3D-printed models: tools for teaching 3D visualization of subsurface geology

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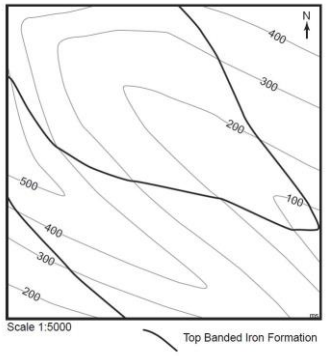
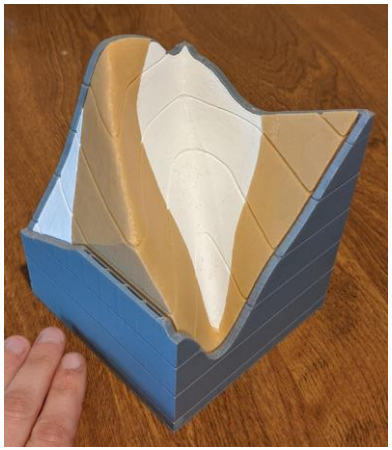
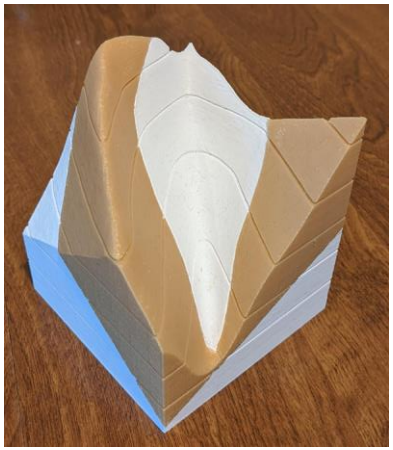
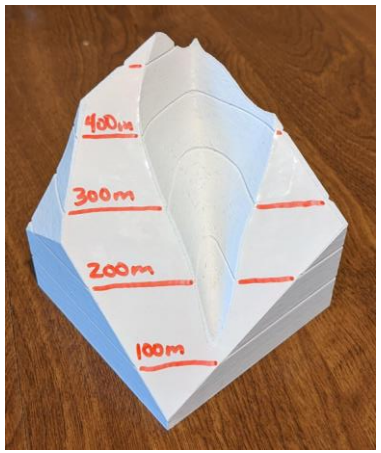




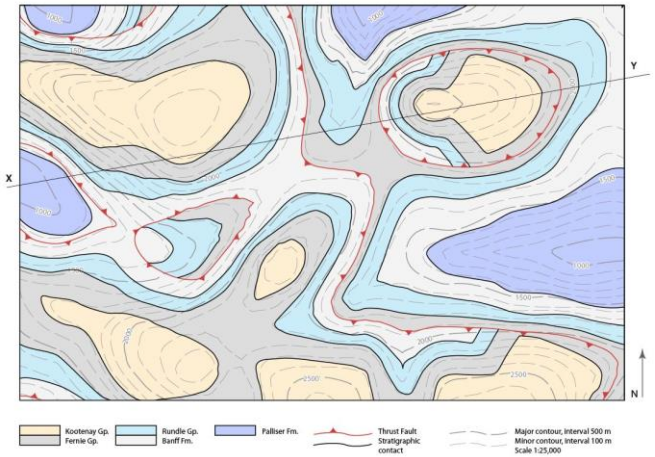




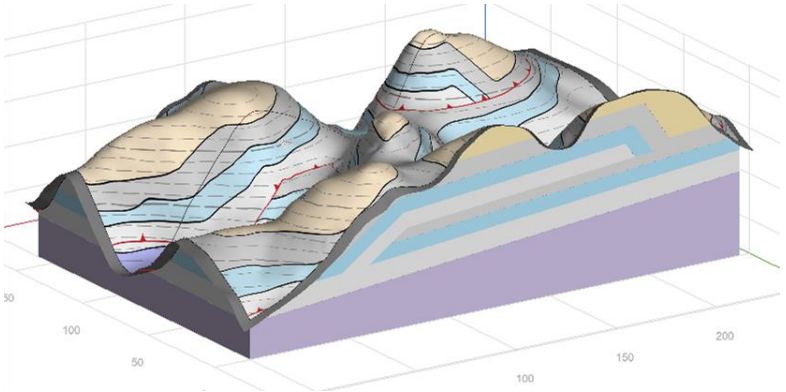
Introduction & Background

An important part of Earth science education provides students with the skills needed to visualize in 3D (e.g., Ormand et al., 2017).

A key learning objective of structural geology is that students will view a geologic map (i.e., a 2D representation of the 3D, opaque lithosphere) and visualize the shapes and relationships of structures in the subsurface.



Geologic Map

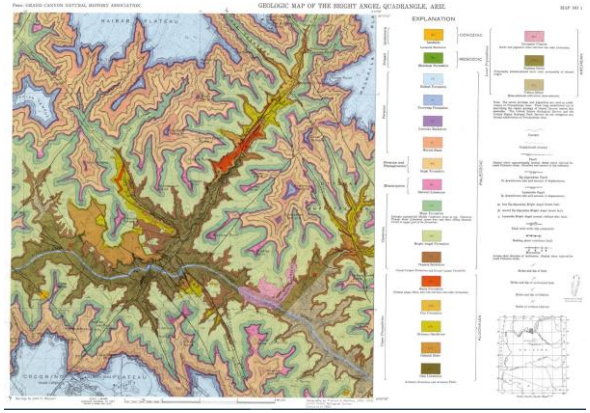


3D Model

[Click here](#) to explore virtual model!

Challenges

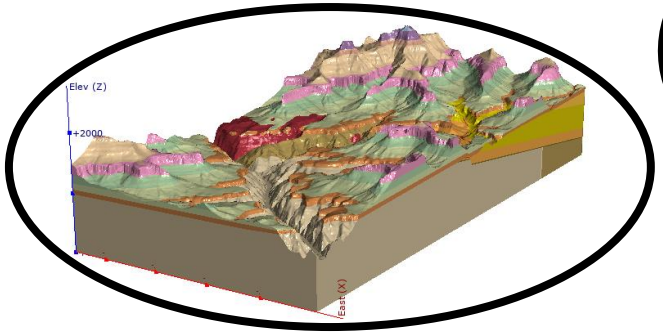
Students are typically taught to use measurements and graphical constructions from a 2D map to create a cross-section showing the structure in 3D. These techniques present students with challenges of:



Maxson's 1961 map of Grand Canyon geology

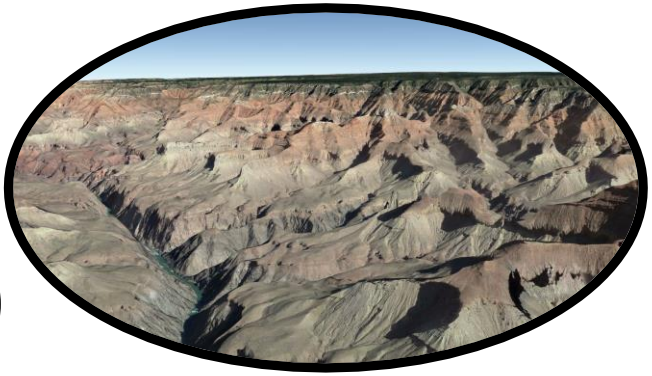
Dimensionality

Rock units exposed at surface extend into the subsurface



Abstraction

Colors on map symbolize rocks



Google Earth (2017)

Scale

The map represents a much larger area

"Scouting Lava Falls rapid - Grand Canyon" by Al_HikesAZ, used under CC BY-NC 2.0 / Cropped from original

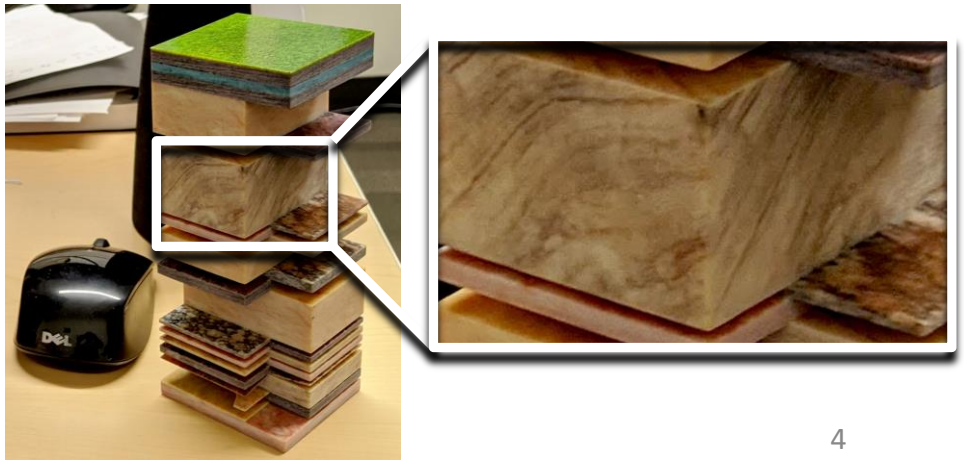
Can 3D-printed models help?

Physical models allow students to directly observe and measure otherwise hidden subsurface structural relationships.

Advances in 3D-printing allow for the creation of very sophisticated physical models:

- Models can be made to exactly match the scale and color of 2D maps introduced in lab exercises.
- Satellite imagery of the Earth's surface can be printed on model surfaces.

For example, the Stratasys PolyJet J750 can print in multicolor including realistic rock textures.

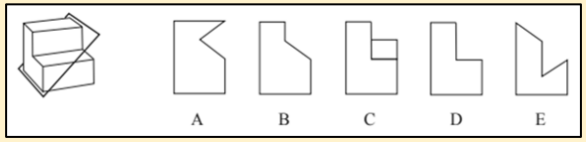


Assessing Student Learning

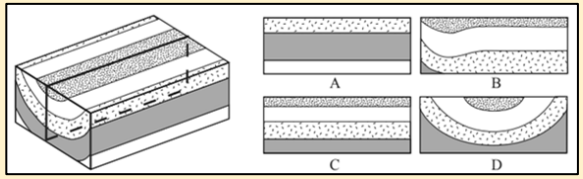
We created an online survey (Qualtrics) to be administered at the beginning and end of undergraduate courses in Structural Geology and Engineering Earth Science.

PART A: Testing instruments used as proxies for spatial reasoning skills including 2D to 3D transformation (1-3), visualizing penetrative relations (1,2), and rotation (3).

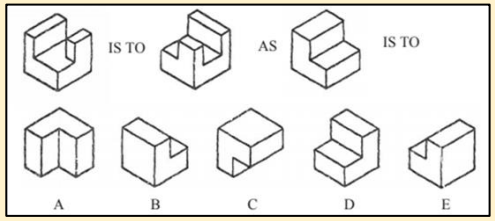
1. Planes of Reference (Titus and Horsman, 2009) – 'Slicing 1'



2. Geologic Block Cross-sectioning (Ormand et al., 2014) – 'Slicing 2'



3. Purdue Visualization of Rotations (Guay, 1976) – 'Mental Rotation'



PART B: Metacognitive Evaluation (semester end only)

How useful were the following in helping you visualize in 3D?

- Measuring with a compass clinometer
- Drawing structure contours on a geologic map
- Making a geologic cross-section
- Physical models
- Online computer tools (e.g., Visible Geology, Google Earth, 3D computer models)
- Plotting structures on stereographic projections
- Making a geologic map

For each item, students can select Not Useful, Somewhat, Moderately, Very Useful, or Essential.

PART C: Basic demographic information

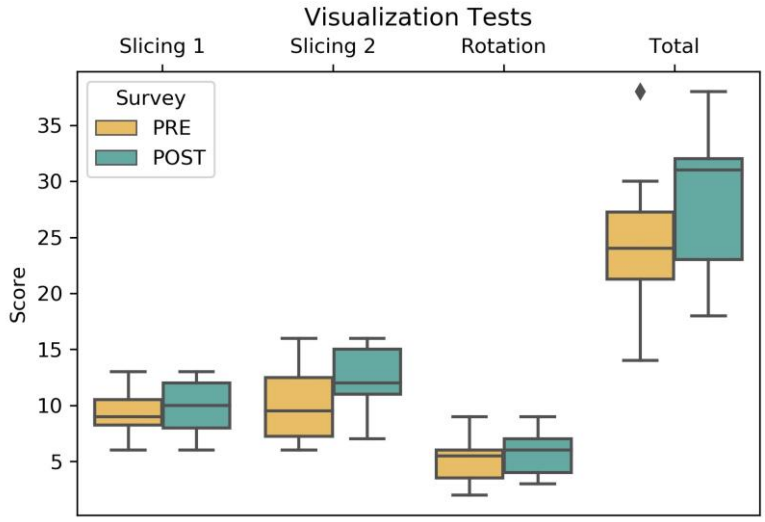
Students were asked to provide information about:

- Gender identity
- Ethnicity
- Other Earth science courses taken
- Device type used to complete the survey

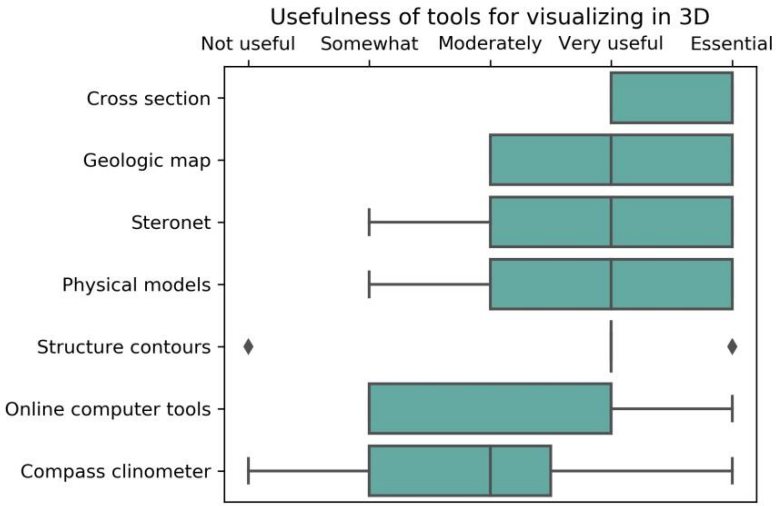
Survey Implementation & Results

- Survey implemented with a control group in Winter 2020
- No new physical models introduced during this semester
- ~50% of students in the course completed the survey at the beginning (n=10) and end (n=9) of the semester

Student performance on visualization tests improved after taking the course. The biggest gain on geology-specific 'Slicing 2' test, which was also the only test for which there was an increase in score efficiency (points earned / second).

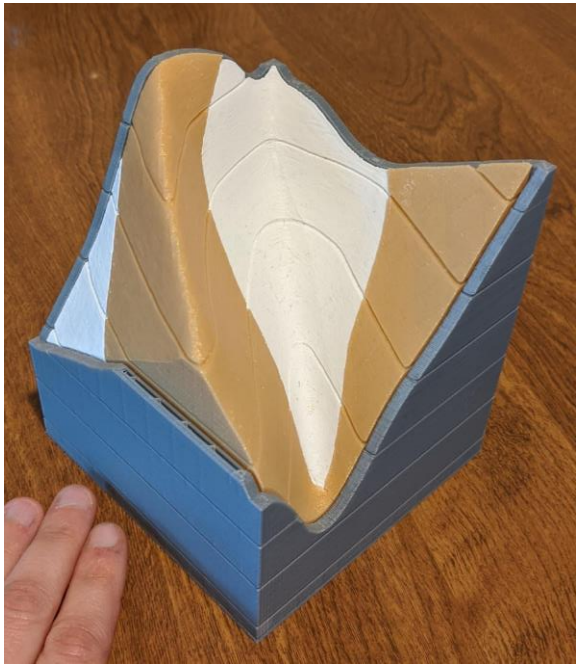


Students found making cross sections to be the most helpful for visualizing in 3D.

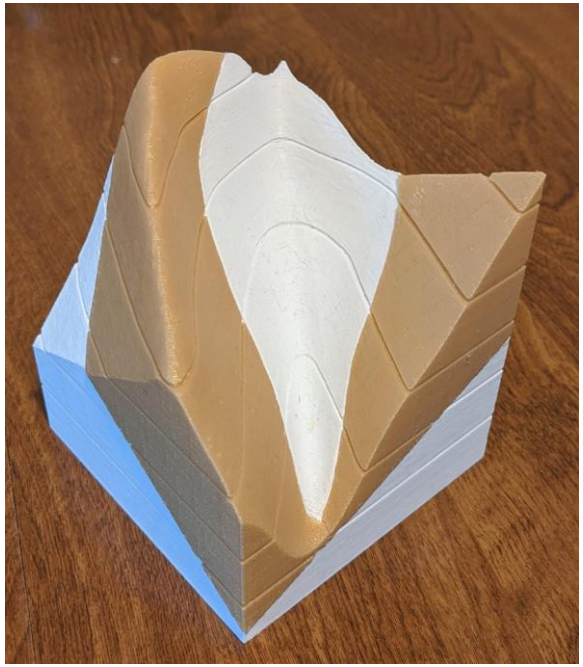


3D-printed models

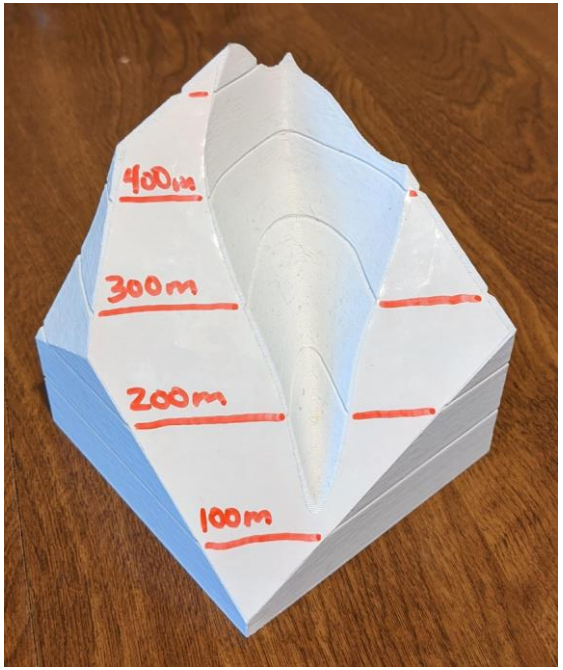
Prototype:



When students first encounter the model they see only the surface geology.



Students can then investigate the subsurface geology.

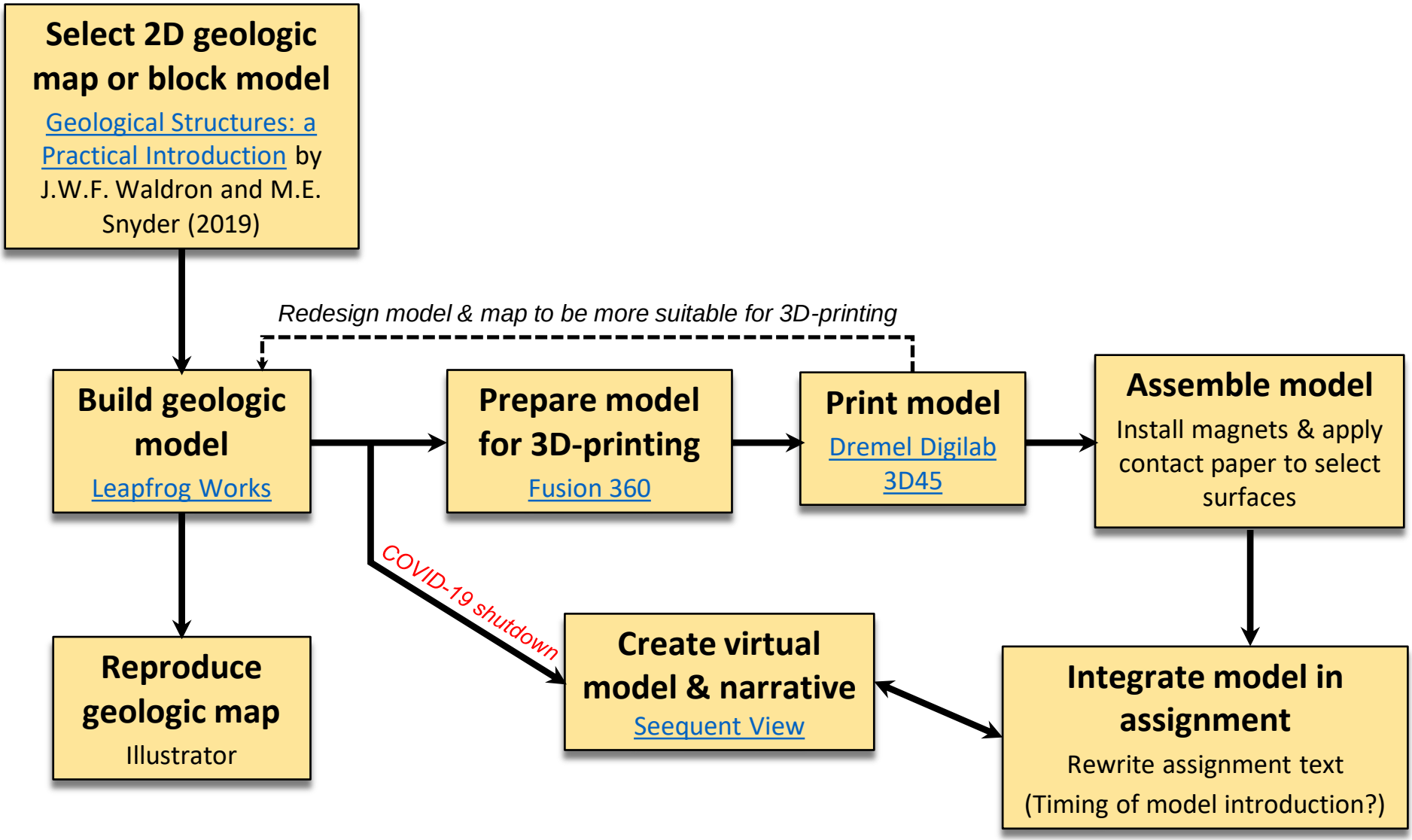


The upper unit has been removed and structure contours drawn on the planar contact surface.

Click here to see a video demonstration of the model.

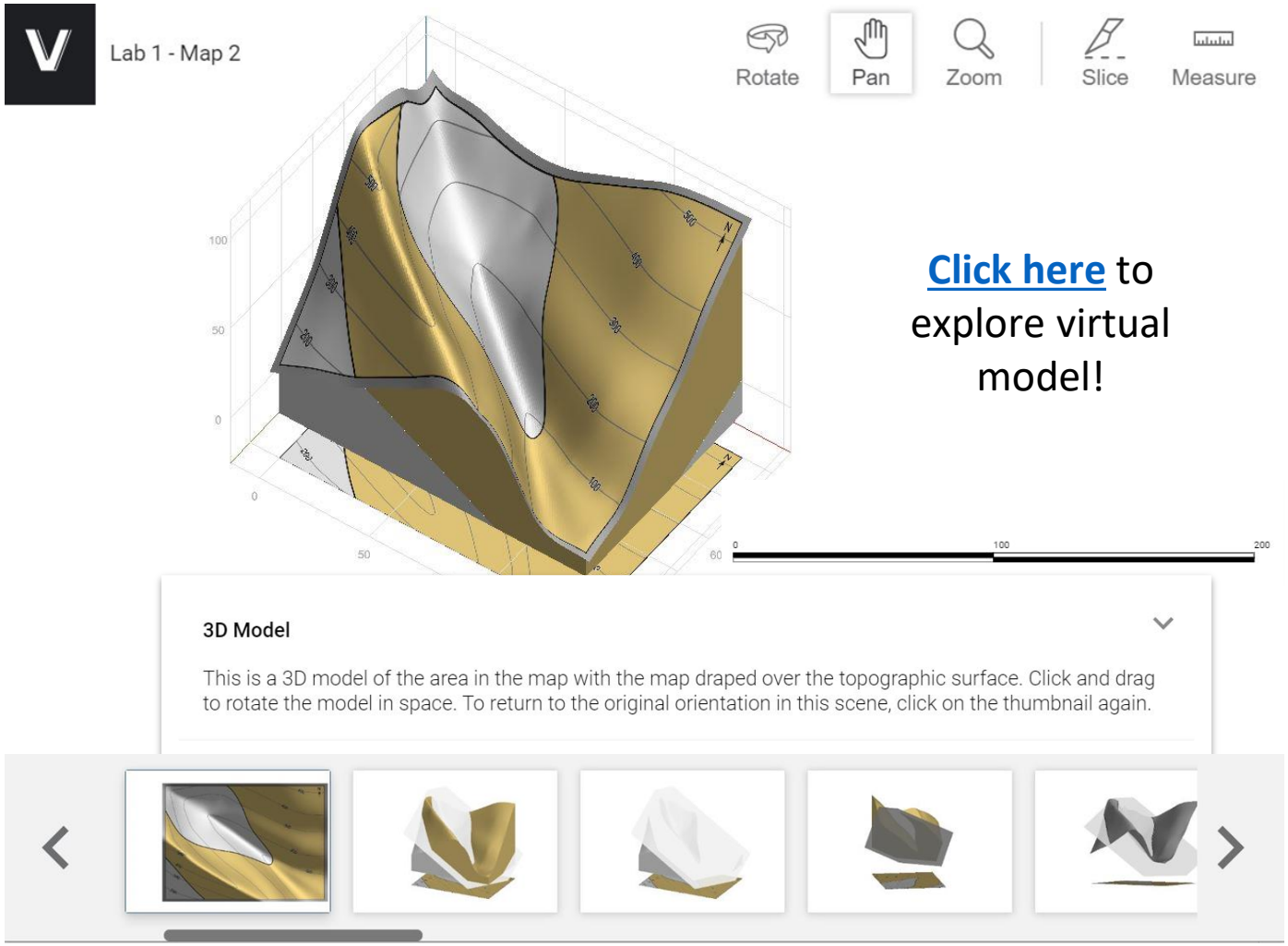
Printing time: 20 hours
Printing cost: $35

Workflow for Creating 3D Models



Pandemic pivot: Virtual models with narrative

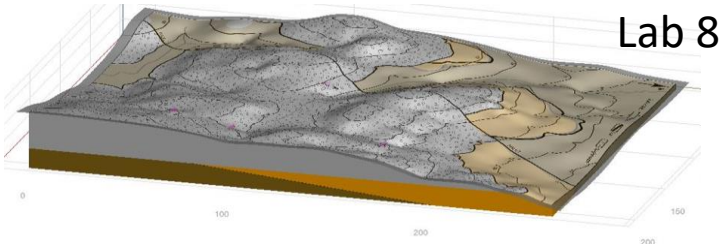
With the closure of 3D-printing facilities during the COVID-19 pandemic, our focus has shifted to creating virtual models.



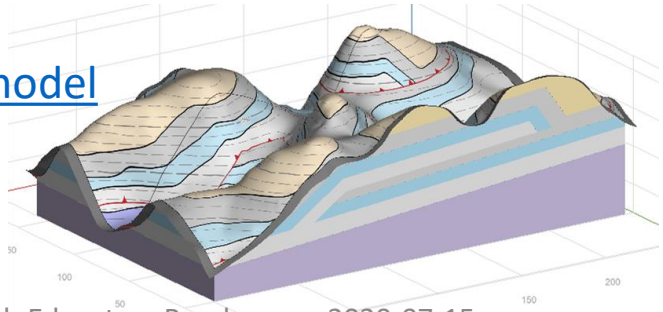
Implementation & Results

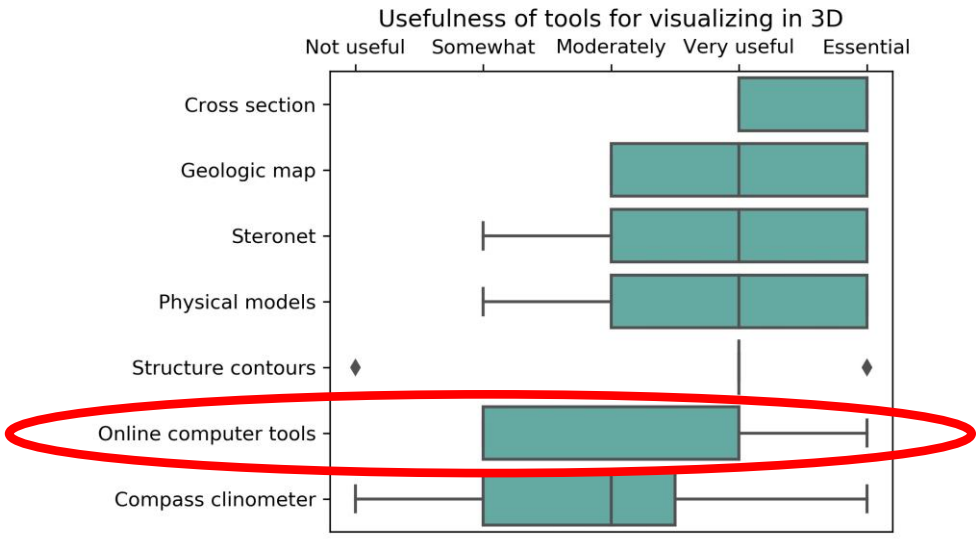
- Two virtual models were used in help sessions after the switch to online delivery.
- It is not clear what impact these had on the students.
- Informal feedback from teaching assistants indicates that having access to such models would have helped the TAs visualize and demonstrate concepts throughout the course.

Virtual model
Lab 8



Virtual model
Lab 10



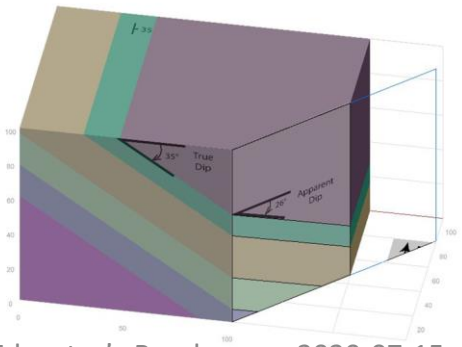


Future Work

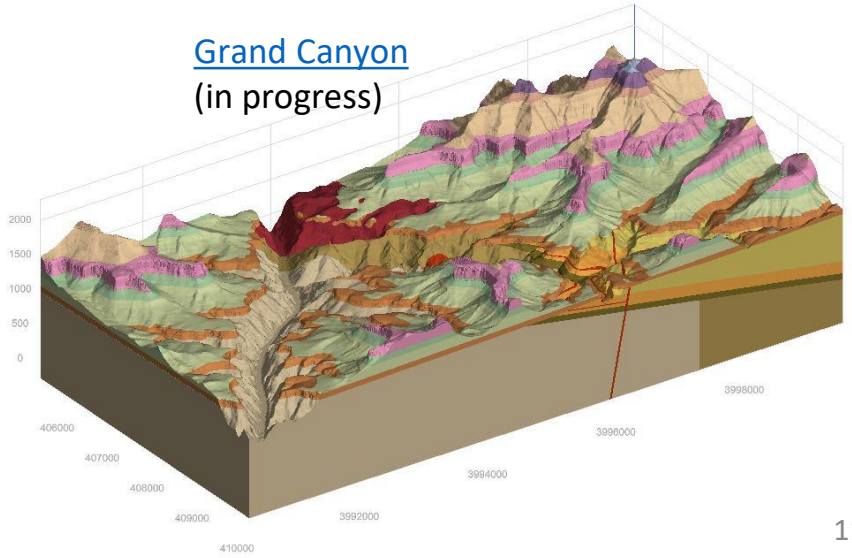
- Create and 3D-print more models (when printing facilities re-open)
- Integrate models into courses (2020-2021 AY) and into the second edition of Geologic Structures textbook
- Collect data on impact of models on spatial reasoning skills (2020-2021) and compare with data from control group
- Make 3D-printing files publicly available (Thingiverse?)

Additional virtual models to be printed:

Concept Demonstration:
True vs. Apparent Dip



Grand Canyon
(in progress)



Acknowledgements

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teaching and learning
enhancement fund

References

Guay R (1976) Purdue spatial vizualization test. Purdue Research Foundation, West Lafayette, Indiana

Maxson JH (1961) Geologic map of the Bright Angel quadrangle, Grand Canyon National Park, Arizona

Ormand CJ, Shipley TF, Tikoff B, et al (2017) The Spatial Thinking Workbook: A Research-Validated Spatial Skills Curriculum for Geology Majors. J Geosci Educ 65:423–434. https://doi.org/10.5408/16-210.1

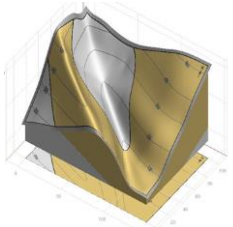
Ormand CJ, Manduca C, Shipley TF, et al (2014) Evaluating Geoscience Students' Spatial Thinking Skills in a Multi-Institutional Classroom Study. J Geosci Educ 62:146–154. https://doi.org/10.5408/13-027.1

Titus S, Horsman E (2009) Characterizing and Improving Spatial Visualization Skills. J Geosci Educ 57:242–254. https://doi.org/10.5408/1.3559671

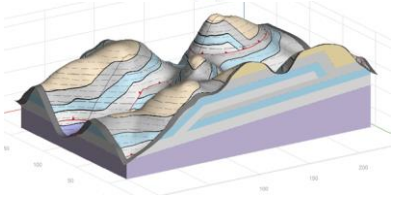
Waldron J, Snyder M (2020) Geological Structures: a Practical Introduction. Education and Research Archive. https://doi.org/10.7939/r3-x15j-kd13

List of embedded links for models

3D-printed prototype:
https://photos.app.goo.gl/bgGp7MG6vG6PJcgb8



Lab 1: introduction to surface traces and structure contours
https://view.seequent.com/embed/lxt457gikcy8jcthbpgh/default/oeza1782r67e00tkslt4



Lab 10: folded fault plane
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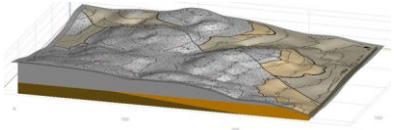

Lab 8: piercing points
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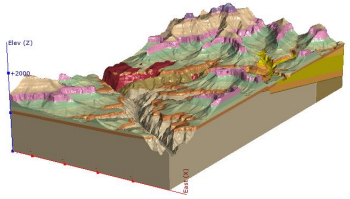

Grand Canyon (in progress)
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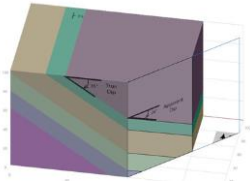

True vs apparent dip
https://view.seequent.com/embed/lxt457gikcy8jcthbpgh/default/wdgs3wr4lznvh4m2lbem