Creating an Open Access *Laboratory Methods* Geoscience Textbook: Interdisciplinary Design-based Research

Juhong Christie Liu¹, liujc@jmu.edu
Elizabeth Johnson², Jin Mao³
¹JMU Libraries, James Madison University
²Department of Geology and Environmental Science, James Madison University
³School of Education, Wilkes University

**Abstract**

This design-based research (DBR) took an interdisciplinary approach to answering the question: *What are effective procedures to create low-cost, meaningful, and accessible textbooks for formal and informal learning of laboratory methods in geosciences?* Between August 2016 and May 2019, the researchers studied the design and development of inquiry-based open educational resources (OER) for analytical techniques embedded in geoscience courses using blended expertise from several disciplines. The DBR study identified a problem, context, and approach, conducted iterative analysis and design with formative evaluation, usability tests and peer review, and collected and analyzed artifacts and class observation notes. Narrative inquiry and document analysis were adopted to generate findings. The findings provide best practices and guidelines for creating effective and accessible media in a scientific lab environment and for collaboratively managing projects and data for media-rich instructional projects in STEM education.

*Keywords*: instructional design, open educational resources (OER), design-based research (DBR), accessibility
Introduction

Learning through laboratory methods classes with access to lab equipment and quality instructional materials has remained a core effective approach in science education for decades (Hofstein & Lunetta, 2004). However, the lack of appropriate instructional materials and resources, excessive costs, and limited access to research equipment present significant barriers to learning the theory and analytical skills that students must acquire to succeed in the geosciences and other science, technology, engineering, and mathematics (STEM) fields. Lack of in-class time, limited access to lab space and high-end equipment, and lack of engaging learning activities remain hurdles to prevent the improvement of quality of laboratory experience for undergraduate students (Hofstein & Lunetta, 2004; Wilson, et al., 2018), which may substantially reduce the probability of student involvement in inquiry-based research activities and pursuit of future careers in STEM fields.

As digital technologies become more ubiquitous and affordable, blending in-class formal learning with out-of-class informal learning through integration of rich interactive media in STEM education has been found effective (Braund & Reiss, 2006). A review of 20 years of laboratory-based science education and recent results from the Research Experiences for Undergraduates (REU) projects urged the discoveries of effective use and creation of media-based instructional materials with current technologies and meeting the needs of students with diverse abilities and learning styles (Hofstein & Lunetta, 2004; Wilson, et al., 2018). Research has also conceptualized and confirmed the effectiveness of technology-integrated STEM teaching and learning with Activity Theory from the perspectives of learning science and technology as scaffolding of human learning activities (Aalsvoort, 2004; Pea, 2004; Roth, Lee, & Hsu, 2009). This design-based research (DBR) took an Activity System perspective to answer the question:

*What are effective procedures to create low-cost, meaningful, and accessible textbooks for formal and informal learning of laboratory methods in geosciences?*

**Literature Review and Conceptual Framework**

Visuals and multimedia have been consistently identified as effective instructional materials in instructional design for science education (Clark, Mayer, & Thalheimer, 2003; Mayer, Bove, Bryman, Mars, & Tapangco, 1996). Effective learning in STEM happens when authentic inquiry and appropriate scaffolding are provided by the context (Bulte, Westbroek, de Jong, & Pilot, 2006; Isssroff & Scanlon, 2002). These inquiries can be presented and assessed with an intentionally designed media-infused environment. From an instructional design perspective, a learning environment is identified as an Activity System (Jonassen & Rohrer-Murphy, 1999; Liu, 2018).

Designing a learning environment considers eight core components in an Activity System: subject, rules, community, division of labor, tools and signs, mediated artifacts, object, and outcome (Engeström, 2001 Jonassen & Rohrer-Murphy, 1999; Liu, 2018) (Figure 1). Subject concerns instructors and students; rules relate to expectations, regulations, and guidelines such as guidebooks for laboratory safety; community relates the contexts, with lab settings as specific context and social-cultural settings as general context; division of labor defines the roles of...
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teacher, student, teaching assistant, lab manager, etc.; tools and signs include the equipment and facility in a lab for scientific inquiries. Object includes student lab reports, research projects, and documentation of field trips if external labs or natural settings like mountains are used. Outcome includes the measures or standards of learning performance. Mediated artifacts are the visuals and interactive media conveying instructional meanings. As illustrated in Figure 1 and a review of the literature about instructional design for science teaching and learning, creating effective mediated artifacts is inseparable from the entire system. Activity Theory has been proposed and proved of its principle foundation in optimizing the impact of educational technology in scaffolding human learning activities (Isssroff & Scanlon, 2002; Pea, 2004). Aalsvoort’s (2004) study confirmed the effectiveness of science education in a general societal context using the Activity Theory framework. Research in science education (Bulte, Westbroek, de Jong, & Pilot, 2006; Gilbert, 2006) supports the impact of social-cultural context for science education.

The design and development of technology-integrated instructional materials for this study included experts in geoscience, learning science, and instructional design, as well as media arts students and geoscience students. These groups interacted with content and technologies, collaborated on project management and content presentation, and investigated learning strategies and assessment measures. All interactions took place within and across a variety of activity systems. Figure 1 presents the conceptual framework that sets the overarching guide for this complex project.

Figure 1. Structure of an Activity System (Engeström, 2001, p. 135)

Methods and Context of Research

A DBR strategy was adopted because it was suited to solving a practical educational problem to create effective, low-cost, and inquiry-based OER for Laboratory Methods Geoscience classes. This research study has been iteratively performed through the following major phases: 1) specifying the research problem; 2) obtaining the necessary information to solve the problem(s); 3) analyzing and interpreting the information that has been gathered; and 4)
developing a solution (McKenney & Reeves, 2019). These phases were initially implemented iteratively between August 2016 and May 2019. The research was conducted in the undergraduate-only geosciences department in a comprehensive university on the east coast of the United States. An Institutional Review Board (IRB) protocol was requested and approved at the beginning of the project.

Prior to using the newly created OER content, students had to purchase costly textbooks to prepare for the classes with only static text and images. The instructor split the class into multiple small groups and taught the complete techniques to each group separately. This resulted in limited time for student use of equipment, and instructor time was allocated towards lecturing and demonstration, rather than aiding students in using the equipment. This needs analysis and a previous study identified improved learning for students when media-based exercises were conducted as informal activities outside formal class time (Liu, St. John, & Courtier, 2017). These included viewing online videos, images, and animations, introduction of unit objectives, and reflection with leading inquiry questions prior to classes.

The current project was intended to design and create inquiry-based OER content allowing students more time for self-reflected learning moments, even without access to lab equipment, resulting in cognitive preparation for face-to-face scientific inquiry sessions. The project generated multiple layers of data sources including documentation of design process, development of instructional material, and documentation of changes in student learning experience. The process of digital data accumulation inspired intentional exploration of data management of design and development process and files. In the process, we adopted a suite of instruments to document learning experience, conduct usability tests, and perform science classroom observations (Koretsky, Petcovic, & Rowbotham, 2012; Reeves, Benson, Elliott, et al 2002; Stearns, Morgan, Capraro, & Capraro, 2012).

Data Collection

Throughout the project, the interdisciplinary team used the research question to guide the design and creation of OER as mediated artefacts. The design followed the needs and context analysis to allow novice students to operate equipment (tools), comply with important safety considerations (signs and rules) as well as avoid possibility of damaging expensive equipment in a scientific lab environment (community).

Data included design documents in Word, Google Sheets, diagrams, usability test results, observation notes, more than 500 images and 200 video footage clips. Mediated artefacts and instruction were created for OER modules including the scanning electron microscope (SEM), thin-section equipment, Fourier-transform infrared spectrometer, and Raman spectrometer. Screenshots were also captured to document the best practices along the process. Thirty-six audio clips were recorded to apply voice-over to the images or video after careful selections. Text files were generated when transcribing videos with audio narration to facilitate accessibility with closed captions (Johnson, Liu, Mao, & Kansal, 2018). Text files were also generated in Microsoft Word and Excel and Google Sheets as outlines, learning activities, and assessment questions. File management and project management was explored through multiple technologies and online services. Team meeting notes also served as narrative data.
Usability tests adapted from Reeves, Benson, Elliott, et al (2002) were deployed with a web-based survey platform. One primary researcher (not the course instructor), explained consent information and announced the survey link at class to ensure research integrity. Random codes were assigned to participating students allowing learning artifacts to be tracked anonymously and compared for later analysis. A usability test was also conducted through a community-based peer review at the December 2018 American Geophysical Union (AGU) workshop with participants who were faculty, researchers, or doctoral candidates in geoscience fields (Liu & Johnson, 2018).

Analysis

Narrative inquiry and document analysis were used to analyze the data (Bowen, 2009; Clandinin, 2006). As a story-telling approach, narrative inquiry was adopted to analyze the data chronologically and extract meaning from the images, videos, and narrative data. The researchers iteratively reviewed the tools, signs, mediated artefacts, and noted meaningful moments of design and development. These moments were articulated at bi-weekly team meetings either in-person or online. Story sharing helped the researchers detect what worked and what did not work in an informal but engaging way. The community component in the Activity System played an important role in the narrative inquiry process. The data analysis always took on collaborative interpretation between the subject matter expert and primary researchers. The document analysis served two purposes: 1) finding themes of best practice in terms of procedures and usage of equipment and settings through reviewing and comparing the mediated artefacts; 2) selecting optimal tools and rules to develop mediated artefacts for further instructional design.

Results

**Tools and rules for media creation**

Light and space are primary natural conditions for creating quality media products (Cartwright, 2012). Laboratories can have limited light sources and small awkward spaces with little room for taking pictures or filming, but it is necessary to capture close-up scenes on equipment or computer monitors while maintaining safety.

The DBR included a careful study of lab blueprints and walkthroughs to appraise the lighting and furniture layout. These aided setup of a tripod and lighting kit which were fundamental to produce stable and well-lit images or video. The observation and analysis of wall materials were also conducted to estimate the audio quality. After screening the environment, the team configured the right position of light sources and microphone choices for optimal production. They also iteratively experimented and documented the adjustment of white balance of cameras, angle, stability, and distance of raw footage capture, selection and availability of high-end or mobile cameras, and length of video clips.

The leverage between the constraints and the needs led to the findings about tools and rules in media content development. The media arts student on the team experimented with a variety of cameras, including those on smartphones of iOS and Android, digital camcorder, and DSLR, and rearranged the light sources in the lab, as shown in Figure 2. Without sufficient
natural light, a photo video studio soft lighting kit with umbrella reflectors, after its position adjustment in the space, was found to provide quality lighting. For close-up shots on tables, the use and adjustment of soft table lamp helped light quality as well. Smartphone cameras worked well to capture images or videos from a wide angle and in a well-lit and comparatively quiet environment. To capture high-resolution close-ups, we found that the manual settings on a DSLR camera worked more effectively, after a careful adjustment of white balance and image stabilization of the tripod and photographer/videographer (Johnson, Liu, Mao, & Kansal, 2018).

Figure 2. Lab settings with lighting and camera kits arrangement

**Tools and rules for project and data management**

To document the project, the team worked to maintain scheduling and organize record-keeping for multiple individuals across different departments. Media development required ample storage space, version tracking, and directory management. We experimented with and evaluated several tools for low cost, efficiency, and privacy. Platforms tested and used included Google Drive, Docs, Slides, and Spreadsheets, Dropbox, FreedCamp, Dataverse, and Open Science Framework (OSF). After one year of exploration, the institutional membership with OSF provided a solution for secured project and data management. OSF kept the version tracking, time, and digital object identifier (DOI) for the data uploaded in the platform and allowed customized visibility/privacy control of files. The project team developed a customized protocol for the project directory and subfolders with detailed documentation.

**Creating accessible video with scientific closed captioning**

With its built-in voice recognition technologies, YouTube applies automatic closed captioning to uploaded and published video. However, YouTube auto-captioning often misinterprets technical vocabulary within scientific videos. After the first cycle of production,
the researchers developed a procedure to apply accurate closed captioning to videos on the project channel, Analytical Methods in Geosciences (AmiGEO):

- Allow YouTube to create auto-captioning;
- Publish the edited video to YouTube as unlisted;
- Edit the scripts of the automatic transcription within YouTube Video Manager to retain its time stamps;
- Download the edited .srt file and edit the scientific terminology and grammar in a plain text editor, for instance, TextEdit for Mac and Notepad for Windows;
- Upload the revised .srt file;
- Delete the automatic version to avoid confusion to audience and make the video public;
- Adjust Creative Commons license attributes and other settings.

Usability and feedback from community

The usability feedback was iteratively collected with an online questionnaire and peer reviews from faculty members, researchers, doctoral candidates, and undergraduate students in geoscience fields. Twenty-three undergraduate students and 17 faculty provided feedback, in the contexts of geoscience classes in the university where the project was development and at the 2018 American Geophysical Union conference. Presented in Table 1 are qualitative feedback samples about what worked well and suggestions.

Table 1. Usability feedback

<table>
<thead>
<tr>
<th>What Worked Well</th>
<th>Suggestions</th>
</tr>
</thead>
<tbody>
<tr>
<td>• “The GEO thin section clips are quite clear to understand and show step wise</td>
<td>• “ones that contain a lot of links rather than embedded material can be</td>
</tr>
<tr>
<td>process for each activity. Once they are complete, we will have a curriculum</td>
<td>distracting and I think would dissuade usage”</td>
</tr>
<tr>
<td>of topics with corresponding videos.”</td>
<td>• “I think there may need to be a few more links to background information</td>
</tr>
<tr>
<td>• “The videos listed in the program are informative and highly facilitate the</td>
<td>on the physics—not a lot, but enough to provide an understanding of the units</td>
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<tr>
<td>learning of the new content”</td>
<td>used in the Raman spectroscopy charts.”</td>
</tr>
<tr>
<td>• “The main page is quite well laid out, and some modules are extremely well</td>
<td>• “I think many of the pages contain a lot of references and links that</td>
</tr>
<tr>
<td>laid out”</td>
<td>although I understand why they would have to be there, it is distracting as</td>
</tr>
<tr>
<td>• “The slides/videos show all the steps of the process, and are beneficial to</td>
<td>a learner.”</td>
</tr>
<tr>
<td>all level of users.”</td>
<td>• “Better to have an instructor or mentor available to help guide the student</td>
</tr>
<tr>
<td>• “I think the guiding questions and check ins were well thought out and useful.”</td>
<td>and assist with the assessment process.”</td>
</tr>
<tr>
<td>• “The content is organized in a way that allows the student to assess his/her</td>
<td>• “I felt the videos mulled over some of the operation of the instruments</td>
</tr>
<tr>
<td>own progress clearly.”</td>
<td>for too long in some cases”</td>
</tr>
<tr>
<td>• Sometimes, I felt the videos were perfectly paced, especially if the</td>
<td>• “I think that more formatting, questions, background readings, etc., would</td>
</tr>
<tr>
<td>instrument’s use needed longer to explain.”</td>
<td>help to keep the reader engaged and flowing through the material.”</td>
</tr>
<tr>
<td>• “The videos deal directly with what we’re doing.”</td>
<td>• “It’s helpful to be able to stop and re-watch, but frustrating not to be</td>
</tr>
<tr>
<td>• “some additional resources may helpful for more difficult topics”</td>
<td>able to ask questions.”</td>
</tr>
<tr>
<td>• “The Canvas site is very clearly laid out and easy to use.”</td>
<td>• “It also may be useful to apply some additional features to track progress”</td>
</tr>
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</table>
Conclusion and Discussion

The open-access content generated from this project provides a scaffold for face-to-face laboratory experiences in geoscience courses. Online informal learning can be designed to support and transfer in-class formal learning through using inquiry-based interactive media so that formal class time can be reserved for students to operate the instruments and ask questions. Availability and repeatability of these materials, especially for costly, delicate, or potentially hazardous instrumentation, may further student interest in the field with maximum access and flexibility.

The iterative analysis of documents and narrative inquiries of the instructional design and development have resulted in best practices and guidelines for video, image, and animation production in a scientific lab environment, for collaboratively managing projects and data for media-rich instructional design projects, and for creating accessible video content for science instruction. These reflect the rules of the design in an Activity System. Using the Activity System has also effectively and holistically organized multiple individuals’ work, complicated tasks, and evolving timelines in a multi-year instructional design project.

Based on Activity Theory, the team investigated instructional design with the contextual references to tools and signs, mediated artifacts, rules, community, and subject. Findings have suggested the needs of cross-system interactivity for OER content hosting and publishing, such as matching instructional materials written by the content expert with the formatting capabilities of the publishing platform to link, embed, or add aesthetic features. The review feedback also revealed the possibility of OER integration in various levels of geoscience curriculum.

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