Testing the Efficacy of 3D-Printed Geologic Block Models as Tools for Fostering Spatial Visualization Abilities

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Abstract

Spatial visualization is crucial to success in the geosciences, especially in courses such as sedimentology and stratigraphy, structural geology, and field techniques. Students with the spatial visualization abilities necessary to succeed in these courses are more likely to continue in the geosciences. Unfortunately, an overwhelming proportion of students are unprepared for spatially intensive coursework due to a lack of spatial training in K-12 and undergraduate education. Previous studies have demonstrated that spatial visualization abilities are malleable skills that can be trained efficiently and inexpensively, yet widespread spatial training is uncommon. With this project, we propose the use of 3D-printed geologic block models (Figure 1) as tools for fostering spatial visualization abilities in conjunction with an introductory-level geologic structures lab exercise. Recent advances in 3D-printing technologies are making 3D-printing more accessible to educators, and material designs can be shared with educators around the world.

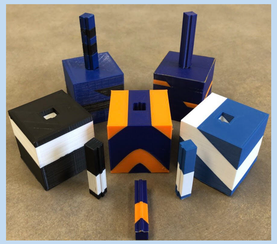

Figure 1. 3D-printed geologic block models. Different block models represent different structural bodies (in particular, horizontal strata, inclined strata, folds, and faults) that are featured in CSUF's geologic structures lab, though they are intentionally designed to have different properties (i.e., different dip angles, differing stratigraphy, and differing offsets) such that they are not simply answer keys for the lab.

Interested in seeing what other blocks we have printed as part of this project? Scan the QR code to the right! We are using 10 different structural block models, but we're always open to ideas. What kind of block models would you like to see or use in your courses?

Current Instructional Methods and Materials

In introductory-level geology courses, instructional materials designed to promote spatial visualization skills range from painted wooden blocks to interactive virtual models (Figure 2).

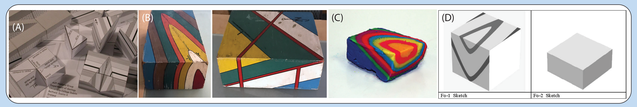

Figure 2. Examples of (A) foldable paper models presented by the Fault Analysis Group at University College Dublin, (B) painted wooden block models, (C) play-doh sculptures used by Gagnier et al. (2017), and (D) interactive virtual block models used by Steven Reynolds at ASU.

Project Rationale

Previously employed instructional materials tend to require more time and funding than are feasible for many geoscience educators. Digital materials help to remedy this issue, but they unfortunately lack tangible, interactive components that allow students to complete spatially-intensive exercises in a fully three-dimensional environment. Recent advances in 3D-printing technologies make it possible to address time, cost, and interactivity through the use of 3D-printed instructional aids. In particular, we are interested in 3D-printed geologic block models as an alternative to previously employed materials for the following reasons:

I. Modern advances in 3D printing make 3D-printed models a cheaper alternative to professionally produced models (Horowitz and Schultz, 2014).

II. 3D-printed models can be produced more easily and efficiently than traditional materials, and are more accessible to students than virtual models.

III. Once models have been designed, the files used to print each model can be easily and quickly shared with anyone who wishes to print their own.

Research Questions and Methodology

This study will target up to 750 students enrolled in laboratory sections of Geology 101 that include a geologic structures lab (Figure 3) as part of their coursework. A pre-lab and post-lab spatial visualization survey (henceforth referred to as "viz quizzes," Figure 4) is being used to assess students' spatial visualization abilities before and after completing the geologic structures lab either with (Experimental) or without (Comparison) the assistance of 3D-printed geologic block models. A demographic background questionnaire is also being administered after each lab to collect data on student demographics such as gender, ethnicity, age, and academic background.

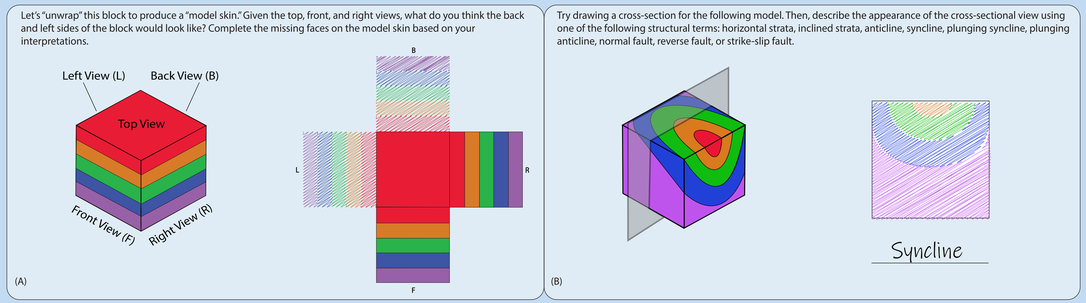

Figure 3. Samples of completed exercises from the CSUF geologic structures lab. (A) After being asked to make descriptive observations about a structural block model, students are tasked with interpreting concealed geometries given visible surface and outcrop views. (B) Students are assigned multiple cross-section exercises based on structural block models presented in earlier sections of the lab. After completing their cross-section, students are asked to describe which geologic structure their section best illustrates, regardless of the true structure modeled by the given block. Want to see more of the lab? Scan the QR code to the right!

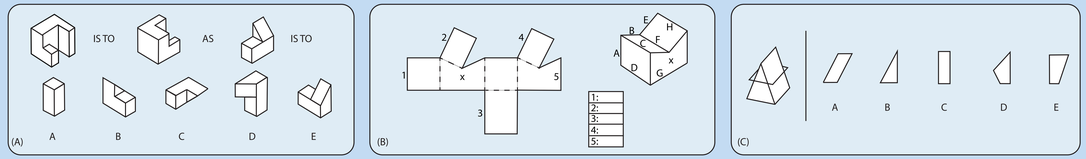

Figure 4. Samples of viz quiz problems given before and after each iteration of the geologic structures lab. We use the viz quizzes to assess three domains of spatial visualization that Titus and Horsman (2009) argue are key to success in the geosciences - (A) spatial rotation, (B) spatial manipulation, and (C) visual penetrative ability. Rather than combining the scores from each and comparing total spatial visualization score differentials, we address each targeted domain individually when processing data and answering our research questions. Want to see the complete set of viz quizzes that we give participating students? Scan the QR code to the right!

The data collected during this project are being processed in R statistical software. Missing values have been imputed for students who did not complete the post-lab viz quizzes and demographic survey using a random forest algorithm. After missing values have been imputed, the data are used to answer the following questions:

(1) Does teaching geologic structures with the assistance of 3D-printed block models impact students' spatial visualization abilities? In other words, is there some correlation between students' access to block models and improvements in their spatial visualization abilities? We hypothesize that students who have access to tangible, interactive block models experience greater improvements in their spatial visualization abilities.

This hypothesis is being tested through one-way multivariate analyses of variance (MANOVA). A one-way MANOVA test allows us to compare differences in rotational, manipulative, and penetrative viz quiz score differential means given access to blocks. P values are subsequently generated to determine if differences in mean viz quiz score differentials are statistically significant.

(2) Do student demographics such as gender, ethnicity, and STEM pursuit have statistically significant impacts on the acquisition/development of spatial abilities? We hypothesize that female students, students of color, and non-STEM students will benefit more from their access to blocks than male students, white students, and STEM students respectively. This hypothesis is based on research conducted by Levine et al. (2005), who found that (i) male students generally have better spatial abilities than female students, and (ii) students of higher socioeconomic status tend to have better spatial abilities than students of lower socioeconomic status (in which minority students are typically overrepresented). We believe that providing students with interactive learning materials will help to close the gap between demographics, putting students on a more level playing field as far as spatial abilities are concerned.

This hypothesis is being tested using two-way MANOVAs, which compare mean score differentials between students of different demographics given access to blocks. For example, the mean score differentials of white students and students of color can be compared while taking block access into account. Though we emphasize gender, race, and college in our hypothesis, the full extent of our measured demographics includes self-prescribed learning style, STEM pursuit, college, course load, family education, Hispanic / Latino heritage, race, gender, and the time of day labs are administered.

Preliminary Findings and Discussion

381 students have participated in this study thus far (of an anticipated 750 by study completion). 298 of the students who completed the geologic structures lab did so without access to 3D-printed block models, or any other form of three-dimensional aid. 83 students - who were taught by the same instructor - have completed the lab with access to team sets of 3D-printed block models.

The current dataset indicates that 3D-printed block models have a statistically significant impact on students' acquisition of spatial rotation skills. Though rotation is the only domain of spatial visualization in which we see statistically significant differences in mean score differentials (Table A), we have plotted the current data to show us trends in spatial visualization development that we will follow through the duration of this study (Figure 5).

	Mean Score Differential	Mean Squared Error	P Values
Spatial Rotation			
No Blocks	0.471	2.732	0.0324*
Blocks	0.032	3.497	
Spatial Manipulation			
No Blocks	0.239	7.864	0.4363
Blocks	0.630	7.121	
Visual Penetrative Ability			
No Blocks	0.447	5.727	0.0790
Blocks	-0.152	6.512	

*Statistically significant difference < 0.05. No Blocks = 298, Blocks = 83.

Table A. Impact of Block Access on Spatial Visualization Score Differentials.

Plotting the effects of block presence on the development of spatial abilities reveals some interesting trends. First, students with access to blocks seemingly improve more in their spatial manipulation ability when compared to students without blocks. Furthermore, the opposite seems to be true for spatial rotation and visual penetrative ability. These trends may relate to the spatial operations allowed by the blocks, and how students are using them to solve problems in the lab.

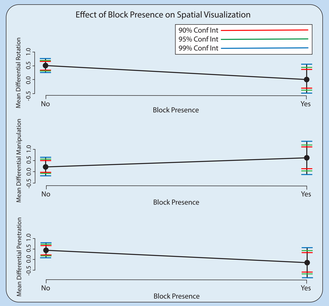

Figure 5. Effect of Block Presence on Spatial Visualization.

Students cannot physically distort the block models to perform manipulative operations. As such, they are required to work through such operations in their head in order to solve problems, practicing skills that they may not practice otherwise and improving accordingly. Conversely, students are able to rotate the blocks in their handsand visually penetrate the blocks with the assisstance of the blocks' removable cores. Because students can easily perform these operations without much thought, it is entirely possible that students are not practicing rotational or penetrative operations in their head like they do manipulative operations, resulting in lesser spatial visualization gains when compared to students who have not had access to blocks.

The current dataset also indicates that students' demographics do not have statistically significant impacts on the development of their spatial visualization abilities, regardless of whether or not they have access to block models. While we had initially believed that students from different backgrounds would benefit differently from our blocks, it seems that we have developed resources that are broadly accessible.

Going forward, we will be producing interaction plots to showcase any trends that manifest with more data. We intend to collect approximately 360 students' worth of experimental data during the Fall 2019 semester with the assistance of 5 other teaching associates. This data will be used to provide us with more reliable information about the impacts of blocks and student demographics on spatial ability development. Find us at the AGU 2019 Fall Meeting to see how our story unfolds!

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