CONTACT: mattea.horne@gmail.com

Pomona College

MULTI-DIMENSIONAL ACCESS IN THE GEOSCIENCES:

IMPROVING STUDENT ENGAGEMENT AND UNDERSTANDING OF GEOLOGIC CONCEPTS USING 3D-MODELED FOSSILS

Mattea Horne and **Win McLaughlin;** Pomona College Geology Department, Claremont, CA

Abstract

The use of 3D models and prints in the classroom alongside traditional lectures to increase students' understanding of processes and concepts is well-documented in various STEM fields. Nonetheless, they remain an underutilized resource in the geosciences, despite their benefits — namely, decreasing our reliance on physical collections that are costly to procure and maintain, as well as making geoscience education more accessible to primary and secondary educational institutions. Additionally, open-source databases that host 3D models enable researchers to more easily collaborate across long distances and share their research with a wider audience. In this study, I compare the effectiveness of photogrammetrically modeled dental and cranial fossils — one carnivore, one herbivore, one omnivore, and one unknown, each from different geologic periods in the Cenozoic — and interactive activities versus traditional lecture-based classes in teaching concepts such as evolution, paleoenvironmental reconstruction, and deep time. The activities target students from middle school to early college, and can be tailored to specific curricula by educators: for example, the activities could be modified to focus mainly on paleoenvironment for an Environmental Studies class, or evolution for a Biology class. To test the models and activities, I will pilot them in an introductory-level Environmental Geology class at Pomona College with anonymous MANOVA surveys that employ Likert-type statements and focus on students' feelings of self-efficacy in the topic. T-tests and correlations will then be performed on the collected data to determine the difference in effectiveness between groups (e.g. those who self-identify as confident science learners versus those who feel intimidated by science). I believe my findings will echo those of previous studies, showing that 3D models increase students' comprehension of paleontological topics — especially when they have less experience in the area of study or are less confident in their abilities as science learners. This type of project has a multitude of potential applications, from supplementing existing curricula in underfunded or non-specialized schools to use in homeschool curricula, and can even reduce cost associated with STEM teaching in novel programs.

Methods

Creating the models:

1. I used my own Nikon D5200 DSLR camera with its lens at a 35mm focal length. Each specimen was propped up with archival putty on a turntable and had two scale bars directly beside it.
2. I constructed the 3D models from my photos using Agisoft Metashape Professional. After each model was complete, I scaled, cropped, and exported them as .OBJ files into Blender.
3. In Blender, I added rectangular bases and text to each model and again exported as .OBJ files.
4. Using Ultimaker Cura, I got the models ready for printing by adding supports and modifying print settings (e.g. layer height, infill density, brim size).
5. I printed the models using standard PLA filament on FLSUN SR printers at Harvey Mudd's Makerspace. Printing time ranged between 2 – 38 hours per model, depending on size.

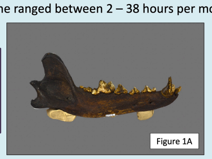
Figure 1A

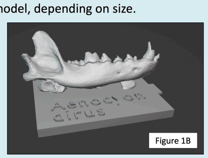

Figure 1B

Fig. 1A: *Aenocyon dirus* model displayed with texture and color in Agisoft Metashape.

Fig. 1B: *Aenocyon dirus* model displayed with base and text in Blender.

Collecting the data:

1. I designed an educational worksheet by drawing inspiration from some of Win McLaughlin's prewritten vertebrate paleontology and evolution lab activities. I focused on improving students' skills in graphical literacy, data collection and analysis, and honing their ability to apply the scientific method to observations they made directly on the models.
2. I created anonymous "Pre" and "Post" surveys in Qualtrics to assess the activities' effectiveness with Likert-type statements that interrogated students' feelings of self-efficacy (e.g. "I feel confident about my ability to execute the scientific method," or "I have a strong understanding of evolution,"). I also included attitude-based statements (e.g., "I enjoy taking science classes," or "I think of myself as a scientist," or "I am interested in Geology"). The statements were rated on a scale of 1 to 5 (1 = "Strongly disagree", 3 = "Neither agree nor disagree", 5 = "Strongly agree").
3. Students from Win McLaughlin's introductory geology class were randomly split into two groups (one group participated in my activity, and one sat for a lecture on the same material), then completed the "Pre" survey. They completed the "Post" survey after the class time was up.
4. I then conducted preliminary analyses on the collected data in Excel. I plan to use the built-in Qualtrics analysis tools and R statistical packages to perform T-tests and correlations in order to determine if the 3D models and interactive activity had a significant impact on students' confidence and interest levels.

Preliminary Data: Surveys

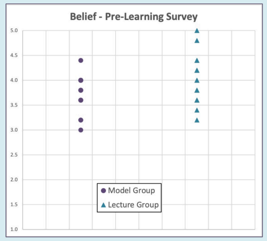

Figure 2A

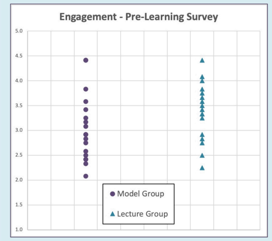

Figure 3A

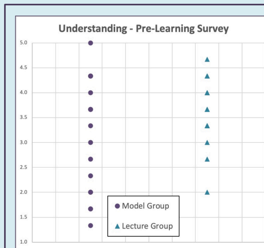

Figure 4A

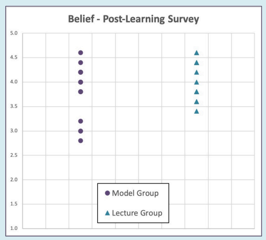

Figure 2B

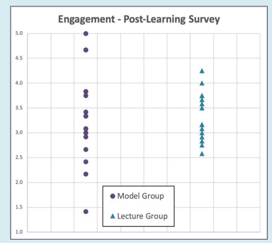

Figure 3B

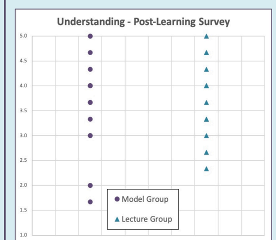

Figure 4B

Fig. 2A: a scatter plot showing participants' scale scores on the **Belief** section of the **pre-learning survey** for the Model Group and the Lecture Group. Note that the Model Group scored generally lower than the Lecture Group, and their scores were grouped more closely together.

Fig. 2B: a scatter plot showing participants' scale scores on the **Belief** section of the **post-learning survey** for the Model Group and the Lecture Group. Note that the Model Group's scores generally increased, while most of the Lecture Group's scores either slightly decreased or showed no change.

Fig. 3A: a scatter plot showing participants' scale scores on the **Engagement** section of the **pre-learning survey** for the Model Group and the Lecture Group. Note that the Model Group scored generally lower than the Lecture Group.

Fig. 3B: a scatter plot showing participants' scale scores on the **Engagement** section of the **post-learning survey** for the Model Group and the Lecture Group. Note that the Model Group's scores generally increased (some significantly), with one exception, while most of the Lecture Group's scores either slightly decreased or showed no change.

Fig. 4A: a scatter plot showing participants' scale scores on the **Understanding** section of the **pre-learning survey** for the Model Group and the Lecture Group. Note that the Model Group's scores showed a larger range than the Lecture Group's.

Fig. 4B: a scatter plot showing participants' scale scores on the **Understanding** section of the **post-learning survey** for the Model Group and the Lecture Group. Note that both groups' scores showed an increase, but the increase in the Model Group's scores was more significant.

Results and Discussion

After collecting data from the surveys, two important trends were noted:

1) Despite the groups being randomized, the group of students that participated in the hands-on activity and interacted with the 3D models had slightly lower scores in Belief, Engagement, and Understanding during the pre-learning survey than the group of students that sat for a lecture.

2) The group of students that participated in the hands-on activity and interacted with the 3D models had noticeable increases in their Belief, Engagement, and Understanding scores, as compared to the group that sat for a lecture (whose scores changed neither as significantly nor as positively).

There was one noticeable outlier within the Model Group, as seen in Fig. 3B; this participant was the lowest scoring of the entire test population in Engagement, with a score of 1.4, which was a decrease from the pre-learning survey to the post-learning survey by 0.9. Their Belief score stayed the same, and their Understanding score increased by 0.3. This participant (ID #7), along with one other subject (ID #5), gave feedback on the activity that provided a new and interesting insight into how online classes and the pandemic may have changed students' experiences in school.

- Participant 7 said that they felt like they were "operating with very little knowledge [sic] so regardless of if that was intentional it made [them feel like they weren't] learning anything because [they] had no previous knowledge."
- Participant 5 said that it "was not clear that [they] could answer wrong" on the worksheet.

These responses were particularly fascinating because they indicate a fear of experimentation and frustration towards open-ended questions with no right or wrong answers – something which I observed a great deal during the Model Group's completion of the activity.

Results and Discussion (cont.)

Observations of student attitudes during completion of activity:

- Students had large focus on obtaining and submitting the "correct" answers to the questions; they showed anxiety towards open-ended questions with no clear or concrete answers and were unsure of what to do when they did not immediately know the answer to said questions.
- Students were reluctant to begin discussions amongst themselves unprompted, especially for the open-ended questions; students seemed more comfortable collaborating on questions with clear instructions and an easily obtainable concrete answer (e.g. measurement data).
- Students were reluctant to raise their hands and ask questions, instead choosing to wait until I walked over to their group and directly asked if they were having difficulties or had questions.
- Could this be an aftereffect of online classes, with the loss of anonymity and "protection" while asking questions (e.g. Zoom chat, direct message with professor) raising anxiety levels for some students?

Positive feedback about the activity:

- Some participants enjoyed moving around and using their bodies during class time (2) and working collaboratively (2).
- Many participants noted that they enjoyed being able to physically interact with the models instead of only examining photographs or diagrams (6).
- Some students noted that while the activity did not make a difference for them in terms of interest or information retention (in comparison to a lecture), they still enjoyed it and thought it was "neat," "cool," and "fun" to look at the fossils.

Future Directions + Broader Impact

Using tooth and jawbone fossils allows discussions of important ideas within geology, such as evolution, deep time, and paleoclimate, to be incorporated into existing biology curricula as well as classes geared specifically towards Earth Systems science. By using the fossils to take key measurements, such as height and width of teeth, the activities enable students to practice important skills such as data collection, analysis of numerical values, plotting and interpreting data, and graphical literacy at age- and competency-appropriate levels, offering further incentive for integration into existing curricula. The activities are flexible: they can be physical and traditionally "hands-on" if the educator is holding in-person classes and has access to a 3D printer, or virtual if the educator is homeschooling, if classes are online, or if the educator does not have access to a 3D printer. All the materials, including the worksheets, supplemental information, and models will be free and open-source.

The author is extremely optimistic about the potential for 3D models to increase accessibility in the Earth Sciences and is currently searching for graduate programs in Geoscience or STEM Education under which to continue this research.

Additional "Behind-the-Scenes" Photographs

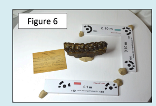
Figure 6

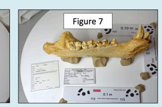
Figure 7

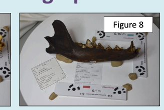
Figure 8

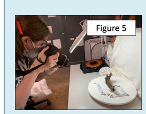
Figure 5

Fig. 5 (left): the author photographing the *Aenocyon dirus* jaw, seen again in Fig. 8, at the Raymond M. Alf Museum of Paleontology in Claremont, CA.
Fig. 6 (top left): the partial *Merychippus calamarius* jaw used for a model. Specimen from the Pomona College Geology Department.
Fig. 7 (top middle): the *Ursus spelaeus* jaw used for a model. Specimen from the Raymond M. Alf Museum.
Fig. 8 (top right): the *Aenocyon dirus* jaw used for a model. Specimen from the Raymond M. Alf Museum.
Fig. 9 (right): the unknown mustelid jaw used for a model. Specimen courtesy of Augustine Lodise and Win McLaughlin.

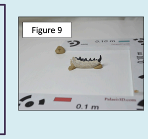

Figure 9

References (QR code) and Acknowledgements

This material is based upon prior work by Win McLaughlin. I am deeply grateful to the Pomona College Geology Department, who has supported me throughout my degree as well as in this thesis work. Additionally, I would like to thank Augustine Lodise for allowing me to use a model of his research specimen in my activity (see Fig. 9, above, and TAXONOMY AND PALEOECOLOGY OF A LATE MIOCENE LOCALITY NEAR WELLS, NEVADA; Lodise et al., 2022) and the Raymond M. Alf Museum of Paleontology for allowing me to use their collections space for photographing as well as two of their specimens for use in my project.