. We suggest utilizing asset-based approaches instead. Our work identifies and recognizes spatial visualization skills by prioritizing the recognition of prior knowledge for spatial visualization skill development for learners in international contexts.

Background

Spatial visualization is a skill that consists of the mental ability to manipulate objects [1], [2]. These skills are vital in engineering to support problem-solving and, in 2D/3D modeling, they are the base for designing and manipulating objects. 2D modeling is the representation of a 3D object in two-dimensions, while 3D modeling is the representation of the object in three-dimensions. Both 2D and 3D modeling can be taught and practiced using pen and paper or digital tools. We are designing a spatial visualization assessment (work-in-progress) to fulfill 3 aims: 1) to identify the existing spatial visualization skills of students, 2) to complement the other assessments recognizing prior knowledge in the curriculum, and 3) to support the development of modeling and prototyping modules.

This paper shares and critiques previous literature surrounding spatial visualization development in engineering learners. We discuss how the literature affected the progress of our assessment's design to elucidate and justify how the current assessments are not suited to accurately acknowledge students' existing spatial skills in the contexts where we teach and learn. While the current literature contributes to the understanding of the prior work done in measuring spatial visualization skills, our work involves contributions concerning international engineering education.

We are embarking on this project to develop a test from scratch rather than using existing assessment tools. Before making our own, we want to learn from previous projects what does and does not work in existing assessment tools with a critical lens. Often, the tests currently used in literature and the subsequent course or curriculum appear to result in score gains of students after the intervention [3]. We are questioning whether this could be a result of the test not accurately capturing the spatial visualization skills initially, whether this reflects ceiling/floor effect in statistical data analyses, or if gains are supported by the students' familiarity with "western standards" of engineering. This paper does not include a statistical analysis as a method of questioning or critiquing the utility of existing spatial visualization assessments. It rather focuses on reviewing literature discussing critiques of applying American education practices and pedagogies in non-American contexts.

This paper focuses on what would be classified as a 'pre-test', or assessment prior to an intervention (course, workshop), as we are collaborating with partners of DeBoer Lab's LED program to design an assessment to better understand the prior skills of the students. Pre-tests in educational research and practice are assessments solely seen as a tool for evaluation or research. The literature primarily discusses the effects of an intervention, but seldom does it discuss program design and contextualization by centering the students. DeBoer Lab's assessment would support the future work of the lab in developing 2D/3D modeling modules to support later prototyping modules. We want to add to the already-existing curriculum by helping students develop their skill set in modeling and prototyping to better articulate the solutions they design to address local community problems. Ultimately, this paper will answer the following research questions:

1. In what ways do spatial visualization assessments support student learning processes?
2. What purposes do spatial visualization assessments serve in engineering learning?

Our Approach

This paper consists of a literature review and critical discussion to contribute to the conversation of spatial visualization skill development and expand it to international education. The initial progress in designing a spatial visualization assessment up to its current beta-testing stage is shared. We examine the literature with the lens of Critical Discourse Analysis [4] to examine the dominant discourses in the literature. We also use the concept of silences in the discourse [5] to understand how ignoring the prior knowledge of students contributes to epistemic erasure. To counter these silences, our literature review includes a synopsis of recognizing prior knowledge (further referred to as RPK) as it is a pillar of the LED curriculum. Its inclusion contributes to acknowledging relevant cultural contexts in understanding diverse spatial skill development. We share the summary of our work introducing a new assessment as the bridge in spatial visualization skill development in international contexts by recognizing learners' prior skills.

Our methodology is inspired by Critical Discourse Analysis (CDA). CDA is an approach for critically investigating how social inequality is expressed, signaled, or legitimized in language [6]. We reviewed the literature with this critical lens to understand the dominant narratives in spatial visualization research and education. CDA is more than a theory or methodology [7], [8], it is a critical perspective on research. We have not used CDA as a qualitative method, but rather as a perspective for examining how dominance, discrimination and power are manifested [6] in the literature.

The literature review was conducted utilizing the search engines Google Scholar as a library aggregator and Purdue University's library database. Key words such as "spatial visualization development", "spatial visualization development engineering education", "spatial visualization assessment", "PSVT:R engineering education", "activity theory engineering", and "activity theory spatial visualization" were searched. Literature included in the review discussed the use of spatial visualization assessments in engineering education contexts (specifically in studies surrounding computer graphics and/or 2D/3D modeling courses). For example, the common trend across reviewed studies was that they used a spatial visualization assessment (such as the Rotations component in the Purdue Spatial Visualization Test, or PSVT:R , Mental Cutting Test, both of which are cited with examples by Sorby and Baartmans [9]) to measure the improvement of engineering students at some point in their undergraduate engineering careers. Literature was excluded if it did not illustrate how assessments measure spatial visualization development or if it did not discuss how graphics and 2D/3D modeling curricula are developed. The area of literature we primarily wanted to understand is how spatial visualization skills are measured and practiced in order to use the skills as scaffolding in 2D/3D modeling education in international contexts. Therefore, additional literature that synthesizes critical analyses of applying western educational pedagogies and assessments in non-western contexts are reviewed.

Prior Literature

Spatial Visualization Development

Spatial visualization is a vital skill according to both researchers and educators [1], [3], [9]–[11]. It is consistently discussed as a predictor of success in engineering for undergraduate students for studies based in American universities. For a factor so important in laying the foundation in our students' learning, it is logical as researchers and educators to want to be able to quantify this skill and measure whether our interventions are, or are not, impactful. The current standard of measurement is spatial visualization assessments or, to identify the one most frequently used, the Purdue Spatial Visualization Test: Visualization of Rotations, otherwise known as PSVT:R (its content discussed by multiple authors [1]–[3], [9]–[11]). This is not to diminish other assessments, such as the Mental Rotation Test (MRT) [12] or Mental Cutting Test (MCT) cited by Sorby [2], but it will be mentioned the most in this paper as the PSVT:R has a consistent recurrence in recent literature. However, all assessments follow similar structures: a timed, multiple choice assessment asking the test-taker to mentally rotate an object or visualize the cross-section of an object. Examples of the assessments are seen in Figures 1-3 [3]. These assessments provide a simple standard of measuring spatial visualization development by the accuracy of student responses.

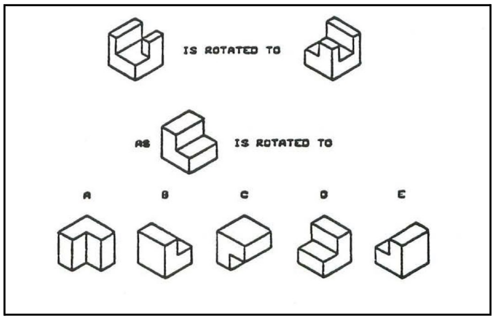


Figure 1. Sample from PSVT:R

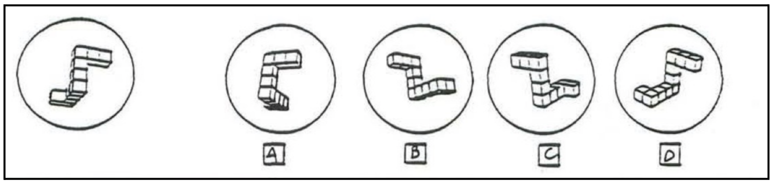


Figure 2. Sample from MRT

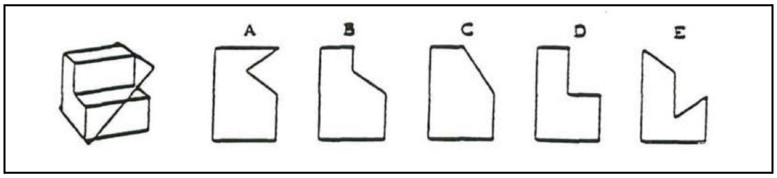


Figure 3. Sample from MCT

Previous studies using spatial visualization assessments to measure these skills typically consisted of undergraduate engineering students in the United States with assumed access to common technologies (phones, laptops, network connections, etc.). The assessments are used to measure the improvement in spatial ability as successful (or unsuccessful) attributable to a particular course or applied to measure gaps based on gender or race/ethnicity. Further, these assessments used to develop curricula are not often shared with one exception of Sorby sharing research development over several years in developing 3D spatial skills [10].

Piagetian theory is one discussed in the context of deconstructing spatial visualization development into stages. The three stages cover the ability to (1) view the object relative to other objects in space, (2) view different perspectives of an object, and (3) combine projected views with scaled measurements. PSVT:R smoothly fits into the second stage component: the ability to perceive an object's image from different perspectives [9]. By observing these stages of development, researchers utilized workshops and courses to improve spatial visualization skills in engineering students and have measured the development (or lack thereof) by the passing rates of the PSVT:R. Psychologists have additionally published critiques of Piaget's work pointing out that he ignored cultural/social influences on children's cognitive development and that his work was largely representative of western societies [13].

Gaps identified in spatial visualization development amongst engineering students tend to follow trends of gender and nationality. It is the historically minoritized students that consistently fall in these gaps. For example, studies often have students participate in the PSVT:R prior to courses, and those with failing rates may be asked to participate in a more introductory-level workshop in an attempt to improve their spatial visualization skills to support their success in their subsequent engineering coursework. Women consistently score lower than men, and their scores after the course/workshop often improve but may still score lower than their men counterparts [3], [9]. In another study, East Asian, Middle Eastern, and domestic U.S. students were observed in their spatial visualization skills on the basis of nationality. East Asians scored identical to domestic students, but Middle Eastern students' scores were recorded to be dramatically lower with an "exaggerated gap" between Middle Eastern women and men students, a gender gap that was similar in magnitude compared to the domestic students [11].

The gaps due to gender bias have been investigated by surveying the past experiences of the students. Sorby and Baartman's study [9] recorded that women were more likely to fail the PSVT:R in the initial pre-tests as compared to men. The factors that were gender-biased in favor of men for comparable success on the PSVT:R were as follows: (1) play as children with construction toys such as Legos, Lincoln Logs, and Erector Sets and (2) previous experience in design-related courses such as drafting, mechanical drawing, CAD, and art. Factors that did not have any influence, whether for men or women, on predicting success on the PSVT:R included age, playing video games, work experience involving spatial skills, and participation in sports.

Another study examined gender differences in spatial visualization development to the standard of the PSVT:R, MRT, and MCT between three universities across the U.S., Poland, and Germany [3]. Women, again, were reported to be more likely to fail and lacked statistically significant backgrounds in design/drafting (what you would expect in design-related courses). Women initially scored lower than the men, and their post-tests, although improved from the pre-tests, did not reach the initial mean scores of the men. The authors interpreted this as "the women started the course with a deficiency and the improvement that they made did not narrow the gap", as the men's scores had also improved a similar amount [3]. The authors concluded "women were not supported enough in these courses to compensate for their deficiency in spatial abilities"[3]. The said "deficiency" was discussed as a result of sociocultural experiences growing up such as previous drafting experience or play with construction toys [3].

Methods to improve spatial visualization skills in engineering students include activities designed to support skills in drafting or rotating objects. For example, one course utilizes construction activities and computer software (I-DEAS software which is currently recognized as NX Siemens) to build practice in isometric and orthographic sketching, scaling objects, rotating and reflecting objects, and visualizing cross sections [9]. One of Sorby's published studies shares the progress over multiple years concerning what has supported engineering undergraduates in their spatial visualization development. Sorby's paper is unique in that it shares the culmination of course materials. It also emphasizes that spatial skills are skills that can be taught, learned, and developed and that sketching has been a consistently strong factor in spatial skill development [10]. Papakostas et. al. [14] discusses the integration of augmented reality into the classroom where students have the ability to complete exercises practicing visualizing orthographic views and freehand sketching. Augmented reality in the classroom appears to be a more popular topic for increasing spatial ability for reasons such as student enjoyment and easy-to-use [14].

Recognizing Prior Knowledge (RPK)

While the literature points out how women and students from different nationalities do not perform well on these tests, we argue that this is not a deficiency in particular students, but rather a limitation of the test. Chilisa [15] points out that such deficit-based theorizing is not uncommon in research. Within academic research, there is a long history and a tendency to perpetuate the dominance of one group by building a collection of theories, methods and tools which disparage or ignore the knowledge and skills of marginalized groups. She offers the example of the Porteus Maze, which was used as a measure of intelligence in Africa at the height of colonial rule. Students were given a printed plan of a maze and had to trace a path they would follow to get to the center of the maze. However, as more Africans than Europeans were successful in getting to the center of the maze, this test was abandoned as a measure of intelligence [16].

The PSVT:R was developed by Roland Guay in 1977 at Purdue University, cites Sorby and Baartmans [9]. Then, it was revised by researchers at Northwestern in the process of investigating the psychometric properties of the assessment [17]. Purdue University is a Predominantly White Institution (PWI) in the Midwestern United States founded in 1869 as a result of the Morrill Act of 1862 and is internationally recognized for its engineering research. Given the PSVT:R was constructed at Purdue and revised at Northwestern, we are skeptical about the validity of this test in contexts where language, culture, and student demographics are dramatically different from the initial context bias introduced when creating the test.

We want to move away from a deficit orientation to an asset-based perspective, so we are focusing on the prior knowledge of students. Recognizing prior knowledge, or RPK, is a pillar in the LED curriculum and is utilized to acknowledge the assets of the students to support their engineering learning. A key component in contextualizing the curriculum is that it makes the educational materials and tools relevant for the students to identify problems and design solutions in their own communities. Previous work surrounding RPK assessments discuss that "curricular contextualization is defined as a generative process for constructing meaning, firstly, from knowing the students; secondly, from knowing the community; and finally, from knowing the culture" [18]. By knowing the students, community, and culture, the curriculum is constructed on a sociocultural foundation. Similarly, in understanding spatial visualization development, author Mary Gauvain, a psychologist, discusses the conceptual framework of activity theory where sociocultural experience greatly influences the development of spatial thinking [19]. In goal-directed activities, human thinking is affected by the "cultural tools and processes" that "provide assistance in solving problems" and "the very way we understand and characterize problems" [19]. With spatial visualization understood to be the ability to mentally manipulate objects, activity theory recognizes how the role of culture can affect the development of spatial thinking.

Eglash et al. [20] describe the development of culturally situated tools where they teach concepts in fractal geometry through cornrow hairstyles. They report the excitement of some students when they realized they had been using those skills all along when thinking about rotating or scaling plaits as they braided. They also give other examples of computational tools such as a virtual bead loom, rug or basket weavers, or modeling Aanishnaabe arcs which can help students learn design and simulation skills based on their prior and cultural knowledge [21]. Other examples of spatial visualization skills in local knowledge can be seen in basket weaving, pottery, making boots from reindeer skins, making fish traps, 3D modeling of mannequin heads etc. [22], [23]. Based on their findings, Eglash et al. suggest that culturally relevant tools are generative and provide a two-way channel, not only to get students motivated for learning STEM (Science, Technology, Engineering, Math), but also to give back value to the communities [21].

Connecting Ideas to Practice

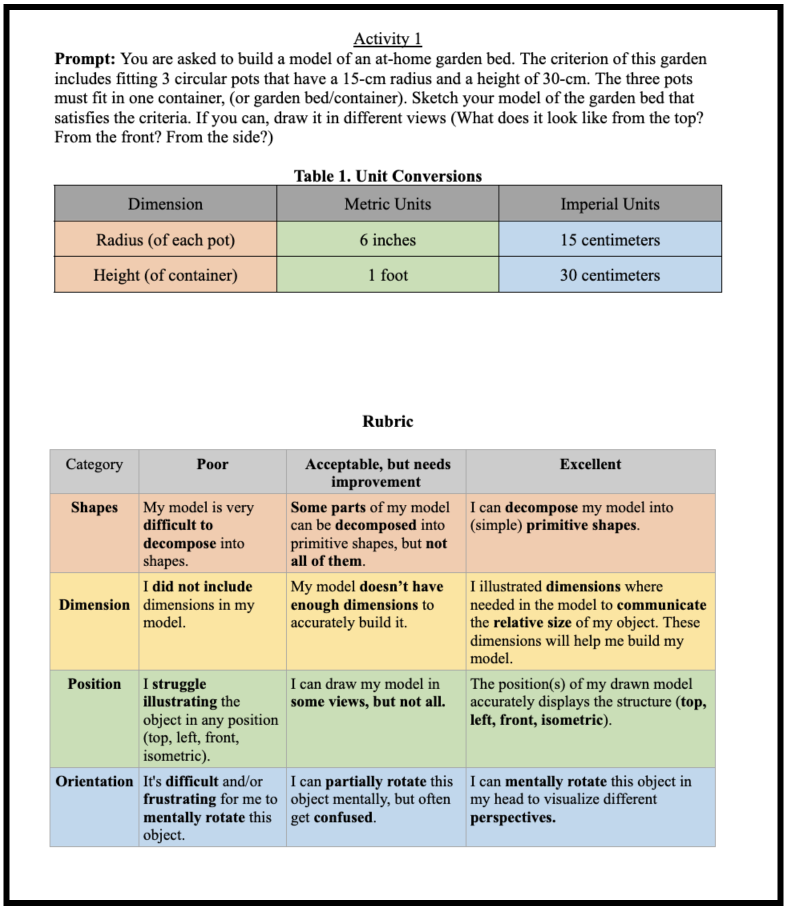
Why Center Student Assets?

The LED program aims to ensure centering the students' assets in their learning. When we ignore the cultural knowledge and experience students bring into the classroom, we participate in a *pedagogy of erasure* [24]. The term *pedagogy of erasure* was first used to refer to the unintentional practice of erasing cultural identity by not recognizing or engaging in cultural presence of the other [25]. However, Eppley [26] uses it to highlight an intentional pedagogy of erasure: erasing the difference to get all students to the lowest common denominator in skill levels. While Eppley talks about reading literacy, the same is also true for spatial visualization skills, and that can be seen from the way the PSVT:R has been used and researched. Studies based in U.S. higher education surveyed background experiences to investigate what prior experience may support students' spatial visualization skills. These surveyed experiences include playing video games, sports, and construction toys [3]. Activities such as weaving/knitting, hair braiding, and others are not explored in how they support spatial visualization development. Simply put, standardized tests imply erasure of the prior knowledge and skills of minoritized students. This contributes to practices of assimilation as students are required to reach certain national educational standards without the recognition of previous knowledge as a backbone of support. Rather than having students reach a common denominator in national educational standards, Kassam et al. discuss the importance in conserving Indigenous and rural knowledge in STEM education [24]. One key point they bring up is the idea of the 'teach-to-the-test' strategy that disregards the previous knowledge of the students and structures success around the familiarity of a particular test. In practice, we want to support the students' engineering learning by contributing to their knowledge. This approach should support their ability to communicate ideas through 2D/3D modeling and prototyping. In one of the case studies Kassam et al. observes, cognitive diversity amongst rural children includes recognizing the importance of connecting the students' experiential habitats in their engineering learning and for their sense of *self*-development [24]. Similarly, in the LED program, a priority in the curriculum is to support students' engineering identities and their self-efficacy related to science and engineering.

In Practice: Our Work Thus Far for 2D/3D Modeling Curricula Development

DeBoer Lab and partners are collaborating in designing an assessment to recognize the prior skills of the students in their ability to communicate ideas for 2D/3D modeling and prototyping. This assessment would support future work in designing a curriculum with activities for students to aid their engineering problem-solving process with 2D/3D modeling and prototyping. The key criteria in designing this curriculum is that it must support student learning without added unnecessary or irrelevant challenges due to culturally irrelevant examples, technology access, or network connections. Additionally, it must be sustainable for teachers/facilitators and students to continue working with the curriculum materials as more students enter the course. We wanted to prioritize students' previous knowledge instead of asking them to perform to the standards of common assessments used in American higher education; Therefore, the assessment is designed to be open-ended to give students the opportunity to showcase how they communicate their ideas.

Multiple drafts were created, as revisions iteratively were updated after reviewing more literature. Figures 4-6 display example questions from the first draft of the assessment.



Activity 1

Prompt: You are asked to build a model of an at-home garden bed. The criterion of this garden includes fitting 3 circular pots that have a 15-cm radius and a height of 30-cm. The three pots must fit in one container, (or garden bed/container). Sketch your model of the garden bed that satisfies the criteria. If you can, draw it in different views (What does it look like from the top? From the front? From the side?)

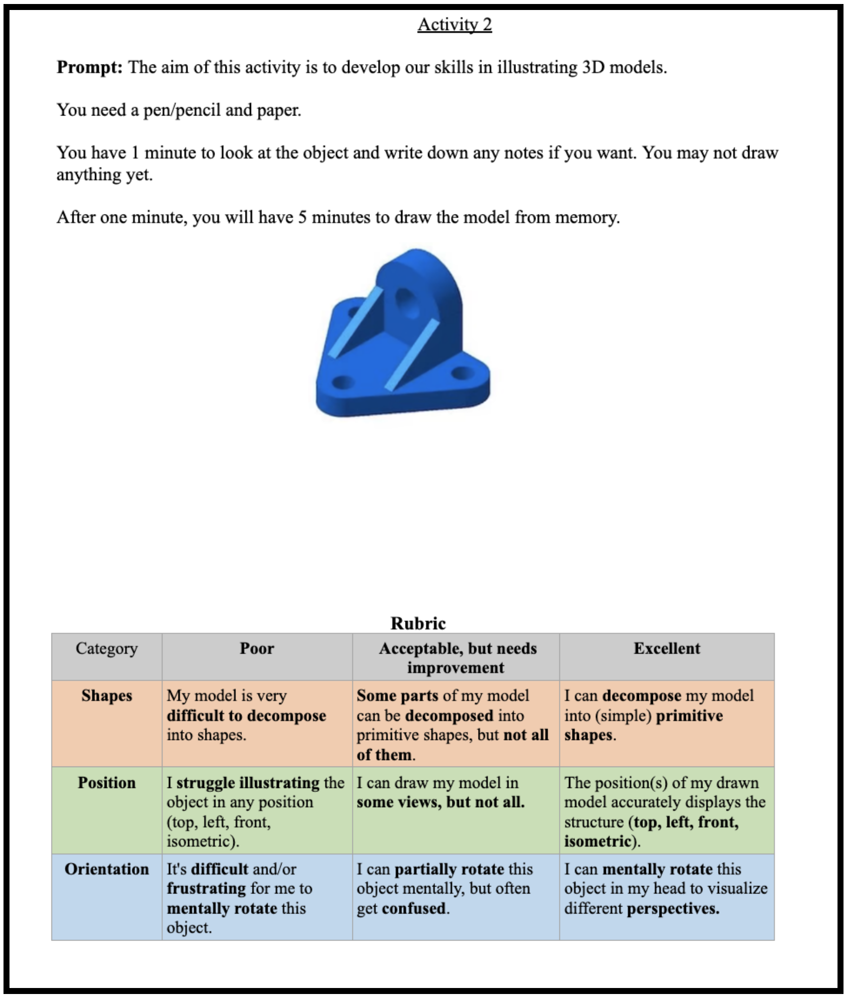
Table 1. Unit Conversions

Dimension	Metric Units	Imperial Units
Radius (of each pot)	6 inches	15 centimeters
Height (of container)	1 foot	30 centimeters

Rubric

Category	**Poor**	**Acceptable, but needs improvement**	**Excellent**
Shapes	My model is very **difficult to decompose** into shapes.	**Some parts** of my model can be **decomposed** into primitive shapes, but **not all of them**.	I can **decompose** my model into (simple) **primitive shapes**.
Dimension	I **did not include** dimensions in my model.	My model **doesn't have enough dimensions** to accurately build it.	I illustrated **dimensions** where needed in the model to **communicate** the **relative size** of my object. These dimensions will help me build my model.
Position	I **struggle illustrating** the object in any position (top, left, front, isometric).	I can draw my model in **some views, but not all.**	The position(s) of my drawn model accurately displays the structure (**top, left, front, isometric**).
Orientation	It's **difficult** and/or **frustrating** for me to **mentally rotate** this object.	I can **partially rotate** this object mentally, but often get **confused**.	I can **mentally rotate** this object in my head to visualize different **perspectives.**

Figure 4. Page 1/3 of first draft of spatial visualization assessment



Activity 2

Prompt: The aim of this activity is to develop our skills in illustrating 3D models.

You need a pen/pencil and paper.

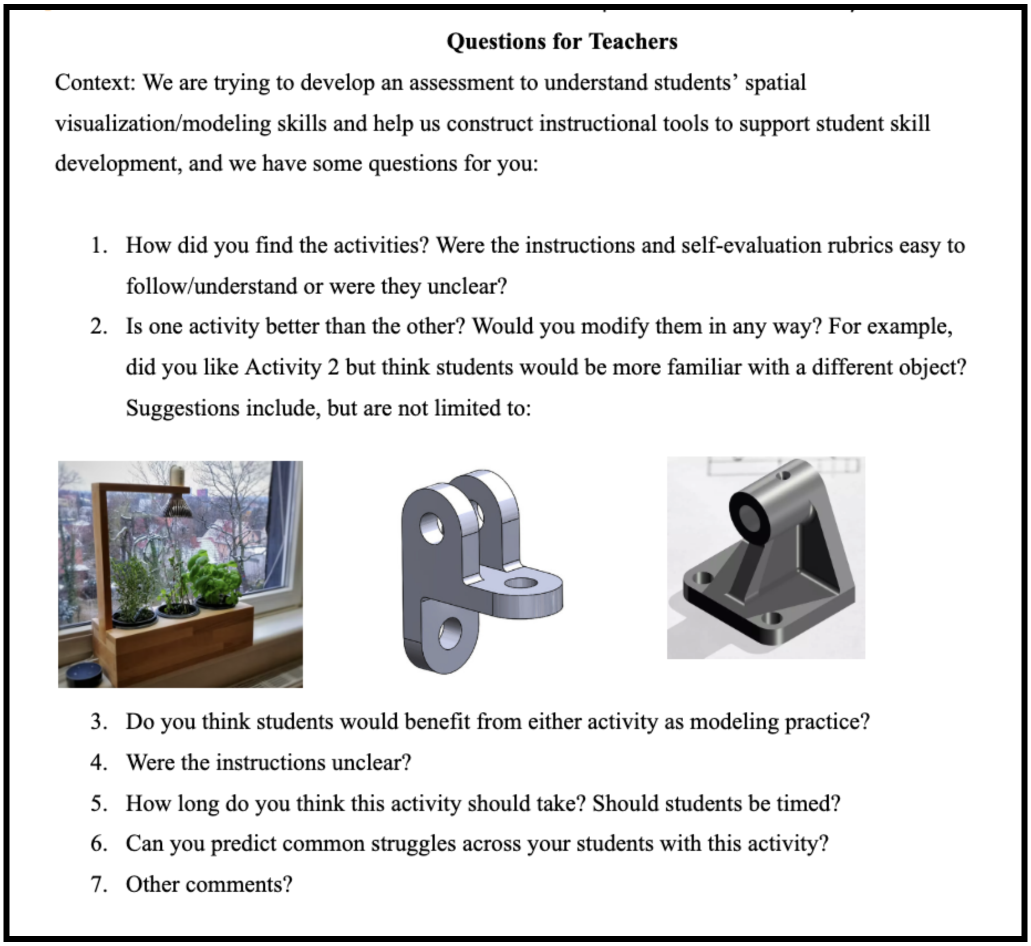
You have 1 minute to look at the object and write down any notes if you want. You may not draw anything yet.

After one minute, you will have 5 minutes to draw the model from memory.

Rubric

Category	**Poor**	**Acceptable, but needs improvement**	**Excellent**
Shapes	My model is very **difficult to decompose** into shapes.	**Some parts** of my model can be **decomposed** into primitive shapes, but **not all of them**.	I can **decompose** my model into (simple) **primitive shapes**.
Position	I **struggle illustrating** the object in any position (top, left, front, isometric).	I can draw my model in **some views, but not all.**	The position(s) of my drawn model accurately displays the structure (**top, left, front, isometric**).
Orientation	It's **difficult** and/or **frustrating** for me to **mentally rotate** this object.	I can **partially rotate** this object mentally, but often get **confused**.	I can **mentally rotate** this object in my head to visualize different **perspectives.**

Figure 5. Page 2/3 of first draft of spatial visualization assessment



Questions for Teachers

Context: We are trying to develop an assessment to understand students' spatial visualization/modeling skills and help us construct instructional tools to support student skill development, and we have some questions for you:

1. How did you find the activities? Were the instructions and self-evaluation rubrics easy to follow/understand or were they unclear?
2. Is one activity better than the other? Would you modify them in any way? For example, did you like Activity 2 but think students would be more familiar with a different object? Suggestions include, but are not limited to:
3. Do you think students would benefit from either activity as modeling practice?
4. Were the instructions unclear?
5. How long do you think this activity should take? Should students be timed?
6. Can you predict common struggles across your students with this activity?
7. Other comments?

Figure 6. Page 3/3 of first draft of spatial visualization assessment

The activities in the first draft ask the student to provide an illustration that communicates a visual concept or provide a sketch that is a replication of an object. The outcome of the activity is understanding the prior knowledge students have in communicating ideas visually. Figure 6 displays the additional questions we pose to facilitators for their input as to how to best support the students. The pilot test of this assessment was conducted solely with the lab group where members reflected on the questions. Members with a background in mechanical engineering discussed the familiarity with the object in Activity 2 (see Figure 5), while others were unfamiliar with it. The members were also timed in completing the assessment but it was agreed that a further discussion with facilitators would provide a better understanding of whether students should be timed and for how long. After the pilot test, however, one co-author suggested a revision after reading about activities where students would be asked to build a structure from any type of building blocks (similar to Legos, snap cubes, Lincoln logs - anything available in the local area or in the school classrooms) and provide sketches of multiple perspectives. The inspiration for this revision was sparked from a paper analyzing a workshop intervention on spatial visualization skills across gender/nationality [1]. Although the study utilized the PSVT:R standards with the activity, we would be using the activity to support the curriculum development by understanding how students communicate ideas visually from their prior experiences. We held a conversation with the facilitators in Kakuma, Kenya (brainstorming instead of pilot testing with facilitators, educators, or students) to discuss initial thoughts on the activities and desires for the 2D/3D modeling curriculum. The purpose of the brainstorming was to co-create the assessment with facilitators rather than simply test it with different groups. The facilitators emphasized the desire for consistent practice with their students. They also discussed that introducing 3D modeling to students that don't have a foundation in design principles or 2D modeling results in a much greater learning curve that has added difficulties when using unfamiliar software. In discussing different softwares, the facilitators shared that training in one particular software would better support the educators and students in learning modeling techniques. That way, rather than restarting the learning process and getting familiar across a breadth of multiple software applications, the area of focus is learning the niche of the technology and, more importantly, focusing on the replicable techniques in the design and modeling process. An added difficulty in supporting student learning according to the facilitators is that network and power issues would affect student motivation. Consistent access to the technology would support student learning by encouraging steady course attendance by providing opportunities to fuel student curiosity. This would benefit continuous progress in such a way that supports student learning of new technologies and building 2D/3D modeling proficiency.

For further context, one location involved with the LED program has 180 students who use pen/paper-based assessments. However, other locations may have smaller groups of 10-15 students or prefer online teaching and learning materials. Therefore, we are working to customize the needs of each location for the assessment and for the future development of the 2D/3D modeling curriculum. We are continuing to hold conversations with facilitators in order to understand what is best for students across multiple contexts.

Discussion

In our discussion, we first review the main ideas gathered from the literature review surrounding spatial visualization skill assessment. First, we answer our research questions, stated again below, to understand the function of spatial visualization assessments and how they are used:

1. In what ways do spatial visualization assessments support student learning processes?
2. What purposes do spatial visualization assessments serve in engineering learning?

Then, we situate the literature into our context of work spanning international locations of engineering learners; we also explain the lens we use to observe the current literature published surrounding spatial visualization assessments and skill development. Lastly, we discuss the bridge between the literature and our work, recognizing the knowledge supplied by peoples' work before us and our partners in the LED program that interact with the students more closely.

Spatial visualization skill development is emphasized to support experts in problem-solving in engineering design. Prominent engineering graphics scholar Sorby has shared that while past authors have attributed spatial skill knowledge to uncontrollable factors such as genetics (cited by Smith and Talley [27]), her work demonstrates that spatial knowledge can be taught, learned, and developed [2], [10]. To recognize which students may need more support in their learning, spatial visualization assessments are commonly used in U.S. higher education (RQ 2) consisting of timed, multiple choice assessments where students are typically asked to either mentally rotate objects or visualize an object's cross-section. Students that score below a certain threshold are asked to participate in interventions such as workshops or courses to build their familiarity of mentally visualizing and manipulating objects in a 3D space. Studies show that retention in engineering is higher and students perform better in future engineering courses with improved spatial visualization knowledge [1], [2], [10], [11], [27] (RQ 1) based on the standards of the spatial visualization assessments used. The trend across studies shows women and historically minoritized students tend to score lower, and, while they may improve after an intervention, they often still score lower than that of the dominant group (men or non-historically minoritized).

While studies demonstrate how the spatial visualization assessments support the recognition of which students may need more help in building a knowledgeable foundation, the assessments were designed in western contexts and are situated in the familiarity of engineering in the United States. Our work spans international contexts in providing a localized engineering curriculum to displaced learners. Therefore, we use a critical lens in this analysis to examine if previously published work in spatial visualization development is appropriate to use in our contexts. For example, the Mental Cutting Test is an assessment initially designed for an American university entrance exam; judging students to standards created for the intent of assessing university enrollment retracts from the goals of the LED program of learners designing long-term solutions to problems identified in their community. As discussed previously, the dominant discourse in the literature indicates that students from historically marginalized groups often score lower on the typical assessments. Using a critical lens, we argue against this deficit-oriented discourse; the lower scores are not a limitation of students, but rather a limitation of the test which does not accurately capture diverse ways of knowing and doing in spatial visualization skills.

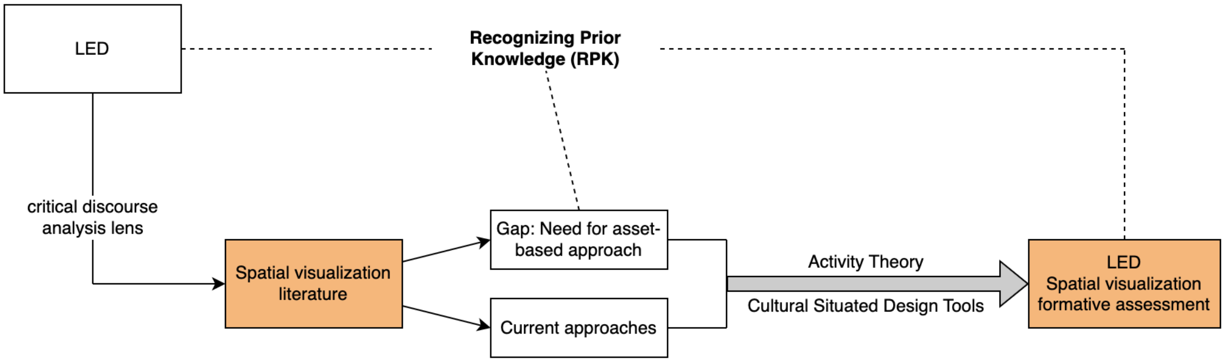


Figure 7. *Scoping Spatial Visualization Development in LED program:* Spatial visualization literature reviewed through Critical Discourse Analysis lens to understand current approaches and identify the gap in utilizing asset-based approaches in spatial visualization skill development.

Figure 7 illustrates the bridge between the LED program and our current work in spatial visualization skill development. We observed the literature surrounding spatial visualization assessments with a critical lens as discussed earlier. From the literature, the current approaches shed light on understanding the consistent practices in the United States with engineering students in higher education. In order to assess the spatial visualization skills of learners entering their undergraduate careers, researchers and educators frequently turn to the assessments such as PSVT:R and others. The literature and our conversations with DeBoer Lab partners agree that scaffolding in the 2D/3D modeling curriculum supports the process that spatial visualization skills can be improved through practice [2], [10]. Additionally, the scaffolding requires sufficient training in one particular software and a foundational understanding of design principles. With a strong foundation in modeling techniques, engineering learners are equipped with an understanding of design principles and approaches to support their work in creating solutions. A gap recognized in the current literature is the lack of an asset-based approach in curriculum development, including assessments. The LED program looks to support the education of engineering learners holistically by creating a curriculum that asks students to design projects that are localized to build off of the student assets and solutions that add value to their community. The student assets are identified through LED's process of Recognizing Prior Knowledge (RPK). In the scope of spatial visualization skills, the LED RPK assessment would have an added formative assessment component of spatial visualization. Here, facilitators and researchers would look to students' knowledge and shape the curriculum by centering their assets.

From the current literature to the spatial visualization formative assessment in the LED program, we focus on two theories to enforce a more culturally relevant approach to skill development:

activity theory and the use of culturally situated design tools. These frameworks support the process of recognizing student assets by centering sociocultural experiences in developing 2D/3D modeling curricula and by aiding motivation for engineering learning by connecting engineering principles to local knowledge. The critique of current methods in spatial visualization skill development primarily focuses on how utilizing the current assessments may reinforce standards in engineering learning developed and sustained in the U.S. These standards use pass/fail results or grades as a measure of success, but for our contexts in the LED curriculum, we want to prioritize student engagement throughout the design process and connect the material through local knowledge. Success, rather than being measured as pass/fail or a grade, is outlined in the students' abilities to effectively use the tools and technology to support them in developing realistic design solutions.

The emphasis of our critique of current methods for spatial visualization skill development is settled in questioning the origin of assessments or theories as different cultures can have different ways of knowing and varying sociocultural experiences. While we cite activity theory in utilizing social engagement for spatial visualization skill development, it is important to note the framework was developed by Soviet psychologists. However, Gauvain reports it has since grown in psychology outside of Russia [19]. Overall, the framework emphasizes the role of social interaction in cognitive development. In the scope of the LED program, this means looking at student experiences in their contexts to support spatial visualization skill development using culturally situated design tools.

Conclusion

Approaching spatial visualization skill development through an asset-based approach remains a work-in-progress. Previously published literature provided insight as to current observed trends for engineering learners mainly pursuing higher education in the United States. However, for international work, we are looking to deconstruct the routine of standardized assessments and center the curricula around identified student assets. The intention with this approach is to support motivation for engineering learning and more effectively share engineering knowledge by connecting it with local knowledge.

The work-in-progress has included initial conversations with facilitator partners in Kakuma, and we plan to continue the conversation and extend it to students. We want to include the facilitators, educators, and students in the curriculum-design process to ensure the content best supports their interests and goals. Future work entails refining the spatial visualization component of DeBoer Lab's RPK assessment so that researchers and facilitators can collaborate in co-constructing modules for student learning in 2D/3D modeling which would eventually feed into prototype development.

We critique the current approaches in spatial visualization skill development using standardized assessments as we want to expand the field to international contexts where we work with displaced learners. This work is useful for practitioners and engineering educators in international contexts, for designing relevant engineering courses to impart foundation skills. Moreover, the work in this paper can also be useful for engineering educators in the U.S. as classrooms are becoming more diverse, and there is an urgent need for inclusive curricula and assessments.

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