Student Design Projects to Improve Spatial Visualization Ability

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with
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Abstract

*In this digest, we describe student design projects for which interactive demonstrations will be provided during the Media Showcase event. We present examples of projects designed to help future students improve their performance in an introductory engineering graphics and visualization class. Projects include "*X-treme Blocks*," designed for students who struggle with visualization from coded plans, a set of 3D models and a matching isolation box to help students visualize 2D projections from 3D objects, and the game "Ortho-Slap," which helps student practice mental rotation skills for interpreting orthographics multi-view drawings in a fast-paced, fun environment.*

Introduction

In the freshmen-level engineering graphics class at the University of California, Berkeley (E25: Visualization for Design), students complete a group design project. When Engineering Graphics was a 3-unit class, the main project deliverables were a complete set of working drawings produced in CAD. More recently, the material was split up, so that the freshman class could focus more on sketching, visualization, and multiview drawing interpretation skills in a 2-unit class, and 3D solid modeling was moved to a separate 2-unit sophomore level class, during which the students output working drawings from within a solid modeling program. Therefore, a new emphasis for the group design project in the freshman class was tried, without any working drawings deliverable: each group was tasked with designing and prototyping something that could be used by future students in the class to improve their learning. This design objective had the advantage/disadvantage that the students understood their target users well because they were their own target users; thus (advantage) they could generate their own user needs, but (disadvantage) they did not get the first-hand experience discovering how much actual user needs (Ulrich and Eppinger, 2015) tend to differ from what engineers believe them to be. Another advantage, however, was that their own classmates could be the subjects for a user testing day where the groups could get feedback and improve their designs.

Motivation

Engineering traditionally has a low retention rate due to the difficulty of certain aspects of the engineering curriculum. At the same time, the demand for engineers is high, due to their technical problem solving skills (Markopoulos, 2015). This indicates an urgency to retain as many motivated students as possible. Student engagement, confidence in one's abilities, and academic success directly impact retention rates in engineering (Bandura, 1989). The design project implemented in E25 at UC Berkeley aims to improve student's academic success, confidence, and engagement through the development of learning tools that can be used by future students.

The purpose of many of the student design projects was to aid in the process of visually converting between 3D objects and either pictorials or two-dimensional 2D views. This will help future students as they develop the spatial visualization skills needed to succeed in engineering classes and eventually as engineers (Allam, 2009). The ability to create 2D orthographic projections of 3D objects is one of the fundamental components of spatial visualization (Sorby, 1999). These design projects address the reality that student visualization abilities vary widely (Milne, 2014).

Sample Projects

Many groups took advantage of a student Makerspace on campus to prototype their projects. Others had access to personal 3D printers. Three exemplars are presented in the following sections.

<u>Example 1: X-treme Blocks</u>

The "X-treme Blocks" group designed a set of modular blocks -- in shapes of extruded squares, triangles, and quarter circles -- in which they embedded magnets to make it easy to build structures corresponding to coded plans such as for the exercises in Chapters 2 and 3 of the Lieu and Sorby engineering graphics textbook (2017).

X-TREME BLOCKS

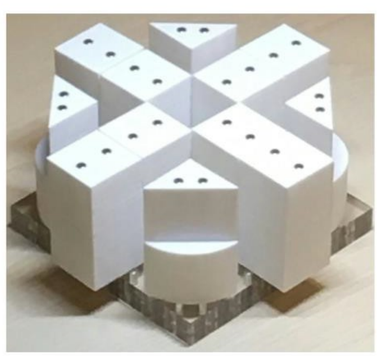

Figure 1: **X-treme Blocks, a set of modular blocks**

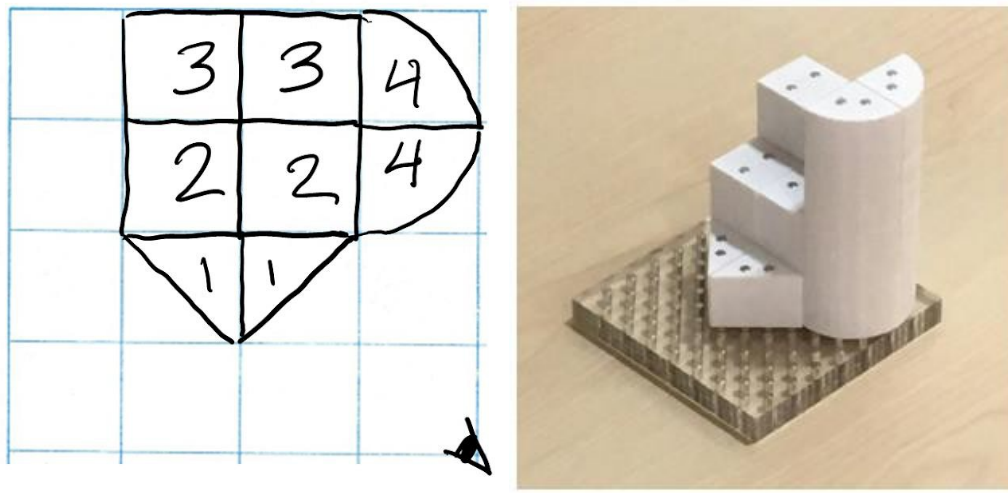

Figure 2: (a) **Coded plan visualization exercise and** ***(b)*** **X-treme Blocks visualization of coded plan**

Figure 2 (a) reproduces one of the more challenging coded plan visualization exercises from Lieu and Sorby (p. 3-42, 2017). The photo of the X-treme block visualization to its right in Figure 2 (b) looks at first glance almost like an Escher drawing of an impossible object, due to the alignment of non-coplanar faces. The blocks allow the students to experiment with inventing other examples with other sorts of coincidences. The clear plexiglass base (also containing embedded magnets) allows students to experiment with more challenging worms-eye views as well as the more familiar birds-eye viewing angle.

<u>Example 2: Multiview Multipurpose Models</u>

The Multiview Multipurpose Models group designed more geometrically complex blocks to aid students who struggle to visually "flatten" what the eye sees as a 3D object when they are asked to produce corresponding 2D orthographic views. 3D objects viewed by the eye are subject to size and shape distortions caused by location and orientation of the viewer. For the project, this group designed a set of five white 3D objects (Figure 3) that all fit inside the same cubic geometry bounds. The objects were fabricated on a 3D printer, and then the edges were marked with a black Sharpie, which makes them stand out clearly. A black bounding cube (the "view-plane isolation box") that the objects can slide in and out of was also constructed.

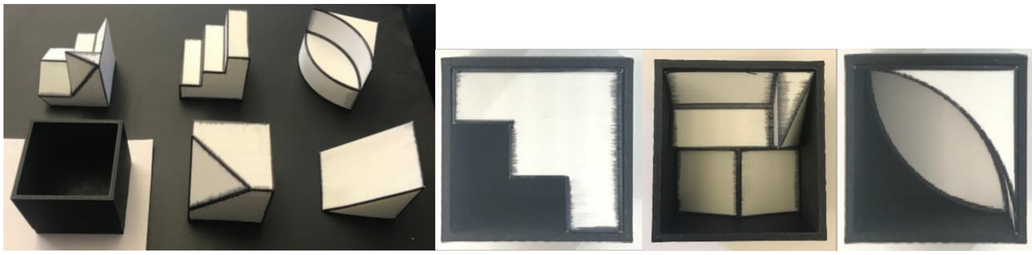

Figure 3: Set of 3D objects (in white with black highlighted edges) that fit into bounding box (black)

The isolation box and edge highlights are helpful learning aids for several reasons. When the 3D object is placed in the box, it is easier for students to adjust their viewing angle so that they are looking straight into the box (viewing direction perpendicular to the corresponding 2D viewing plane). In this head-on view, the object shape is closer to an orthographic projection, reducing the shape distortion for viewers. Aligning a light with the viewing direction can help eliminate shadows. In addition, the sides of the isolation box block the side surfaces of the object, which otherwise give perspective cues when the viewing angle isn't perfect. Furthermore, with the high-contrast Sharpied edges, viewers are less likely to rely on interpreting changes of orientation between adjacent faces to recognize where edges are located. With the orientation less salient, the projected shape of faces is easier to visualize. Eliminating 3D cues that are distracting in this context should be helpful for converting complicated 3D objects to multiview drawings, allowing the viewer to focus on the shape of a single planar face at a time.

Example 3: Ortho-Slap

The "Ortho-Slap" group designed an ingenious, competitive game designed around rolling a "die" of a rather non-standard shape. Overall, it has six "sides" it could land upon, but each has a different orthographic projection when hidden lines are considered. Players each have a set of cards corresponding to these projections, including both the hidden and center lines on each view. The original prototype is shown below (Figure 4).

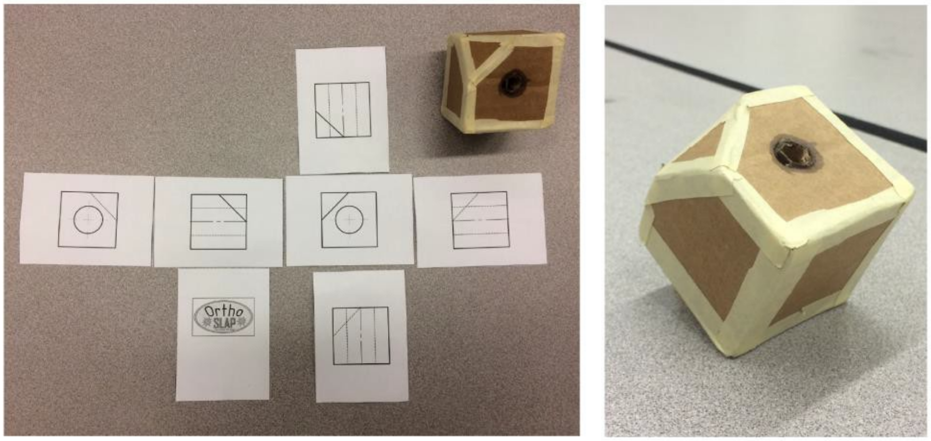

Figure 4: **Original prototype of "Ortho-Slap"**

For a "solitaire" version of the game, a student rolls the "die" and lays out the cards in appropriate unfolded-glass-box position, based on how it lands, as shown above left. But the real fun is the competitive version, where after the "die" is rolled, students compete to be the first to slap down the card corresponding to the view facing "top," in the correct orientation. With the sturdy 2nd prototype from a 3D printer (Figure 5), the card can be slapped down right on top of the "die," and there are no ties because one player's card is clearly the one that made it onto the die first (though sometimes incorrectly chosen or oriented; the other players help to judge).

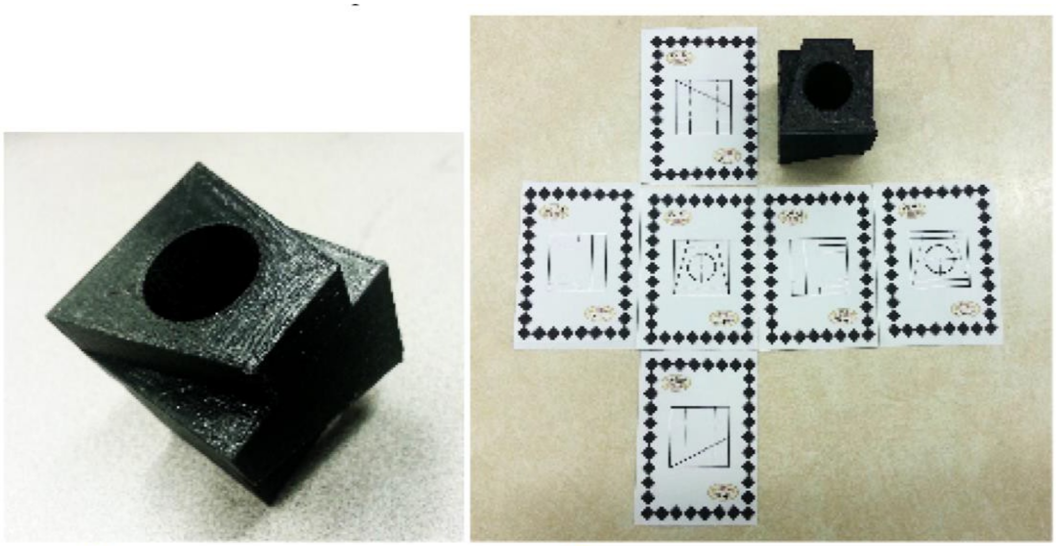

Figure 5: **Second 3D printed prototype of "Ortho-Slap" with set of projection cards**

Other students really enjoyed playing this fast-paced game the following semester; one written comment was that "It was surprisingly fun!" The top mental rotator in the student group that invented the game (right) challenged the professor to a game, where adrenalin ran high. (She barely managed to pull of a win, much to her relief but to the obvious disappointment of the student.)

Discussion and Future Work

For a second iteration of the X-treme blocks, one change we would make is to choose a plastic filament and/or 3D printing process that allows for a matte finish. When teaching engineering students who have such a wide range of art backgrounds, it is our practice to only teach students about simple diffuse shading that is dependent only on surface orientation and surface normal, omitting specular highlights that vary with the eye position. The shiny finish of the current blocks picks up specular highlights, so that could be confusing for students trying to shade their sketches using only the diffuse shading rules.

The ortho-slap concept would be a fun inspiration for a design exercise in a 3D solid modeling class. One complaint from students learning solid modeling is that for typical homeworks and labs, they are always given designs and then they just have to reproduce them in CAD, rather than designing anything themselves. Designing alternate ortho-slap die geometries would be a fun exercise that would incorporate both visualization skills to design something that had six unique projections, but also incorporate analysis of moments in order to design a fairly weighted die. (Or perhaps they want to design an unfairly weighted one, so that students could beat their professors more often by being able to predict which side is most likely to land facing up!)

“Fun” and “play” were characteristics of many of the most successful projects. Gamification (Kapp 2012), the integration of games into non-traditional contexts, has been used a teaching technique in a variety of contexts. Games give participants immediate feedback and provide a way to practice concepts in a fun environment. Empirical results from previous studies are limited, but it is theorized that gamification will increase student interest,

motivation, and ability to learn difficult concepts (Markopoulos, 2015). The results of this design project support that conclusion. Overall, projects that were games were among the most popular, gaining lots of interest and feedback from the testers. Gamification may have as promising a future in higher education as in K-12.

Acknowledgements

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