

Experiential Learning in an Online Science Methods Course

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Abstract

Although demand for online courses and degree programs is high, trends in online instruction point to lecture- and discussion-heavy courses as well as a general wariness towards online science education. This article outlines the challenges of online teaching and describes a pedagogical model for e-learning that leverages multimedia to support experiential learning in science teacher education. End-of-course evaluations are used as data sources to inform reflections and conclusions about the affordances of the model. Examples of how the model is being used in an online science methods course are provided.

Introduction

A growing number of institutions of higher education are offering part, or all, of their degree programs online. Allen and Seaman (2016) reported that in fall 2014, more than 5.8 million students were enrolled in at least one online course, including over 2.85 million taking all their courses online (p. 43). Most of these students attend public institutions (73% undergraduate and 39% graduate; pp. 17–18). However, many of the faculty members teaching online courses tend to adopt traditional approaches to teaching that manifest in a reading-, lecture-, and discussion-heavy course rather than one in which students actively create their learning experiences (Lane, 2013). The National Science Teaching Association (NSTA, 2017)

recommends that all science teacher preparation programs have a curriculum that includes substantive experiences that will enable prospective teachers to . . . engage in meaningful laboratory and simulation activities using contemporary technology tools and experience other science teaching strategies with faculty who model effective teaching practices. (p. 1)

At the center of NSTA's recommendation is the need for teachers and teacher candidates to experience science learning and teaching, a need that seemingly conflicts with the ways in which online learning typically occurs. Miller (2008) describes six myths about inquiry-based online science education.

1. "Good on campus face to face instructors make good instructors online" (p. 81).
2. "Online delivery is similar to correspondence coursework and limited to content learning" (p. 82).

3. “You cannot model constructivist inquiry teaching strategies online” (p. 83).
4. “Interaction among peers is weak in online delivery formats” (p. 84).
5. “Online delivery does not allow students to take theory into practice” (p. 84).
6. “In order to succeed as a teacher, students studying to be teachers must be able to watch the instructor model an appropriate lesson” (p. 84).

Subscribing to these myths, the instructor (first author) was skeptical about the ability of online science methods courses to actively engage teachers and future teachers in experiential learning opportunities. Lacking a vision and experience with online teaching in general and online science teaching in particular, the instructor created online science methods courses requiring students to mostly read, watch, listen, and write. Since then, the instructor has engaged in continuous improvement efforts and explored evidence-based practices for effective online teaching. As a result, students’ experiences and learning outcomes improved over time (see Table 1). In an effort to counter Miller’s (2008) myths and support other science educators who are beginning their online teaching career, this article describes an experiential model for e-pedagogy that is aligned with the National Research Council’s *Framework for K-12 Science Education* (NRC, 2012) and embodies NSTA’s (2017) recommendations for teacher education and professional development. The article provides examples of how the instructor leveraged the model in an online science methods course to transform the virtual learning space and reframe her thinking about what a good online learning experience for science educators looks like. As a result, she created a learning environment that was more meaningfully organized and provided students with authentic opportunities to engage in course content and reflect on their developing practice.

Table 1

Mean Evaluation Scores for the Online Science Methods Course by Academic Year

Academic year	Model used	Enrollment	Global <u>index</u> ^c
1	None	37	2.96
2	R2D2 ^a	48	3.92
3	R2D2 ^a	44	4.09
4	R2C2 ^b	36	4.17
5	R2C2 ^b	39	4.33

^a R2D2 model: read, reflect, display, and do (Bonk & Zhang, 2006). ^b R2C2 model: reflect, review, communicate, and conduct. ^c Global index (1 = low and 5 = high) represents the mean score of student responses on the Class Climate Survey.

Context

Like many colleges across the nation, our large Midwestern university's College of Education has embraced virtual courses and online programs, offering general and specialized programs at the graduate level. The fourth- and fifth-grade endorsement is a completely online summer program that allows licensed early elementary teachers (up to third grade) to work with students at the fourth- and fifth-grade levels. The 2-credit-hour online science methods course is one of four courses required for the endorsement. It is offered asynchronously over a 7-week period and taught a science educator (first author) at the university who teaches science methods in the early childhood, middle childhood, and secondary education programs. Course enrollments ranged between 25 and 50 students. Course outcomes focus on advancing teachers' knowledge, skills, and dispositions to teach fourth and fifth grade science as prescribed by the Ohio's Learning Standards for science (Ohio Department of Education, 2018). Specific outcomes include:

1. Use fourth- and fifth-grade science content, inquiry practices, and an understanding of the nature of science to create safe and technology-rich learning environments aligned with state and national standards;
2. Develop lessons and activities that are responsive to the cognitive, personal, socio-emotional, and cultural needs of all fourth- and fifth-grade students;
3. Design and evaluate a variety of assessment formats and techniques to identify and evaluate science ideas, monitor student learning, and inform data-based instructional decision-making;
4. Develop and use a repertoire of science teaching strategies; and
5. Use reflective skills to monitor their learning and situate it within current understanding in the field of science education.

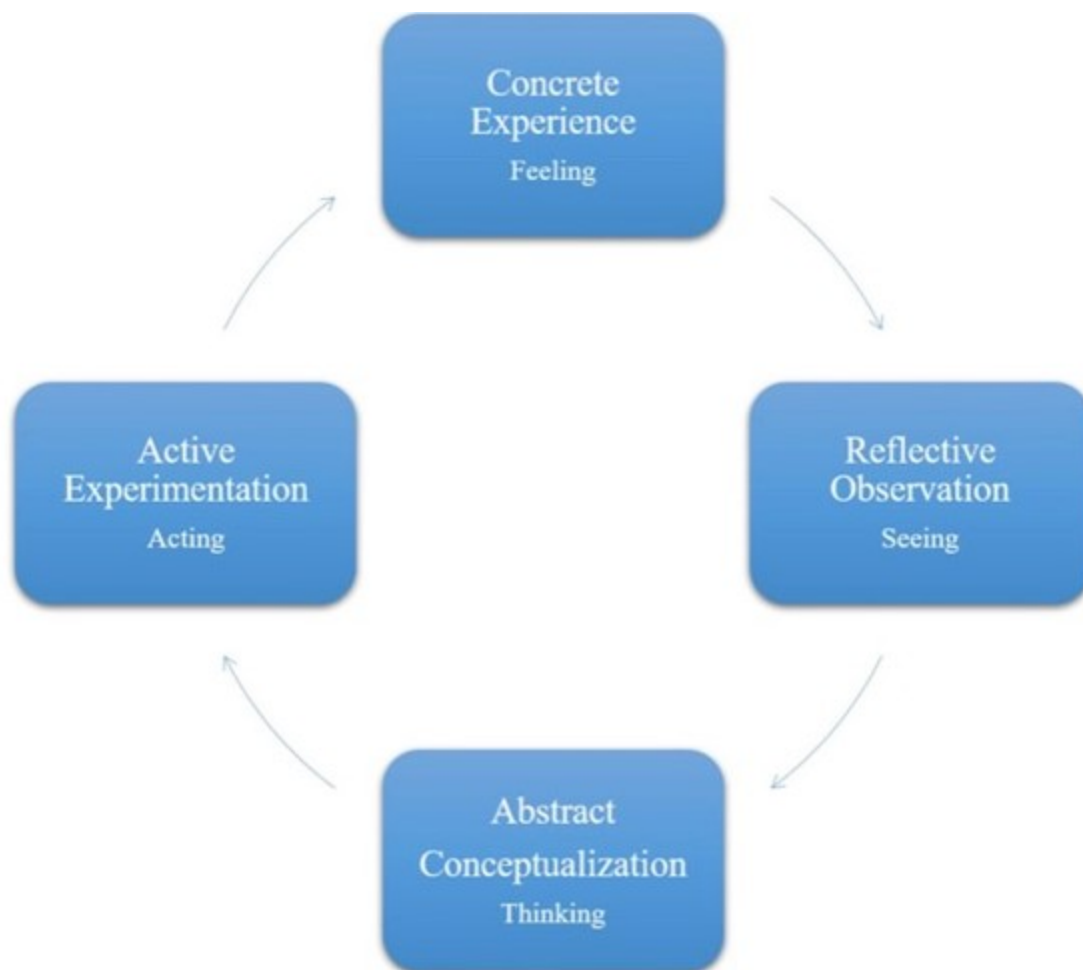
In early iterations of the course, instruction consisted of selecting readings, recording demonstrations and lectures, developing and evaluating assignments, and providing feedback to individuals and groups. Course assignments provided opportunities for teachers to synthesize course content through the development of lessons and units. Discussions, an integral component of the course, required teachers to make at least three contributions in response to the instructor's prompt and their peers' contributions. However, these contributions were more like individual papers that shared teachers' finalized positions about topics, interactions between peers consisted of agreement and praise, and discussions lacked the dialogic component that characterizes meaningful and productive learning. These course characteristics and weekly writing expectations made the workload overwhelming for the instructor and the teachers. Furthermore, the course did not provide opportunities to rehearse and enact science teaching principles in authentic and experiential ways.

Experiential Learning and the R2D2 Model

According to Kolb's (1984) theory of experiential learning, learning occurs when "knowledge is created through the transformation of experience" (p. 38). The process of transformation is represented as a learning cycle that consists of "concrete experience," "reflective observation," "abstract conceptualization," and "active experimentation" (p. 30; see Figure 1). *Concrete experiences* occur when learners encounter a new experience or situation or reinterpret an existing experience. *Reflective observations* occur when learners review their experience and identify consistencies or inconsistencies between understanding and experience. *Abstract conceptualization* occurs as learners formulate new ideas and generalizations or reorganize existing ideas. In the last stage of Kolb's experiential learning cycle, *active experimentation*, learners actively test new ideas by applying them in authentic contexts. This phase leads to new experiences that can begin a new learning cycle.

Figure 1

Kolb's Learning Cycle for the Transformation of Experience



Using Kolb's (1984) theory of experiential learning, Bonk and Zhang (2006, 2008) proposed a new model: "The R2D2 method—read, reflect, display, and do—is a new model for designing and delivering . . . online learning" (p. 249). Bonk and Zhang explain the R2D2 model and its applications and describe the tasks, resources, and activities that instructors

can use to design and facilitate online learning. The model supports a shift in online instructors' practice from text-centered and lecture-based teaching toward incorporating activities that utilize active learning, problem-solving, virtual collaboration, and multimedia. The four phases of the R2D2 model integrate learning activities that are aligned with each of the four phases of Kolb's experiential learning cycle: "reading/listening," "reflecting/writing," "displaying," and "doing" (Bonk & Zhang, 2006, p. 251).

The first R2D2 phase, *read*, "focuses on knowledge acquisition" and involves students in reading, viewing, and listening to spoken or written explanations (Bonk & Zhang, 2006, p. 255). The second phase, *reflect*, provides learners opportunities to observe, view, watch, self-test, and think deeply about their developing ideas from the read phase. Phase three, *display*, focuses on how learners can demonstrate their developing understanding by creating and interpreting visual representations of target content. Technology resources and tools that support this phase include concept maps, advance organizers, pictures, diagrams, simulations, virtual tours, and videos. In the fourth and final phase of the R2D2 model, *do*, learners apply the knowledge they learned in real and virtual contexts. According to Bonk and Zhang (2006), this phase is concerned with action and presents instructors with the opportunity to evaluate learning. In terms of technology tools and resources, they propose the use of case studies, wikis, simulations, and games and collecting real-world data.

R2C2: Adapting the R2D2 Model for Science Teacher Education

Although the R2D2 model provided a strong foundation for online teaching, the instructor found that it had too strong a focus on the types of digital technologies recommended for each phase (some of which may be outdated) (Bonk & Zhang, 2008). Kirkwood (2014) recommends selecting specific tools and technologies that will allow learners to achieve necessary learning outcomes and enable desired forms of participation rather than attempting to incorporate a multitude of elements to represent the variety of tools and technologies available. Because of the variability of learning management systems, technological abilities, and the ebb and flow of fads in the world of digital technologies, we chose multimedia as the anchoring experiential digital technology for the adapted R2D2 model. Multimedia provide online learners with multisensory experiences (Krippel et al., 2010) and represent computer-based tools and products (e.g., text, graphics, sound, animation, and video) that facilitate the creation, manipulation, and exchange of information (Mayer, 2009). Recent research suggests that the use of multimedia in online courses promotes achievement and improves motivation (Krippel et al., 2010; Mayer, 2009; Reed, 2003). Mayer (2009) asserts that it is the content of multimedia and the way it is used for instruction that engenders positive effects not its presence or absence.

More importantly, the R2D2 model did not address how to sequence instruction and promote the development of students' knowledge, skills, and dispositions (Bonk & Zhang, 2006, 2008). Each phase was designed to be responsive to various types of learners, learning

styles, and learning preferences (Bonk & Zhang, 2006). For example, the read phase caters mostly to auditory and verbal learners, the reflect phase to reflective and observational learners, the display phase to visual learners, and the do phase to hands-on learners. This reliance on types of learners, learning styles, and learning preferences to justify the selection of activities was not pedagogically fruitful. Even though learning style theories are popular, they are not empirically supported (Cuevas, 2015; Willingham et al., 2015).

Teaching the online science methods course several times using Bonk and Zhang's (2006) R2D2 model allowed the instructor to consider these matters and make iterative improvements. She considered the roles that the instructor and social interactions have in supporting engagement as well as the centrality of reflection to the experiential learning process. The adapted R2C2 model consists of phases similar to the original—*reflect*, *review*, *communicate*, and *conduct*—but places reflection at the center of the experiential learning process because it occurs during each phase, not as a standalone exercise (see Figure 2). The cyclical and overlapping nature of the model better represents its affordance for providing learners diverse opportunities to engage with the same content to varying depths. Although teachers are encouraged to start with review-phase activities and then proceed with activities from the other phases, completing reflect- and review-phase activities before starting other phases is not required. In many cases, teachers must engage in activities from all phases simultaneously. The following four sections provide an overview of each phase of the adapted R2C2 model and include sample activities from the online science methods course that illustrate phase applications (see Table 2). Course activities, whether classic or innovative, use principles and multimedia that support best practices in science education according to the *Framework for K-12 Science Education* (NRC, 2012) and NSTA (2017). Work samples illustrate the successes and challenges teachers experienced as they met course objectives.

Figure 2

The Reflect, Review, Communicate, and Conduct (R2C2) Model for Online Science Teacher Education



R2C2 model and sample activities in the online science methods course

Phase	Purpose	Learning activities & multimedia	Course examples
Reflect	Critical analysis, evaluation, and synthesis of knowledge, skills, and dispositions.	Engage in self-analysis paper; Develop science teaching philosophies; Engage in discussions and peer evaluations.	Integrated within each of the phases of the model (e.g., Guiding Questions, Draw a Scientist Task and Strategy Affordances)
Review	Active construction of knowledge through review of new information.	Review articles, books or book chapters, videos, podcasts, and other information rich sources.	Use of a variety of resources (e.g., NGSS Lead States 2013b; Zemba-Saul et al., 2010)
Communicate	Sharing developing ideas and abilities.	Develop digital stories, concept maps, diagrams, and other graphic organizers.	Use of Visuals (e.g., Draw a Scientist Task and Science Topic Concept Map).
Conduct	Participation in authentic activities and investigations.	Create reports, movies, case studies, portfolios, slideshows, and other projects that document and showcase experience.	Using simulations, rehearsals, manipulatives, and hands-on projects (e.g., Science Investigation and Teaching Strategy Video)

Reflect Phase

We chose to start the R2C2 model with a discussion of the reflect phase because we believe that reflection is most effective when it is tied to all experiential learning activities (see Table 2). Similar to Bonk and Zhang's (2006) model, this phase focuses on the critical analysis of

personal beliefs and experiences while reading and reviewing resources. In addition, it engages learners in evaluating their developing knowledge, skills, and dispositions using the evidence gained in other phases. Reflection can occur through peer evaluation activities, synchronous and asynchronous discussions, self-analysis papers, and teaching philosophies. Because of the centrality of reflection to the learning process, we integrated reflection into the activities of each of the other phases, which is described in subsequent sections. For example, the Strategy Affordances activity is tied to the Teaching Strategy Video activity in the conduct phase. In the Teaching Strategy Video activity, teachers are asked to view peers' videos and participate in a reflective discussion about the ways in which each teaching strategy supports three-dimensional science learning, anticipated difficulties and possible solutions, and key considerations for implementation. Overall, reflect-phase activities must help teachers identify alternative viewpoints and develop arguments to support the practical theories that will guide their teaching practice. Reflection begins with review-phase activities.

Review Phase

In the review phase, teachers actively construct knowledge by exploring content and acquiring new information presented through text and multimedia. Several technological resources and tools can be used to support learners in the review phase, including online scavenger hunts, podcasts, webinars, lectures, virtual conferences, and readings (Bonk & Zhang, 2006, 2008). Rather than selecting review-phase resources based on the variety of technologies recommended by Bonk and Zhang (2008), our model advocates the purposeful selection of resources to allow teachers to consider course content from multiple perspectives.

In the online science methods course, the instructor identified, curated, and developed a variety of readings, video-streamed lectures, slideshow presentations, and other multimedia related to the module content. Examples include orientation videos to the *Next Generation Science Standards* (NGSS; NGSS Lead States, 2013a) and a discussion of “constructing explanations from evidence” (Zemba-Saul et al., 2015). The instructor developed other videos using a video streaming platform that allows instructors to create screencasts of lectures and demonstrations. In these 15–20 minute videos, the instructor presented and discussed module content, highlighted different features of readings, provided examples, and clarified activities. Review-phase resources also consisted of articles and book chapters selected from professional journals, magazines, and publications such as NSTA's *Science and Children* and *Science Scope* (e.g., Dolan & Zeidler, 2009; German, 2017; Katsh-Singer, 2011; NGSS Lead States, 2013b; Tugel & Porter, 2010). Guiding questions were used to support teachers' reflection as they reviewed review-phase resources (see Table 3). In most cases, the reflective questions formed the basis for communicate-phase activities.

Communicate Phase

Building on Bonk and Zhang's (2006) display phase, the communicate phase focuses on how learners share their developing understanding by creating and interpreting visual representations of target content. Teachers individually or collaboratively create multimedia displays that convey their ideas and abilities and disseminate them to their peers. They develop concept maps, diagrams, digital stories, and other types of graphic organizers to tell about the principles of practice (science pedagogical content) and instructional materials that they will use in their classrooms. The Draw a Scientist Task (DAST), adapted from Chambers's (1983) draw a scientist test, is an example of a communicate-phase activity from the course. Individually, teachers attached a drawing that represented their perception of a scientist and what they do to their introductory discussion post to their group members. Group members compared their DAST products and summarized the similarities and differences among their perceptions (see Figure 3). Groups then analyzed instructor-created collages of DAST products to determine general, class-wide perceptions (see Figure 4). For the last element of this activity, teachers discussed their findings using concepts from review-phase resources, reflected on the difference between small-group and whole-class findings, and identified principles to guide their science teaching practice.

Figure 3

Draw a Scientist Task (DAST) Graphic Organizer

Compare your drawing and explanations with those of your group members

Using the following chart to calculate and report the frequency of different features of scientists that are apparent in your group.

[illegible]

Figure 4
Example DAST Drawings



In another communicate-phase activity from the course, teachers closely examined the science content that is the focus of the fourth- and fifth-grade standards. They reviewed the standards that focus on their topic, noted how the topic is developed from grade to grade (K–8), and used open-source science textbooks (e.g., CK-12 at <https://ck12.org/>) to identify key concepts and their definitions. Using principles described by Novak and Cañas (2008), teachers developed a concept map to use with elementary students. They used paper and pencil, word processing applications, or free web-based concept mapping applications to develop their maps. Figures 5–9 share sample concept maps developed for a fourth-grade earth and space science topic, fifth-grade life science topic, fifth-grade earth and space

science topic, fifth-grade life science, and fifth-grade physical science topic, respectively. This communicate-phase activity allowed teachers to reflect on their developing content knowledge as they determined how to best represent the relationships between concepts and examples in their maps.

Figure 5
Example Fourth Grade Earth and Space Science Topic Concept Map

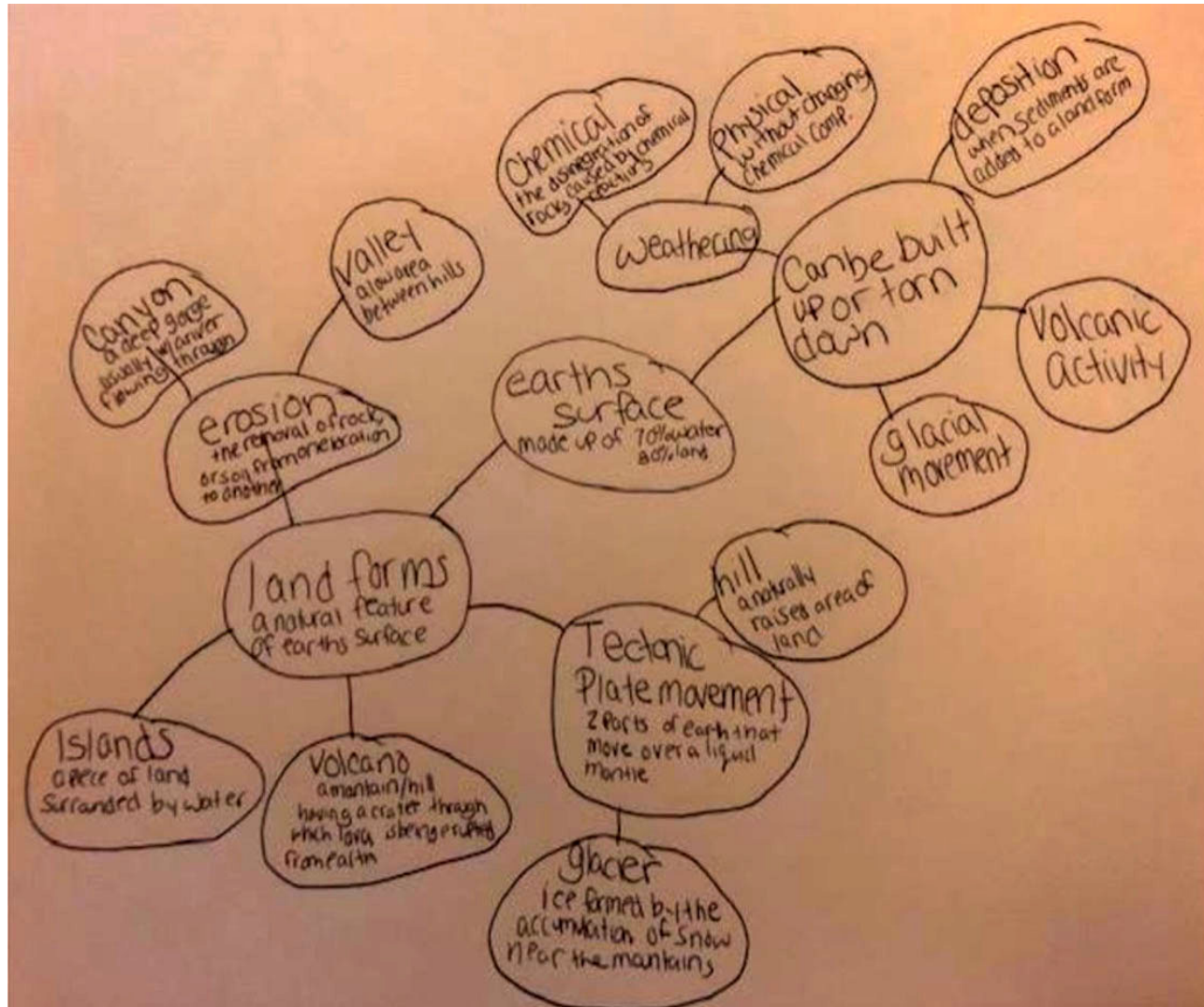


Figure 6
Example Fourth Grade Life Science Concept Map

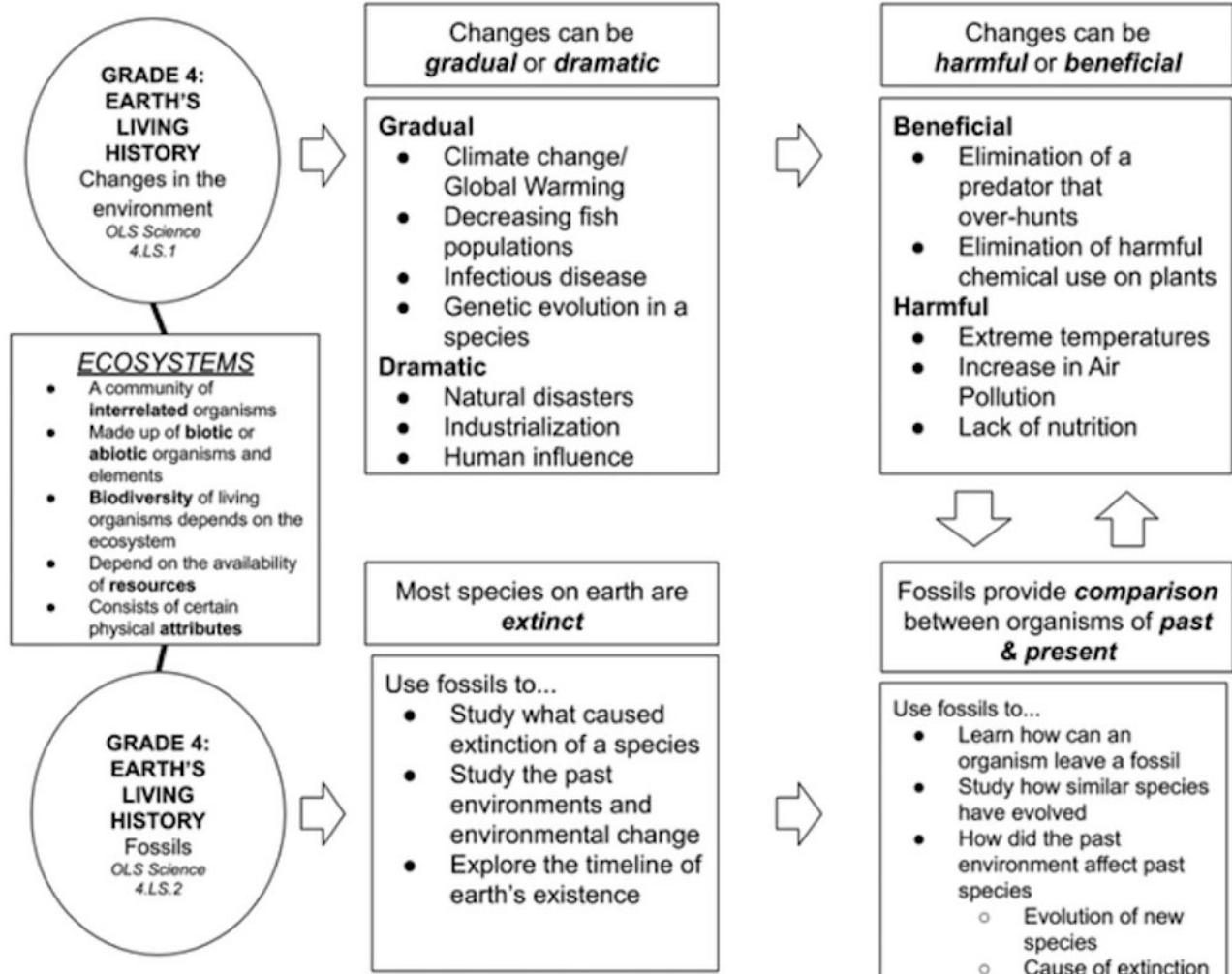


Figure 7
Example Fifth Grade Earth and Space Science Concept Map

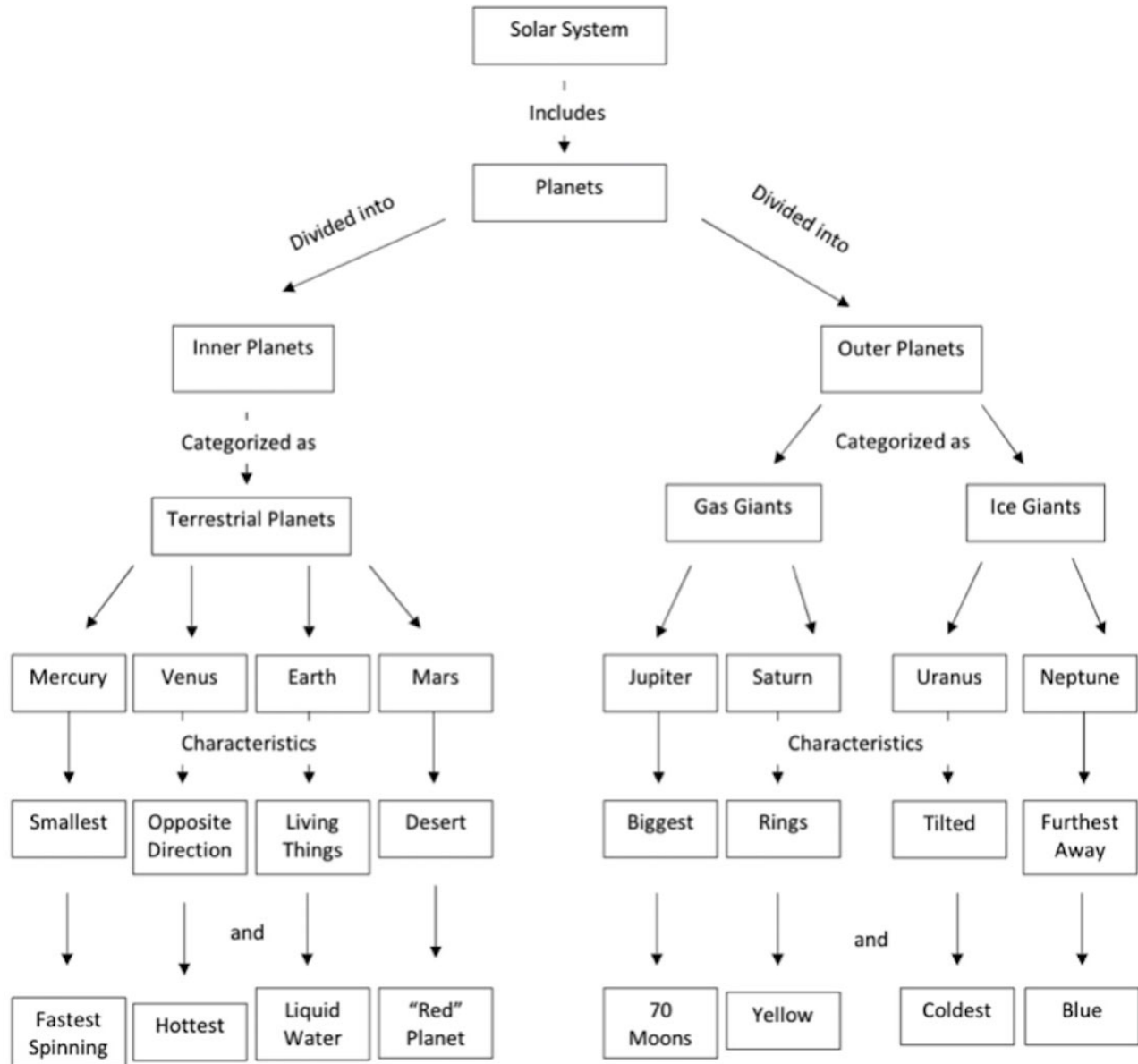


Figure 8
Example Fifth Grade Life Science Concept Map

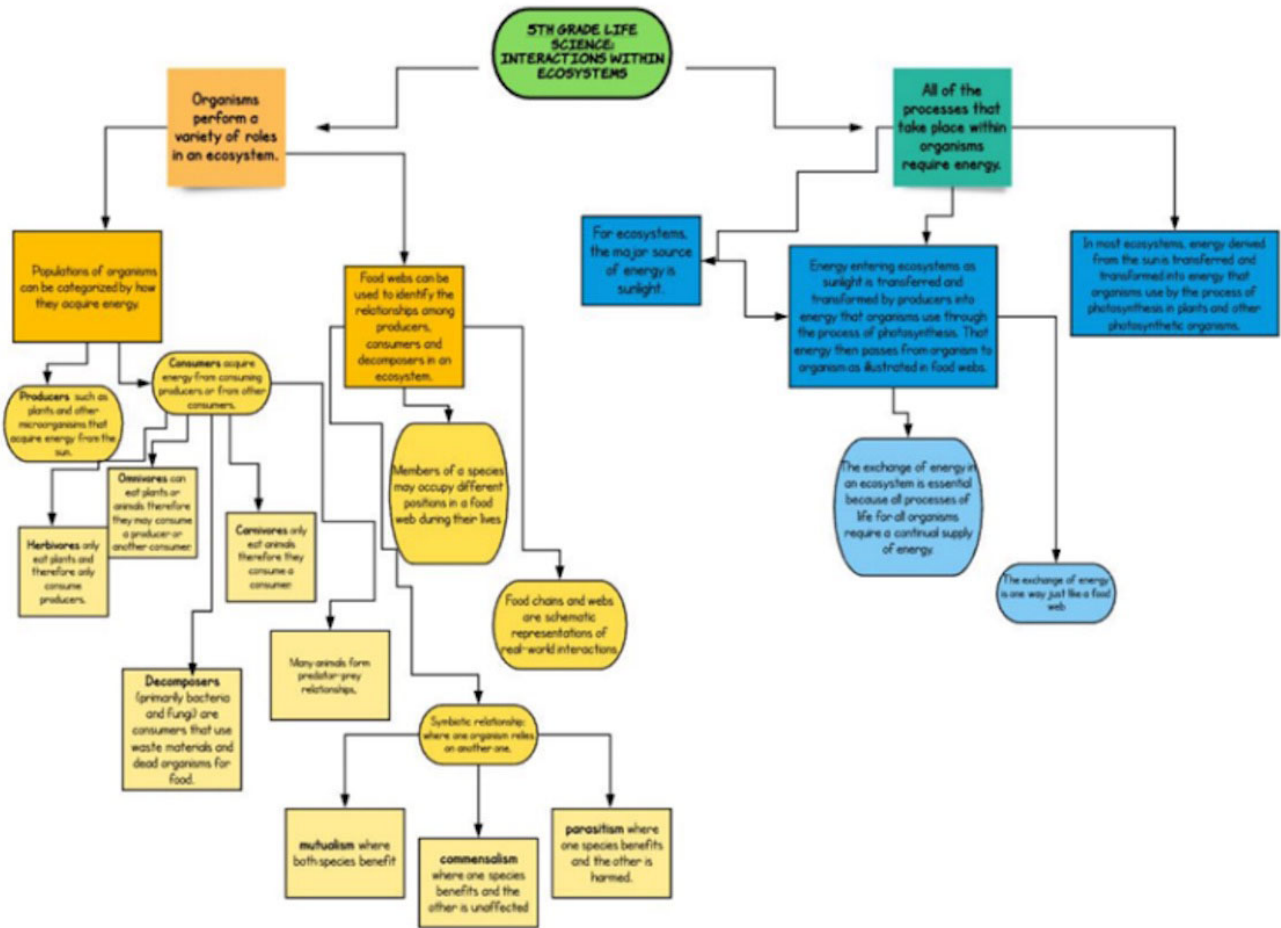
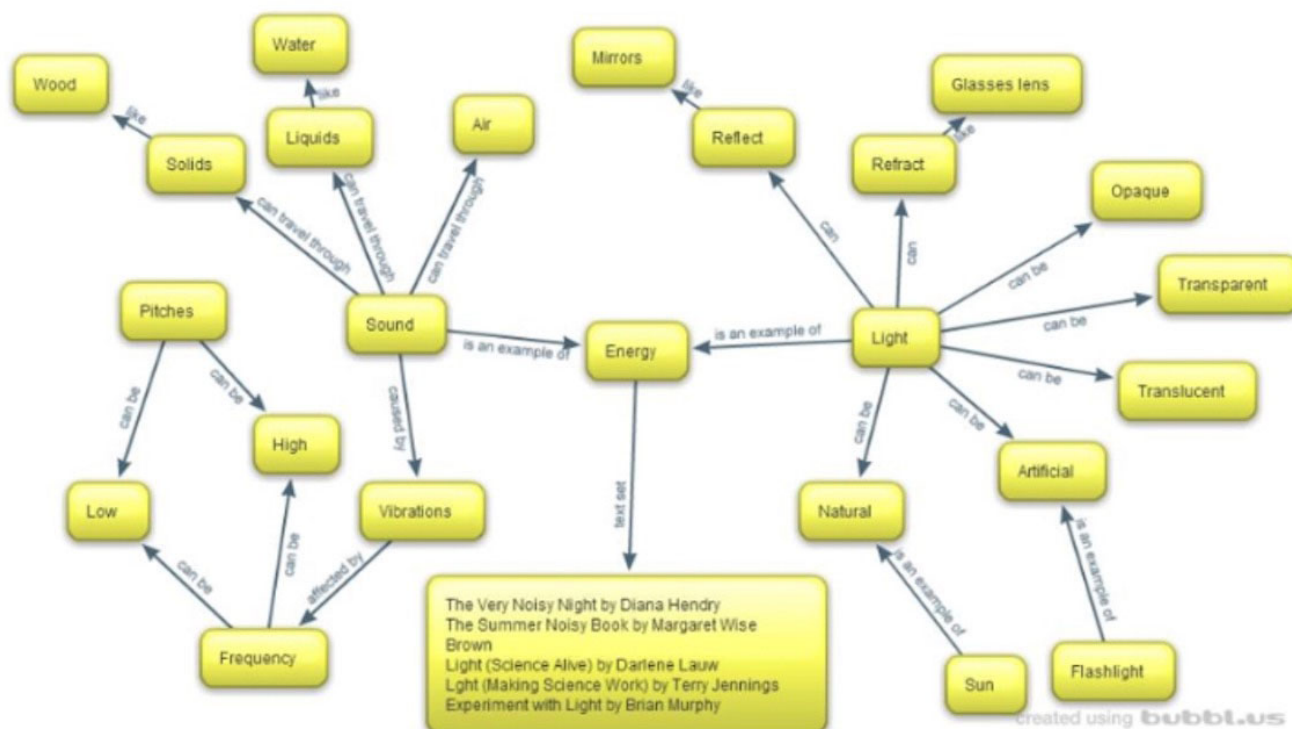


Figure 9
Example Fifth Grade Physical Science Concept Map



For a third communicate-phase activity, teachers developed instructional materials that showcase their understanding of science teaching strategies such as engineering design challenges (Schnittka et al., 2010) and model-based inquiry (Neilson et al., 2010). They signed up for one of the teaching strategies and created handouts that describe the key features of the strategy, considerations for implementation, and justifications for its use. Teachers also developed graphic organizers to support and scaffold fourth- and fifth-grade students' engagement in a learning activity that uses the strategy (e.g., argumentation discussions; the Claim, Evidence, Reasoning framework; asking science questions; or developing design solutions). In most cases, communicate-phase activities complement conduct-phase activities to ensure that teachers examine and apply multiple elements of target content and pedagogical content.

Conduct Phase

In the adapted R2C2 model, the conduct phase continues to be concerned with action. In this phase, learners apply course content in real and virtual contexts. However, in accordance with the *Framework for K-12 Science Education* (NRC, 2012) and NSTA declarations for teacher preparation (NSTA, 2017), conduct-phase activities engage learners in science and engineering practices through real-world or online simulations and applications. For example, they plan and conduct investigations; collect, analyze, and interpret data; formulate and communicate conclusions to investigative questions; and

design solutions to predefined problems. Some technology-based resources that allow for conduct-phase activities include PhET (<https://phet.colorado.edu/>), the Web-based Inquiry Science Environment (WISE; <https://wise.berkeley.edu/>), citizen science projects (e.g., <https://www.zooniverse.org/>), and GIS or other dynamic map interfaces (e.g., <https://www.esri.com/en-us/industries/education/schools/geoinquiries-collections>). Conduct-phase activities also engage learners in authentic science teaching activities. They create products that showcase their ability to rehearse or enact their developing pedagogical content knowledge and then document and share their experiences within their groups or with the whole class. Sample conduct-phase products include reports, movies, slideshows, case studies, portfolios, and curricula.

In a conduct-phase activity from the course, teachers used the PhET Bending Light simulation (University of Colorado Boulder, n.d.) to investigate and answer the science question: “How does light behave as it travels through matter?” This guided inquiry activity provided a self-directed opportunity for teachers to plan and carry out an investigation, analyze and interpret data, construct evidence-based explanations, and complete a science investigation report that communicates procedures and findings (see Figures 10 and 11). In another conduct-phase activity, teachers developed a video to showcase their application of a science teaching strategy, including demonstrations (Orgill & Thomas, 2007) and analogies (Brown & Friedrichsen, 2011; Smith & Abell, 2008). A key requirement of this activity was that teachers integrate science and engineering practices into their presentations (see Figure 12). This requirement ensured that teachers would plan for and engage in science and engineering practices as they applied their selected science teaching strategy. Teachers video recorded themselves doing the activities and going through the lesson as if explaining it to other teachers. They used their phones, cameras, tablets, or laptops to create their recordings. Some teachers involved their children or friends as students, whereas others simply recorded themselves without an audience. As a safety measure, teachers used password-protected cloud storage to share their videos with group members. These applications provide control over video share settings, and teachers were encouraged to unshare their work after the course.

Figure 10
Investigation Report Guidelines

Investigation Report Guidelines

In this activity, you will use the [PhET Bending Light simulation](https://phet.colorado.edu/en/simulation/bending-light) (<https://phet.colorado.edu/en/simulation/bending-light>) to conduct an investigation and answer the following science question:

- How does light behave as it travels through matter?

Take great care to document your experiences by taking pictures or screen shots of your work. You will use your documentation in the investigation report that you will submit for feedback and a grade. Your report should:

Areas for Improvement	Criteria	Grade /18	Areas of Excellence
	Describe an appropriate plan that clearly and completely explains data collection, instruments, and procedures that are used.	___/3	
	Visually organize and present your data.	___/3	
	Report findings in the form of claims, evidence, and appropriate science reasoning.	___/3	
	Predict how light will behave in different conditions.	___/3	
	Use accurate science concepts/principles/theories and relevant science vocabulary to explain findings and predictions.	___/3	
	Provide logical and connected next steps/new questions and an explanation of how they can advance learning about the topic are provided.	___/3	
	Reflect on how this investigation can be adapted, improved, and extended to support 5 th graders' learning about light.	___/3	
	Be well organized and formatted.	___/3	

Figure 11

Screenshot From a Science Investigation Report on the Behavior of Light with Instructor Feedback

4. Observations/Claims-Evidence

- A. In each of the activities, the different materials effected the bending of light to create a different angle of refraction. In the activities above, with water on top and glass on bottom a 90 degree and 62 degree on bottom for two different angles. In the next activity with glass on top and air on bottom a 90 degree angle was created. In the last activity with water on top and bottom, a straight line was created and an 80 degree angle was produced. The denser the material or index reaction the greater the degree created.

did it happen every time?

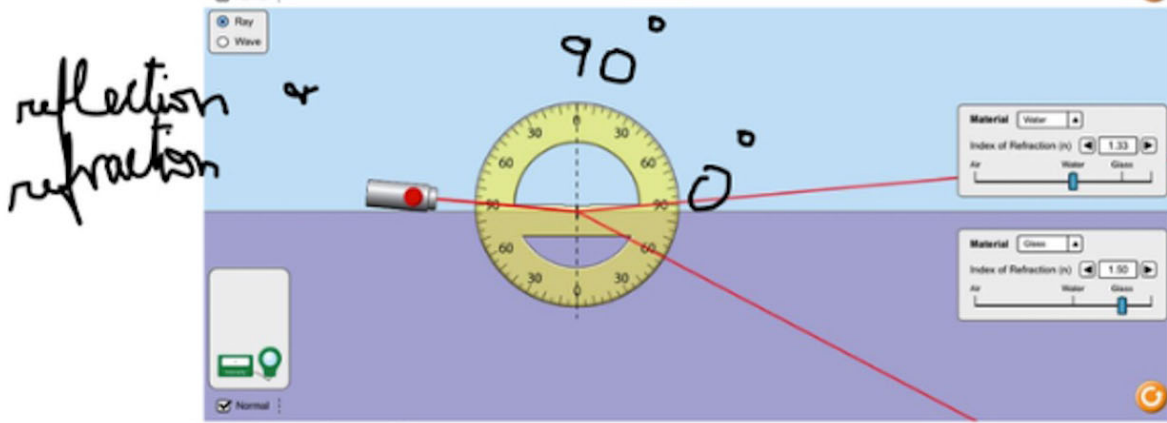
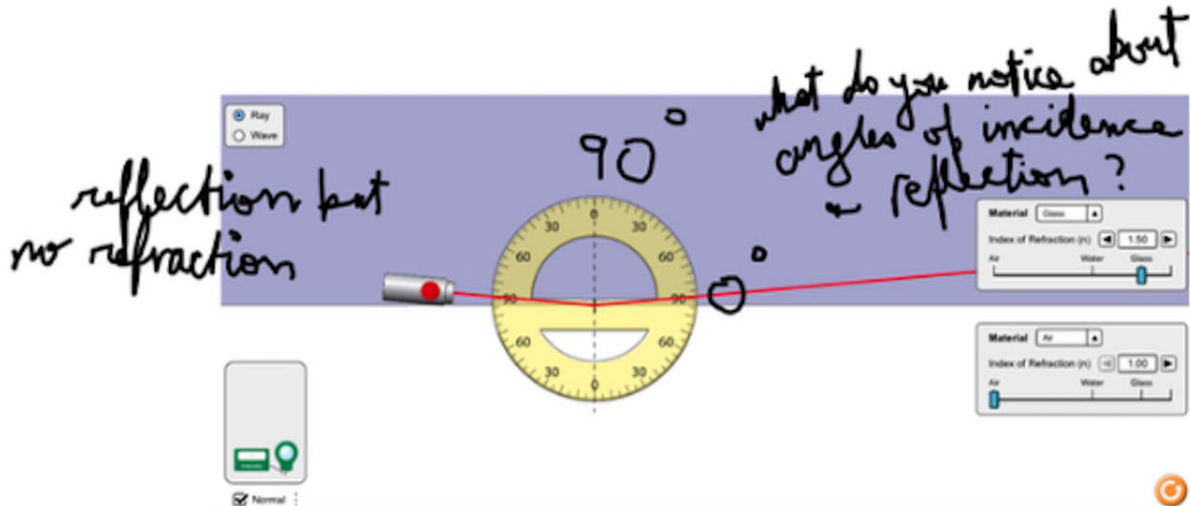
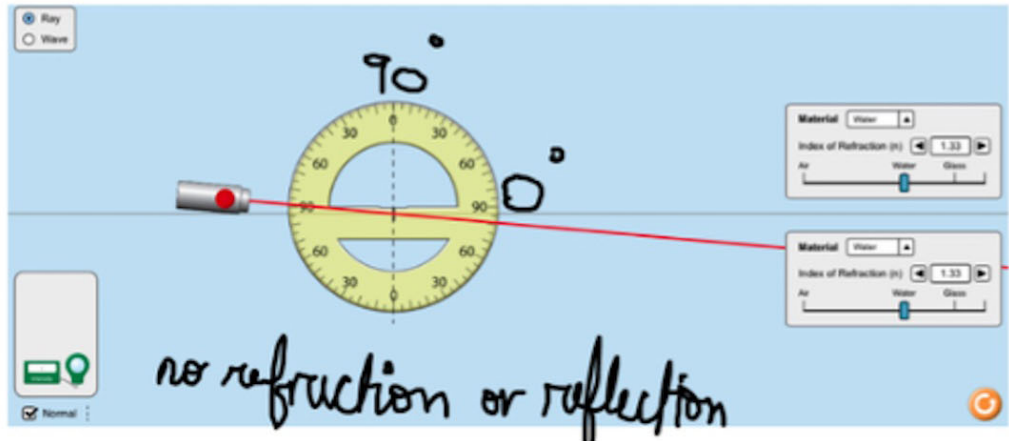


Figure 12*Teaching Strategy Project Guidelines***Teaching Strategy Project Guidelines**

In this activity, you will develop a video/movie that showcases your ability to apply a science teaching strategy to teach a cognitively demanding science lesson (integrates science content, science and engineering practices, and cross-cutting concepts). You will have the opportunity to sign up for a science topic and a science teaching strategy that are predetermined by the course instructor. Your video should be about 5 minutes long; you will share it with your group using a one drive link. Your video will be evaluated using the following guidelines:

Areas for Improvement	Criteria	Grade /20	Areas of Excellence
	Appropriately apply all elements of the teaching strategy.	___/3	
	Use the professional language associated with the strategy.	___/3	
	Use accurate science concepts/principles/theories and relevant science vocabulary.	___/3	
	Explicitly and appropriately integrate at least two science and engineering practices.	___/3	
	Explicitly and appropriately connect to a cross cutting concept.	___/3	
	Reflect on how this strategy can be used to support 4 th and 5 th graders' science learning.	___/3	
	Provide a brief explanation of where this lesson would fit in a curricular sequence (student prior knowledge and experiences as well as next steps for advancing learning about the topic).	___/1	
	Be well organized and formatted.	___/1	

Screenshots from two teacher-developed science videos are used to illustrate this conduct-phase activity. In the first video, the teacher used a classic phenomenon, pencil in water, to demonstrate refraction of light (see Figure 13). He first placed a pencil in an empty cup and asked students to draw the pencil. Then, he asked students to predict (and draw) what will happen to the pencil if he adds it to a cup of water that is filled halfway. To demonstrate, the teacher added water to the cup, placed the pencil in the water, and asked students, “What do

you notice about the pencil?” In his post demonstration discussion questions, the teacher asked students to share their thinking about what is causing the phenomenon and, as an invitation to further investigation, develop science questions that can help them describe it. To provide his audience with an example, the teacher asked his own science question: How would the pencil behave when placed in other materials, such as oil? In the second teaching strategy video, the teacher’s content focus was the conservation of matter (see Figure 14). She completed an investigation to examine the effect of heat on the mass of different materials in a closed system (butter, chocolate chips, and water). The teacher overlaid her video with questions and modeled her thinking to justify her experimental choices.

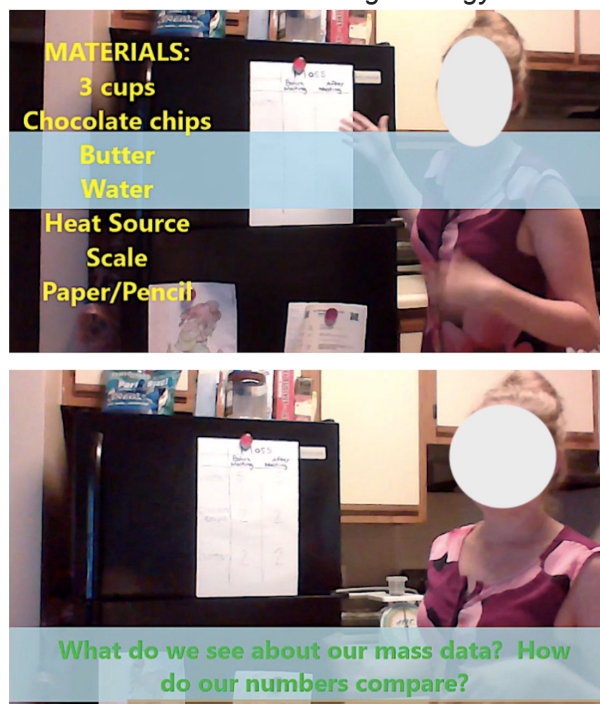
Figure 13

Screenshots From a Teaching Strategy Video Demonstration of Refraction



Figure 14

Screenshots From a Teaching Strategy Video Demonstration of Conservation of Mass



Reflecting on Implementation of the R2C2 Model

In this section, we describe the instructor's experience implementing the adapted R2C2 model and discuss the key considerations that informed her practice, how the considerations push against the myths about inquiry-based online science education described by Miller (2008), and the lessons she learned that might help others avoid similar pitfalls. Key considerations focus on subject matter and pedagogical content knowledge integration, meaningful activities and feedback, supporting interactions among students, and instructor presence.

Integrating Subject Matter and Pedagogical Content Knowledge

Science subject matter knowledge, including disciplinary core ideas, science and engineering practices, crosscutting concepts, and the nature of science, is central to science methods courses, including online courses. However, course outcomes also emphasize pedagogical content knowledge such as science teaching strategies, topic-specific representations, and knowledge of students' difficulties (Magnusson et al., 1999). Considerations for integrating subject matter and pedagogical content knowledge were important given the shortened nature of the course (2 credit hours over 7 weeks) and the myth about online science education being "limited to content learning" (Miller, 2008, p. 82). In its first iteration, the course was organized into three modules: science in the standards (2

weeks), learning and assessment (2 weeks), and planning and teaching strategies (3 weeks). In this organizational scheme, subject matter knowledge was the focus of the science in the standards module, and pedagogical content knowledge was more explicitly targeted in the remaining modules. After implementation, the course instructor noted that teachers tended to use only a few strands and topics, usually those they were most comfortable with, when completing course assignments. For example, only four of 35 learners selected a physical science topic for the communicate-phase concept mapping activity. Most teachers developed maps for relationships within ecosystems or cycles and patterns in the solar system.

To ensure that teachers engaged with several fourth- and fifth-grade topics beyond those they were already comfortable with, subsequent course iterations required them to sign up for different topics and strands when completing each course activity. This change provided the instructor with opportunities to assess teachers' science knowledge and abilities in several topics. In this manner, she was able to identify areas of strength and provide guidance, skill development, and informative feedback for areas of challenge like the ones shared for the light investigation (see Figure 10). Despite the added emphasis on science subject matter afforded by the new approach to assignments, a systematic focus on content in all modules was still lacking, which is contrary to the myth described by Miller (2008). To achieve a more balanced approach, each module in the most recent course iteration was designed to address specific science content by strand (e.g., physical science), science and engineering practices, and pedagogical content knowledge elements (e.g., misconceptions, formative assessment, and model-based inquiry). Regardless of the approach to subject matter and pedagogical content knowledge integration, many teachers found the content of the course valuable. As one teacher wrote on the end-of-course evaluation, "[The instructor] provided us with a wide variety of valuable sources for us [*sic*]. These are resources that will equip me in my first year teaching 4th grade. I feel prepared to teach science this upcoming year." Another teacher stated,

I liked the instructors [*sic*] video lectures that she did in which she sort of outlined what was coming up next in the course as well as recapped to help me see what science will look like in the 4/5 classroom.

Authentic and Meaningful Activities

Using the R2C2 model allowed teachers to engage experientially with course material through a variety of strategies. They applied what they were learning in meaningful and authentic activities that are central to the work of a science teacher. Teachers planned lessons and activities, rehearsed and shared them with their peers for commentary and feedback, and critically considered how their science teaching practice can engage their students in learning and doing science. In this manner, teachers were able to translate theory

into practice, contradicting another myth described by Miller (2008). As one teacher wrote on the end-of-course evaluation, “I loved the intro assignments, especially the drawing. The big assignments were hands-on and experiential.”

Course activities were designed to be resources that teachers could readily use in their fourth- or fifth-grade classrooms. As one teacher wrote, “The best assignment was the last one (assessment plan). I will actually be able to take this and use it in my new 4th grade classroom.” This teacher was referring to a conduct-phase portfolio activity that required learners to identify or develop formative and summative assessments aligned with fourth- and fifth-grade science standards. In the next iteration of the course, an additional activity will be added to engage teachers in critically evaluating the required state fifth-grade standardized assessment and generate implications for their practice. For this new conduct-phase activity, teachers will individually complete a practice version of the fifth-grade state science assessment; take screenshots of an easy question, a challenging question, and one of their choosing; and use the three dimensions of science learning to analyze test items. They will share their findings using an application that allows participants to create, share, and comment on images, presentations, and other multimedia using microphones, text, or webcams (e.g., VoiceThread). Teachers will conclude this activity by writing a reflection paper discussing the dimensions of science learning that are assessed with the fifth-grade science assessment, cognitive demand of the items, challenges and affordances for fifth-grade students, and implications for science teaching and assessment strategies. Review-phase resources that can support this activity focus on three-dimensional learning (German, 2017), NGSS evidence statements (NGSS Lead States, 2013b), and aligning instruction and assessment through a process of deconstruction (Katsh-Singer, 2011).

Course activities required teachers to create products that showcase their developing science ideas (e.g., concept mapping and DAST), ability to engage in science and engineering practices (e.g., science investigation and teaching strategy video), and facility with applying science-specific pedagogical content knowledge (e.g., teaching strategy instructional materials). According to the university-required end-of-course evaluations, teachers found course activities to be relevant and valuable. As one teacher wrote, “The activities and assignments really put us in the place of learners.” Another teacher stated, “They were taught in a way I would want to teach my 4th/5th graders including hands-on activities.” Through the R2C2 model, the instructor was able to teach course content using the principles, tools, and technologies that were advocated for in the course.

Interactive, Student-Centered Learning Opportunities

Opportunities for learner interaction were embedded within each phase of the R2C2 model. Because smaller group sizes allow for more student–student and student–instructor interaction (Baker, 2011), teachers in the course engaged in module activities in groups of 6–

12, depending on course enrollment. The smaller group sizes made participation in discussions more manageable for the instructor and group members. All course discussions occurred asynchronously using the learning management system platform. Volume and frequency of interaction were prioritized because these factors are key to the efficacy of online discussion as a learning tool (Ertmer et al., 2007). For example, teachers were required to interact with at least two different peers and make a minimum of three discussion contributions. However, the platform and asynchronous discussions pose several limitations. For example, the platform does not allow the instructor to track teachers' continuous engagement with the discussion after completing their contributions. Future iterations of the course may benefit from leveraging video conferencing software for small-group discussions instead of relying on fully asynchronous activities.

The asynchronous discussions were most effective when they centered on the products that teachers developed. Instead of being solely the endpoint of learning, teachers' work served as a springboard for small-group and whole-class learning. Peers watched each other model standards-aligned science teaching, analyzed their products and those developed by others, and co-constructed shared implications for practice. As one teacher wrote, "It was out of my comfort zone to have to video record myself doing a science experiment, but it was helpful to see others' experiments and have feedback from my teaching peers on my own experiment as well." This approach positioned teachers as professionals who have control over their learning and contribute to the learning of others. It promoted a sense of community during the short, 7-week course as participants interacted with each other and not just with the instructor. As one teacher wrote in the end-of-course evaluations, "I really liked the small groups. It allows us to look deeper at the material and have in-depth conversations about the content." Although strong interaction among peers is an essential constructivist element of online science methods courses, meaningful interaction with the instructor is equally important.

Instructor Presence

As Miller (2008) described, some of the myths about online science education are that it "is similar to correspondence coursework" (p. 82) and does not allow instructors to "model constructivist inquiry teaching strategies" (p. 83). Instructor presence determines the extent to which this myth holds true. In the online science methods course, the instructor's presence was evident through her continuous involvement in the class by way of communication and facilitation to support teachers' sensemaking. Communication occurred through weekly announcements about expectations (email, video, or audio) and timely responses to students' questions. As one teacher wrote on the end-of-course evaluation, "The instructor was extremely quick to reply to student needs and questions and that was very much appreciated."

Even though the instructor did not “model constructivist inquiry teaching strategies” (Miller, 2008, p. 83), she facilitated teacher learning by providing introductory videos and individual feedback on teachers’ implementation of teaching strategies. In many cases, the feedback was publicly shared in the discussion forum for the benefit of all group members. For example, in this comment on a teaching strategy videos, the instructor praises the teacher’s work, provides informative feedback about the strong elements of her practice, and gives suggestions to support student learning:

So impressed Stacia!!! Well planned and executed. Thought about multiple aspects of teaching science: content (conservation, units), skills (measuring, controlling variables), and provided suggestions and guidelines. The questions you posed in overlay focus on those and would get your students thinking and talking about the experiment.

Consider asking students what they think will happen to each . . . you will get great insight into their thinking that helps with the explanation process. If their thinking is inconsistent with the scientifically accurate ideas then they will be pretty surprised and more curious to know more (cognitive dissonance). I attached a formative assessment probe [Cookie crumbles; Keeley, 2018) that I have used in the past to see how my students’ ideas are developing in relation to conservation of mass.

Instead of solely being the “behind-the-scenes” planner and evaluator of learning, the instructor reviewed and synthesized student work within and across groups, highlighted common characteristics and experiences, discussed differences and diverse perspectives, explained key ideas that were overlooked, and clarified lingering ambiguities. This form of facilitation that occurs in the moment in a face-to-face class was more involved and similar to qualitative data analysis in the online environment. Teachers appreciated the type of feedback the instructor was providing them. As one teacher wrote, “[The instructor’s] videos made the class more valuable (feedback provided to the whole class, evaluations, etc.).” Another teacher stated, “The feedback to assignments were very helpful.”

Teachers’ comments on course evaluations highlight the value they place on instructor presence; however, two circumstances can challenge instructors’ ability to maintain similar levels of involvement. The first is enrollment. Table 1 provides a snapshot of the higher than typical enrollment in the online course at Ohio University. High enrollment may occur as institutions try to maximize efficiency and increase revenue. Because the course described herein is part of a revenue-generating program, 83 teachers were enrolled in the course when this article was written. The second challenge arises from the shortened time frame of the course, a trend that is manifesting at neighboring institutions (e.g., 3 credit hours over 5 weeks). High enrollment and shortened summer courses limit an instructor’s ability to facilitate and scaffold teacher engagement (e.g., checkpoints or providing informative feedback) and increase workload with respect to evaluation and grading. In such situations, we recommend hiring facilitators who assist the course instructor when enrollment exceeds

25–30 students, a practice at our institution. Facilitators are typically assigned up to 25 students, and their pay is prorated based on the number of students for whom they are responsible. We also recommend that instructors consider which activities can be integrated into larger projects and still allow teachers to demonstrate their developing competencies using the R2C2 model.

Conclusion

The R2C2 model transformed the learning space in the asynchronous science methods course described in this article. It provided students and instructors a rewarding, innovative, and cognitively demanding experience with online science teacher education. Model phases allowed the instructor to situate learning in authentic practice, providing early elementary teachers opportunities to apply course content, receive supportive feedback from the instructor, and develop confidence in their ability to teach science to fourth and fifth graders. Too often, online courses are critiqued for their over-reliance on text (reading and writing discussion board prompts) and the absence of hands-on experiences. The R2C2 model provides a useful structure for developing and organizing the learning environment in an online science methods course. Using the phases of the model, instructors are able to meaningfully engage current and future teachers of science in authentic, standards-aligned activities that are representative of the pedagogical work of the profession. Future research should examine the affordances of the model for teacher learning of subject matter knowledge and pedagogical content knowledge as well as the creation of a dialogic online space.

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