Playdough Modeling in Geological Fieldwork to Support Spatial Skills

Kathryn M. Bateman, Temple University, kathryn.bateman@temple.edu,
Jonathan Ham, Temple University, jonathan.ham@temple.edu,
Thomas F. Shipley, Temple University, tshipley@temple.edu
Basil Tikoff, University of Wisconsin, Madison, basil@geology.wisc.edu
Naomi Barshi, University of Wisconsin, Madison, barshi@wisc.edu
Carol Ormand, Carleton College, cormand@carleton.edu

Abstract: Fieldwork serves as a critical piece of novices' introduction to the geoscience community. Comprehending geological phenomena is challenging for novice geologists because successful fieldwork requires not only spatial thinking skills but translation from spatial patterns into time evolution of processes that created the features seen today. In this mixed-methods study, researchers participated in a three-day field trip to the Black Hills. Students and instructors used playdough to model three-dimensional structures encountered in the field. Survey data from students in the field supports the use of playdough as a tool for improving students' explanations of geological phenomena and their confidence in those answers. Instructor explanations were also seen as significant supports, indicating a tie between the use of the playdough models and how they were used by the instructors in the field.

Keywords: Discipline-based education research, geoscience education, fieldwork, spatial skills, modeling

Introduction and purpose

Teaching Earth sciences presents a unique challenge for instructors. Whereas school science often prioritizes traditional scientific methods based on lab data, the Earth sciences often use field observations as a basis for scientific interpretation. Earth sciences, like other field-based sciences such as ecology, draw on three-dimensional spatiotemporal reasoning to solve complex problems. Providing scaffolds to learning about three-dimensional concepts while in the field is the design focus for this discipline-based educational research case study.

Discipline-based education research (DBER) in geoscience field-based instruction is a growing field, with attention previously focused on field decision making and GPS navigation (NRC, 2012). Here we take a sociocultural perspective to examine how learning is happening in the field, with special attention to the ways in which students' spatial skill development is supported as they engage with their instructors and peers. While the development of spatial thinking skills is traditionally examined by cognitive scientists in laboratory settings, we situation our study in the field. We suggest that our findings will inform geoscience education and training that more closely support the skills required of professional geoscientists and more generally expand DBER research in fields where spatial reasoning is important.

In geoscience education, advocacy for technological skill building for all (Bellanca, 2010) has provided a push for geology to integrate technology-rich tools into geoscience teaching. Augmented reality sandboxes (Woods, Reed, Woods, & Woods, 2016), VR headsets (Klippel et al., 2019), and 3D printing (Carrera, Avrvarei, Chelariu, Draghia, & Avarvarei, 2016) show some promise in the literature for improving spatial skills or reducing cognitive load while using spatial thinking in geoscience but are costly and/or difficult to transport to the field. In contrast, playdough can provide more portable and adaptable three-dimensional models of geological phenomena in the field. It is accessible, cheap, reusable, easily transported, and a familiar tool for most students, regardless of their socioeconomic status. This line of reasoning brought playdough into our study design as a tool for improving spatial skills in the field.

Frameworks: Theoretical, conceptual, and methodological

This work draws on sociocultural approaches to learning, specifically drawing on work in learning sciences and cognition in geological fieldwork. Fieldwork is vital to the geosciences not just for data collection but also as a sociocultural process, allowing students access to the tools and cultural norms of geologists as they develop spatial skills (Goodwin, 1995). Fieldwork embedded in geoscience courses, therefore, provides opportunities for undergraduates to engage more fully in the community and practice of expert geologists.

Learning in the field can be grouped into three domains: embodiment, inscriptions, and initiation into the geological communities of practice (Mogk and Goodwin, 2012). We choose not to focus on the initiation into a community of practice; instead, we concentrate on the link between embodiment in the field and the inscription of observations. We use playdough as a means of embodiment, incorporating gesture, pointing, and manipulating the playdough to create an inscription of the geological phenomenon present in the fieldwork, which can be further inscribed by students through mapping and sketching, central to geoscience practice. Beyond helping inscription, three-dimensional models, such as playdough models, can help students to reduce spatial thinking demands (Newcombe, 2012). Hegarty (2011) found that students prefer to engage with more realistic models, even though such models are more cognitively demanding, emphasizing the importance of having instructors offer abstract models. By bringing models to the field, students can see a simplified model alongside the actual geological feature and contrast the two representations.

Spatial skills needed to engage in the geosciences include disembedding, visual penetration ability, mental animation, mental rotation, and perspective taking, among others (Kastens & Manduca, 2012). For this particular study, we examine the skills students would need to explain the geological phenomena present in this specific field area. *Disembedding* is the ability focus on important information in a complex setting. *Visual penetrative thinking* requires students to use visible surface structures to imagine the interior of an object, such as what the three-dimensional shape of faults is beneath the surface of an outcrop they see. *Mental animation* is engaging with the geological processes, both temporal and spatial changes, to recreate the invisible past based on the observable present. *Mental rotation* requires students to think about how an object would look if it were rotated into a new position. Similarly, *perspective taking* requires students to imagine how an object or feature would look from a different point of view, but, rather than mentally moving the object, they must imagine moving themselves to visualize the structure from a new perspective. To this set of skills, we added the skill of *visually connecting*, which requires linking together spatially separated rock structures by recognizing that rock layers used to be connected before erosion isolated them into separate outcrops. We added this skill after we observed this skill was critical to the disciplinary tasks in this particular field site. Furthermore, it is often overlooked as a vital thinking process in interpreting geologic structures and history.

When collating the information on fieldwork and spatial skills, we recognized the importance of understanding how different scaffolds commonly used in fieldwork support students' explanations of geological phenomena and draw on their use of spatial skills. Therefore, we ask the question, "how do educational scaffolds, particularly playdough models, impact students' understanding of three-dimensional geology in the field?"

This study uses both quantitative and qualitative methods to examine students' thinking about geological phenomena. In the creation of the study, we followed the principles of design-based research (specifically as outlined in Barab, 2014) so as to produce both student outcomes (improvement in spatial skills) and outputs (improvement in geological explanations) while contributing to the theory around spatial skills learning in the field. This data is part of a larger in-progress mixed methods study including quantitative analysis of survey data, qualitative coding of constructed responses, and participant observation of fieldwork in a mid-level undergraduate geoscience course. We present the findings from the quantitative analysis which investigated the correlations among the scaffolds, spatial skills, and student explanations of geological phenomena.

Data collection and analysis

Data for this study were collected during an undergraduate geology field trip which took place over three days in the Badlands and Black Hills of South Dakota. Two of the authors were instructors in the course, and the first author attended as a participant observer (Spradley, 2016). Prior to the field trip, the three attending authors designed a survey to be administered at the six stops during the field trip. Stops were selected for their challenging geological phenomena based on prior experiences of the instructors. For each stop, students (N=38) were asked an evaluative question about a geological phenomenon present and to rank their confidence in their explanation on a scale of one to seven. Next, students ranked how helpful five scaffolds (instructor's sketches, the instructor's explanation, teaching assistants' explanation, conversation with a peer, playdough model) were for understanding the geology of the stop on a scale of one to seven, and if they found playdough helpful, they were asked to explain how it helped them. As a participant observer, the first author recorded field notes about the field activity focusing on the interaction between instructors and students, particularly around the use of playdough. Geological phenomena and the corresponding playdough models and instructor sketches were photographed. Copies of all maps and other distributed information were collected. Samples of student field notebooks were photographed when sketches were made.

The analysis presented here focuses on the quantitative data collected through the student surveys. All student survey responses were assigned a score for their geological explanations (accuracy of explanation) and then the research team qualitatively coded students' written reflection at each stop, looking for references to specific spatial skills which were supported by the use if play dough. The first author open coded all survey responses to create an initial set of codes for the spatial skills that students reported the activity supported. These codes correlated closely with the spatial skills for geoscience outlined by Kastens & Manduca (2012), so the code book was created around these with additional codes emerging from student responses. The research team met to co-code the first ten data points for each variable. Interrater reliability from researchers' independent coding was initially 57%, however, in several instances this was due to multiple possible codes. After discussion and inclusion of multiple acceptable codes per data point, consensus agreement of 100% was reached. We also coded the use of playdough at each location into three categories of sites: process-relevant and structure-relevant playdough use and no playdough use. Process-relevant playdough use occurred when the instructors used the playdough to model a change over time, actively manipulating the playdough to demonstrate a process or change. Structure-relevant playdough use occurred when the instructors modeled the geometry of physical features of the landscape (such as layering, faults, intrusions) but did not actively manipulate the playdough into these structures for the students.

Using the qualitatively coded data, we conducted statistical tests to look for patterns in explanation accuracy by type of playdough use and correlations between survey items. First, we ran pairwise contrasts to see if accuracy was higher for field stops where instructors used playdough as an instructional tool than for the stops where playdough was not used. Within this test, we also examined whether students' accuracy of explanation was differentially affected by process-relevant playdough versus structure-relevant playdough use. After assessing the impact on accuracy of explanation, we used Pearson's r correlation matrices to examine correlations between the accuracy of explanation, confidence in explanation, students' perceived usefulness of scaffolds, and the spatial skills supported by playdough. All possible correlations between the items of the surveys at each field stop were run, with special attention given to potential relationships between accuracy of students' explanations of the geology at the stop, confidence in their answers, and the perceived efficacy of the playdough. Finally, we have examined the spatial skills articulated in the open-ended question on the survey (how did playdough help you understand the geometry of this area?).

Findings and implications

Using playdough in the field appears to support students' geological explanation accuracy and improve their confidence in those explanations. We found significantly higher accuracy of student explanations when structure-relevant playdough was used and when process-relevant playdough was used (Table 1) compared to those when playdough was not used (M = 0.32, N = 103). Within the group of stops where playdough was used, students' written explanations scored higher at stops where playdough was used to model a static structure compared to stops where playdough was used to model the kinematics of a geological process (Table 1). We hypothesize that the higher accuracy for questions asked about geometric aspects of the geology was due to the challenge of explaining process in geology, a task which requires relating current spatial patterns to spatiotemporal processes that produced the current structure starting from a different structure in the past.

Table 1: Comparisons of mean accuracy by playdough use

Pairwise Contrast	t	df	p	Cohen's d
Process and None	3.07	261	0.002	0.49
Structure and None	6.33	261	<0.0005	0.89
Structure and Process	2.49	261	0.013	0.4

Results of the Pearson's r test for all data showed significant correlations between student accuracy and confidence, instructor explanation and confidence, instructor explanation and playdough, and confidence and playdough (Table 2). We interpret these correlations to indicate a relationship between the two scaffolds (instructor explanation and playdough) and two outcomes (accuracy and confidence). We hypothesize that both the playdough and accompanying instructor's explanation are integral to the higher level of accuracy in explaining the geological phenomenon, and as such, students felt more confident in their explanations. We believe the link between playdough and instructor explanation exists because students did not engage with playdough models in isolation but as part of the field classroom community, which included the instructor providing information about the geology at the stops through building and/or manipulating the playdough models.

Table 2: Correlations from all field sites

	Confidence	Instructors' explanation	Playdough
Accuracy of explanation	0.156*	0.087	0.093
Confidence	-	0.454**	0.180*
Instructors' explanation	-	-	0.292**
** significant at p<0.005, * significant at p<0.05			

Spatial skills currently appear to be bolstered at all stops in the field trip where students indicated playdough was helpful, regardless of type of playdough modeling conducted (process-relevant or structure-relevant). We believe this supports the findings that playdough is helpful to students' understanding of geology. For example, one student stated, "The playdough helps me *visualize* what exactly is going on/what it [looks] like from *different views*," which indicated support of perspective taking. At one stop in which an intrusive igneous formation had pushed up layers of sedimentary rocks, a student noted that the playdough helped them see how this *process* occurred *through history*, indicating support of mental animation. Our added spatial skill, visually connecting, was also present across the field stops, with students indicating that the playdough "helped in seeing the *missing layers* and how they would have *connected*." These qualitative responses help us understand why playdough is an effective tool for improving understanding of geologic structures and processes in the field.

Bringing novices into the geological community of practice requires attention to the design of curriculum and instruction at all levels, from K-12 to professional training. A key tenet for joining this community as a full member is navigating the spatial reasoning required to understand the processes that created geological features in the field. We found that a simple, familiar 3D model material (playdough) can improve students' explanations of geological phenomena and offers a tool for K-12 teachers looking to improve students' spatial skills. Teachers can provide students at all levels with inexpensive, portable, malleable models to support their explanations of geological phenomena, especially when in the field, thus leveraging the time-limited opportunity to show students how to practice geology and gain critical spatial thinking skills.

References

Bellanca, J. A. (Ed.). (2010). *21st century skills: Rethinking how students learn*. Solution Tree Press.

Barab, S. (2014). Design-based research: A methodological toolkit for engineering change. In *The Cambridge Handbook of the Learning Sciences, Second Edition* (pp. 151-170). Cambridge University Press.

Carbonell Carrera, C., Avarvarei, B. V., Chelariu, E. L., Draghia, L., & Avarvarei, S. C. (2017). Map-reading skill development with 3D technologies. *Journal of Geography*, *116*(5), 197-205.

Goodwin, C. (1995). Seeing in depth. *Social studies of science*, *25*(2), 237-274.

Hegarty, M. (2011). The cognitive science of visual-spatial displays: Implications for design. *Topics in cognitive science*, *3*(3), 446-474.

Klippel, A., Zhao, J., Jackson, K. L., La Femina, P., Stubbs, C., Wetzel, R., Blair, J., Wullgrün, J.O., & Oprean, D. (2019). Transforming Earth Science Education Through Immersive Experiences: Delivering on a Long Held Promise. *Journal of Educational Computing Research*.

Manduca, C. A., & Kastens, K. A. (2012). Mapping the domain of spatial thinking in the geosciences. *Earth and mind II: A synthesis of research on thinking and learning in the geosciences. Geological Society of America Special Paper*, *486*, 45-49.

Mogk, D. W., & Goodwin, C. (2012). Learning in the field: Synthesis of research on thinking and learning in the geosciences. *Earth and mind II: A synthesis of research on thinking and learning in the geosciences. Geological Society of America Special Paper*, *486*(0), 131-163.

Newcombe, N. S. (2012). Two ways to help students with spatial thinking in geoscience. *Earth and mind II: A synthesis of research on thinking and learning in the geosciences. Geological Society of America Special Paper*, *486*, 85-86.

Smallman, H. S., & Cook, M. B. (2011). Naïve realism: Folk fallacies in the design and use of visual displays. *Topics in cognitive science*, *3*(3), 579-608.

Spradley, J. P. (2016). *Participant observation*. Waveland Press.

Wenger, E. (1998). *Communities of practice: Learning, meaning and identity.* Cambridge, UK: Cambridge University Press.

Woods, T. L., Reed, S., Hsi, S., Woods, J. A., & Woods, M. R. (2016). Pilot study using the augmented reality sandbox to teach topographic maps and surficial processes in introductory geology labs. *Journal of Geoscience Education*, *64*(3), 199-214.