ELECTRONIC JOURNAL FOR RESEARCH
IN SCIENCE & MATHEMATICS EDUCATION
VOL. 24, NO. 3, 45-52

Evolution in the Digital Age: Implementation of 5E and NGSS in the Virtual Biology Classroom

Marcy E. Maulucci
Baker High School

Sarah K. Guffey
University of South Alabama

ABSTRACT

The abrupt transition to remote learning through digital platforms may be compared to the volcanic eruptions taking place 1000 years ago in the American Southwest: while one altered a natural environment, changing golden deserts to blackened landscapes, our current pandemic has drastically altered the physical and social environment in which we teach and learn, dramatically changing the landscape of education. In this paper, we offer a small contribution to our collective persistence by providing a source from which problems can be defined, questions asked, and new models generated and tested.

Introduction

The abrupt transition to remote learning through digital platforms may be compared to the volcanic eruptions taking place 1000 years ago in the American Southwest: while one altered a natural environment, changing golden deserts to blackened landscapes, our current pandemic has drastically altered the physical and social environment in which we teach and learn, dramatically changing the landscape of education. Similar to the species in the Valley of Fire that were met with sudden pressures selecting for the propagation of particular traits over others, educators are experiencing pressures forcing adaptation from traditional face-to-face classrooms to virtual learning environments (Basilaia & Kvavadze, 2020; Reich et. al., 2020; Richards & Valentine, 2020). Fortunately, K-12 teachers have the capacity to develop traits necessary for survival in this digital landscape, in part, due to the same scientific and engineering practices underlying the *Next Generation Science Standards,* (NGSS) (NGSS Lead States, 2013) that K-12 teachers strive to embrace. Thus, through communicating this model of Bybee's 5E unit (1996, 2014) designed for the virtual biology classroom and sharing the analysis of student learning outcomes, we offer a small contribution to our collective persistence by providing a source from which problems can be defined, questions asked, and new models generated and tested.

Method

Participants

Participants were enrolled in a large, urban public high school in the southeast region. Academically, the school was ranked better than 80% of public high schools in the state. The racial makeup of students enrolled in this high school was 55.9% white, 31.8% African American, 6.3% Hispanic, 3.3% Asian, 2.3% from other races, and 0.4% American Indian. Additionally, 41.5% of students received free and reduced lunch. There were 71 students in the sample for this study that were divided into three blocks, with 21 students being in the first block, 28 students in the second block, and 22 students in the third block. Two students were hearing impaired and required a translator during instruction, 12 were English Language Learners, and 12 had Individualized Education Plans or were in a Problem Solving Team.

Virtual Learning in a Biology Classroom

Amid swift exile from the traditional classroom, successful course completion relies as much upon digital literacy as it does upon science literacy. During traditional face-to-face instruction, students in our classroom had limited access to technology both during the school day and at their homes, intensifying the challenge presented by this additional learning demand. When schools transitioned to a fully online setting, hotspots and laptops were provided for students as needed. As a result, development of each instructional unit for our five weeks in the virtual classroom relied upon sequential introduction of digital skills in addition to an explicitly organized format with accessible content. Content and activities were selected to limit the number of platforms outside Google Classroom (GC), allowing students to become accustomed to a few external websites without overwhelming them. Specifically, materials from CK12.org, use of teacher-modified videos through EdPuzzle, student created videos in Flipgrid, and live lessons through WebEx represent the main platforms accessed by students. These resources were free for teachers and students. Live lessons occurred two times during each learning unit, typically on Tuesdays and Thursdays. On average, 22% of the total sample (71 students) attended the live lessons and 28% viewed the recording after the live session. The 5E unit presented here represents the culmination of the digital learning sequence and begins to capture the richness of what 5E and NGSS might look like once students and teachers have fully adapted to a digital learning landscape. This unit focused on natural selection as a means of evolution and addressed two standards: (a) Alabama Course of Study*,* (ALCOS), Biology 14: Analyze and interpret data to evaluate adaptations resulting from natural and artificial selection that may cause changes in populations over time (e.g., antibiotic-resistant bacteria, beak types, peppered moths, pest-resistant crops) (2015) and (b) NGSS HS-LS4-4: Construct an explanation based on evidence for how natural selection leads to adaptation of populations (2013).

Assessing Misconceptions

Instructional design followed a Wiggins and McTighe backwards design model (2005), with a pre-test used to gauge initial student misconceptions. Two test items were selected from the American Association for the Advancement of Science's (AAAS) Project 2061 (n.d.), which addressed common misconceptions among high school students most aligned with the unit standards. Two questions from AAAS were asked: (a) *Which of the following correctly describes what happens when a population of bacteria becomes resistant to an antibiotic?* and (b) *A population is a group of individuals of the same species. Could a population living today differ from their ancestors from many generations ago? Why or why not?* The standards and misconceptions along with their alignment to each test question are found in Table 1.

Table 1
Alignment of Standards (NGSS & ALCOS), AAAS Item, and AAAS Misconception

Standard (NGSS & ALCOS)	AAAS Misconception	Question
NGSS HS-LS-4-4 ALCOS Biology 14	ENM047: Evolution happens when individual organisms acclimate or "get used to" new conditions gradually.	A
NGSS HS-LS-4-4 ALCOS Biology 14	ENM037: Changes in a population occur through a gradual change in all members of a population, not from the survival of a few individuals that preferentially reproduce.	A
NGSS HS-LS-4-4 ALCOS Biology 14	ENM034: Change occurs in the inherited characteristics of a population of organisms over time because of the use or disuse of a particular characteristic.	B
NGSS HS-LS-4-4 ALCOS Biology 14	ENM033: Change to the characteristics of populations (i.e. the proportion of individuals in the population having certain traits) of organisms is always random and is not influenced by the favorability of that change in a given environment.	A
NGSS HS-LS-4-4 ALCOS Biology 14	ENM031: Individual organisms can deliberately develop new heritable traits because they need them for survival.	A, B

Inclusion of these questions on both the pre-test and post-test provide a foundation for evaluating student progress towards learning targets not only in terms of individual student or whole class achievement, but also in terms of student performance at the national level. Ultimately, evaluation of such data will better inform subsequent changes to instruction. Additionally, while addressing state and national standards, instructional design also considered four specific questions in the context of the digital environment specifically applying the tools for ambitious science teaching (Windschitl, Thompson, & Braaten, 2018): (a) How will student thinking be made visible?, (b) How will changes in student thinking be best supported?, (c) How will students be supported to talk about science?, and (d) How will a feedback culture be created?

5E Inquiry-Based Lesson

Google Classroom (GC) served as the virtual classroom and students encountered each unit as a new topic listed on the classwork page. Materials and assignments were provided sequentially under each topic, titled with both a number and a description to orient students with the order and purpose of each activity. Discussion during live lessons in the first weeks of virtual learning established the general schedule of instruction which included the unit launch on day one (pre-test, engage, explore), a live lesson day two (explore, explain), additional student-lead learning day three (explain), another live lesson day four (extend), a student-lead wrap-up day five (extend), followed by a culminating assessment day 6 (evaluate). Although each unit had clear organization, the virtual classroom easily accommodated the flexibility mandated by the diverse spectrum of student needs, including the additional demands from the unprecedented circumstances. For instance, while live lessons were offered, attendance was not mandatory. Rather, live lessons were recorded and subsequently posted as material under each topic thus making these sessions available for later viewing. Moreover, this format provided the added benefit of making content freely available to the whole class for second delivery of instruction as needed. In addition, live lesson recordings included closed captioning, further benefiting students specific learning needs. Another form of accommodation including ensuring that each unit incorporated a weekend during the six-day sequence, inherently providing additional time for assignment completion. This design supported development of student autonomy while seamlessly meeting the requirements for additional time as commonly included in many IEPs and ELPs.

Engage

Following the pre-test, students were asked to respond to a question. In this case, students were presented with two images, and asked to make a prediction about each. The first image showed the average size of a chicken in 1957, 1978, and 2005 and asked students to explain what caused the increase in average size over time. The second image showed two phenotypically different peppered moths, one black and one white, photographed against dark tree bark. Students were asked to explain why different moths of the same species show such variation in color, and why the most common phenotype varies with environment. Students submitted responses by typing in the *Your Answer* section of the *View Question* page in GC and selecting *Turn In*. This method, as opposed to a forum-style public posting, encouraged expression of initial student ideas about a science topic without the added intimidation of having to do so publicly. It afforded students an opportunity to prepare to talk about science by writing first, and further supported ELL students by removing time constraints present in the traditional classroom setting. At the same time, capturing initial ideas in writing generated an artifact that could be looked back upon and later modified to represent changes in student thinking. Finally, this approach created an opportunity for individual feedback, allowing the teacher to respond to each student's predictions with targeted questions to further probe their thinking.

Explore

Next, students were presented with an assignment adapted from the HHMI BioInteractive website, Color Variation Over Time in Rock Pocket Mouse Populations (2018). In the assignment, students had access to a Google Document (separate, editable copy provided to each student), and a PDF of the HHMI Mouse Population Illustrations. Students were asked to create a table in their Google Doc representing the number of mice with each fur color at location A and at location B for each time point. Students were also asked to predict the correct sequence of images over time. This assignment illustrates a progression in the development of student digital competency as it asked students to create a table, rather than simply filling in a table provided for them as done in earlier assignments. At the same time, the assignment asked students to engage in scientific practices by determining how to organize and represent data, again at a level of rigor above filling in a pre-designed table, yet below generating a final graph using Google Sheets, a task that remained beyond the scope of the course given the constraints of the abrupt transition to an all-digital environment.

Following independent exploration, WebEx was used to host a live lesson. Initially, students were presented with a teacher generated PowerPoint slide anonymously summarizing student explanations about each *engage* image to promote discussion. Next, students were asked to help create a teacher-generated table on a new slide by referencing their own. This facilitated examination of data by the whole class and supported discourse about student predicted sequences, encouraging use of quantitative data to draw conclusions.

Explain

During the second segment of the live lesson, student-centered sense-making began while viewing the HHMI Video, *Making of the fittest: Natural selection and adaptation*. Prior to watching the video, a list of new vocabulary terms was displayed to anchor students' attention. After, students were asked to suggest definitions for those terms, which were recorded by the teacher on a PowerPoint slide to make thinking visible and create an artifact for revision during the second live lesson. Then, students revised predictions about the chronological order of mouse population illustrations and shared their thoughts by responding to an embedded poll using Poll Everywhere. The poll was followed by slides presenting bar graphs of the mouse population in each location over time, taken from the HHMI BioInteractive website (2018). Scaffolded questions facilitated student discussion about the causes of population change, and students were pressed to support conclusions with data while using new vocabulary. The live lesson concluded with a short teacher-lead presentation about natural and artificial selection, linking the concepts to the images introduced during the engage. Finally, a demonstration on creating and adding a Google Doc to an assignment helped expand students' digital skill set. It is relevant to note that the video (also embedded in the PowerPoint), along with the transcript and Spanish translation, were all posted as material in GC following the live lesson. This provided a range of optional support for all students, while also preemptively addressing technical difficulties students might encounter when trying to watch the embedded video.

Following the live lesson, continued student learning was supported by two additional assignments. In the first, students followed a link from GC to EdPuzzle (2020), where they watched the video *What is Natural Selection* and responded to embedded teacher-designed questions. This activity provided a platform for feedback, allowing the teacher to leave comments on student responses. For the second assignment, students followed a link from GC to the CK12.org Flexbook 2.0 section, *Theory of Evolution*, which provided students with a reading selection as well as related adaptive practice questions. Student performance data is automatically captured by CK12.org, facilitating effective feedback during subsequent instruction. Finally, students created a Google Doc to answer the review questions at the end of the reading section, thus demonstrating acquisition of both digital and scientific competency.

Extend

A second live lesson introduced the concepts of directional, disruptive, and stabilizing selection using two PLIX from CK12.org: (a) Natural Selection: Natural Disasters, and (b) Natural Selection: Directional Selection of Flower Colors, in conjunction with questions generated using Poll Everywhere to make student thinking visible and stimulate discussion. After completing the first PLIX, students revised proposed definitions to the terms adaptation, natural selection, and evolution by revisiting the PowerPoint slides from the first live lesson. The teacher annotated the slides to reflect changes in student thinking, striking a single line through information that was incorrect and adding new text in a different color. The second PLIX facilitated discussion of the relationship between an organism's fitness, specific traits, and the relative numbers of individuals in a population. Afterwards, students examined definitions for each type of natural selection and matched the terms to related scenarios via live polls. As a final step, students examined a set of four graphs, and through discussion, determined which graph illustrated each type of natural selection. As with the first live lesson, both the recording and PowerPoint slides were posted afterwards as Material in GC.

At the conclusion of the live lesson, students were directed to complete two follow-up activities in GC. The first had students read the CK12.org Flexbook 2.0 *Natural Selection* and complete the adaptive practice questions. The second served as a culminating activity and asked students to respond to a question using Flipgrid, accessed as a link in a GC. Students were asked to describe a scenario involving stabilizing selection and to distinguish between the types of selection encountered during the unit Engage, articulating the difference between natural and artificial selection. While these questions challenged students to talk about science, the format supported students' ability to do so by providing an opportunity to prepare, record, review, and edit responses before publicly posting .

Evaluate

Finally, students were asked to post an evaluation of one classmate's response following a 3-2-1 format. Specifically, students identified three aspects of their classmate's Fligpgrid that were well done or that the evaluating student agreed with, two similarities to or differences from their own Flipgrid response, and one aspect of their classmate's Flipgrid that could be improved or done differently. In this way, students were encouraged to provide constructive feedback to one another. Additionally, students completed the post-test, which included the same questions as the pre-test. A paired-samples *t*-test was conducted to compare students' pre- and post-test scores on the evolution exam. Results revealed there was a significant difference in scores for the pre-test (M = 4.05, SD = 1.70) and post-test (M = 6.64, SD = 1.98), $t\,(38) = 9.99$, $p < .005$. These results suggest that the virtual evolution 5E lesson significantly impacted students' learning.

Reflection

Students who attended live lessons generally participated during discussion and benefited from targeted practice using essential vocabulary, while having the opportunity to ask questions and clarify misconceptions. Further, students who did not attend live lessons missed out on opportunities to fully engage in science practices. In this regard, the most important approach to enhancing student engagement using this model would be to increase the number of live lessons and to require student attendance. A second modification would be to switch platforms from use of PowerPoint to use of Nearpod. Nearpod is designed with student engagement in mind, and thus has features to facilitate real-time participation. For instance, lesson Engage questions could be posed using Nearpod's *collaborate* slide rather than as an assignment in Google Classroom. This way, the question is asked on a slide during live instruction and student responses are visibly posted for everyone to see. If partnered with a conferencing technology, such as Zoom, students would be able to view and create content while simultaneously participating in discussion.

Mandatory live lesson attendance would also increase opportunity for deeper exploration of content while allowing students to engage in discussion, data collection, and analysis through use of teacher assigned break-out sessions. In these sessions, small groups of students could collaborate in virtual conference rooms while running freely available simulations such as the PhET Natural Selection simulator from the University of Colorado or the HHMI Lizard Evolution virtual lab available through HHMI Biointeractive, thus providing more authentic opportunities to engage in science practices.

Although the transition to virtual learning carried a significant workload, integration of assessment data from multiple platforms was straightforward. Opportunities for providing individual student feedback were greatly enhanced by the features contained in platforms such as edPuzzle and Google Classroom. Likewise, edPuzzle and CK12.org both provided clear and easily accessible summative class and individual student data. Once teachers and students become accustomed to specific platforms, real-time student data collection and enhanced feedback options will be tremendous assets supporting instruction and student learning. The greatest challenge will be in helping teachers and students rapidly increase digital technology skills.

Resources for Teachers

In response to COVID-19, the current state of education has drastically changed and will perhaps look different over the next academic year(s). In particular, during the transition to online teaching and learning, science teachers must become familiar with and learn how to use resources that allow students to engage in science, while also maintaining the rigor of inquiry-based learning and the NGSS (National Science Teaching Association, 2020). Using a variety of digital tools together may facilitate the instructional design of Windschitl and colleagues (2018) ambitious science teaching model which, in this 5E unit, included: (a) making student thinking visible; (b) supporting changes in student thinking; (c) supporting science talk; and (d) creating a culture of providing feedback. Creating a community of science teachers to share resources that will help students succeed in virtual learning environments during this challenging time is of the utmost importance (National Science Teaching Association, 2020).

Sarah K. Guffey (skguffey@southalabama.edu) is an assistant professor of science education at the University of South Alabama where she teaches the secondary science methods course. Dr. Guffey specializes in pre-service teachers' conceptual understanding of the Earth and weather sciences, pre-service teachers' understanding of the Next Generation Science Standards, and equity in science education.

Marcy E. Maulucci is a science teacher at Baker High School in Mobile, Alabama.

The authors received no financial support for the research, authorship, and/or publication of this manuscript.

References

Alabama State Department of Education. (2015). *Alabama course of study: Science.* Alabama learning exchange, ALEX. https://www.alsde.edu/sec/sct/COS/2015%20FINAL%20Science%20COS%2010-1-15.pdf

American Association for the Advancement of Science (n.d.). *Science assessment.* AAAS Project 2061. http://assessment.aaas.org/topics.

Basilaia, G., & Kvavadze, D. (2020). Transition to online education in schools during a SARS-CoV-2 coronavirus (COVID-19) pandemic in Georgia. *Pedagogical Research*, *5*(4), 1-9.

Bybee, R. W., Taylor, J. A., Gardner, A., Van Scotter, P., Powell, J. C., Westbrook, A., & Landes, N. (2006). The BSCS 5E instructional model: Origins and effectiveness. *Colorado Springs, Co: BSCS*, *5*, 88-98.

Bybee, R. W. (2014). The BSCS 5E instructional model: Personal reflections and contemporary implications. *Science and Children*, *51*(8), 10-13.

CK-12. 5.21 Natural Selection. https://flexbooks.ck12.org/cbook/ck-12-biology-flexbook-2.0/section/5.21/primary/lesson/natural-selection-bio.

CK-12. 5.14 Theory of evolution. https://flexbooks.ck12.org/cbook/ck-12-biology-flexbook-2.0/section/5.14/primary/lesson/theory-of-evolution-by-natural-selection-bio.

Edpuzzle. (2020). What is natural selection? https://edpuzzle.com/media/5ecd736e4b74407392b74530

HHMI Biointeractive. (2018). Color variation over time in rock pocket mouse populations. https://www.biointeractive.org/classroom-resources/color-variation-over-time-rock-pocket-mouse-populations.

National Science Teaching Association (2020). Teaching in the coronavirus era. *NSTA Reports, 31*(9), 1-20.

NGSS Lead States. (2013). Next generation science standards: For states, by states. Washington, DC: The National Academy Press.

Reich, J., Buttimer, C. J., Fang, A., Hillaire, G., Hirsch, K., Larke, L. R., Littenberg-Tobias, J., Moussapour, A. N., Thompson, M., & Slama, R. (2020). Remote learning guidance from state education agencies during the covid-19 pandemic: A first look. *MIT: Teaching Systems Lab.*

Richards, R., & Valentine, S. J. (2020). A letter to educators teaching online for the first time. *EdSurge: Teaching & Learning.* https://www.edsurge.com/news/2020-03-13-a-letter-to-educators-teaching-online-for-the-first-time.

Wiggins, G., & McTighe, J. (2005). Understanding by design (2nd ed.). Upper Saddle River, NJ: Prentice Hall.

Windschitl, M., Thompson, J., & Braaten, M. (2018). *Ambitious science teaching.* Harvard Education Press.