Project NEO: A Game to Promote STEM Teaching in Middle School by Changing Attitudes and Skillsets of Preservice Teachers

Richard Van Eck, University of North Dakota
Mark Guy, University of North Dakota
Robert Brown, Triad Interactive Media
Scott Brewster, Triad Interactive Media
Austin Winger, University of North Dakota

Introduction

The number of STEM majors needed to meet the expected needs of our future workforce will grow, yet fewer students are choosing to major in STEM areas, and those who do may be underprepared (Broussard, La Lopa, and Ross-Davis, 2007; Langdon, McKittrick, Beede, Khan, & Doms, 2011). This has led many to suggest that middle school students should be targeted for improving STEM competency and career interest, yet evidence suggests that their teachers are themselves underprepared (Darling-Hammond, 2000; Llewellyn, 2002). Further, middle school students can only benefit if they have the foundational STEM knowledge from their elementary school years, which is often not the case (Ball, Lubienski, and Mewborn, 2005; Wu, 1999). In part, this results from elementary teachers' weaknesses in procedural and conceptual understanding (Hawk, Coble, and Swanson, 1985). Unlike middle school and high school science teachers, who must meet credentialing requirements to ensure competency in their disciplines, elementary teachers teach all subjects and are not credentialed in any subject. During their college education, most elementary teachers are exposed to science content only through lower-division college courses that are not necessarily aligned with teaching standards (California Council on Science and Technology, 2010). Because elementary teachers typically graduate from college with a weak understanding of scientific principles, they lack confidence in and enthusiasm for teaching science (Jarrett, 1999; Stevens & Wenner, 1996). Therefore, interventions planned for the middle school level must be preceded by interventions for elementary teachers (Hill, Rowan, & Ball, 2005), and they must begin during preservice teacher (PST) education, before teaching habits and philosophies are formed.

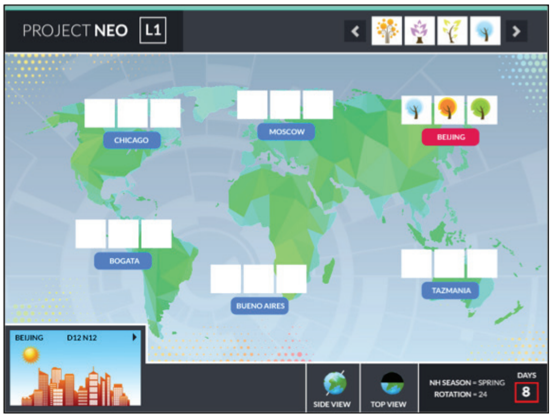
Project NEO

The goals of *Project NEO* were to see if a game built around the next generation science standards (NGSS Lead States, 2013) standards could 1) improve PSTs' attitudes toward science; 2) improve science competency for PSTs; 3) improve PSTs' attitudes toward games in the classroom, and 4) improve PSTs' attitudes toward teaching science. This phase I project, funded by the NSF, designed, developed, and tested a game based on the NGSS to help elementary PSTs learn some of the more challenging content they and their future students will face. This foundational knowledge may be critical to their ability to teach and confidently model science expertise for elementary students who may, in turn, enter middle school with more skills, confidence, and positive attitudes toward science.

The project team took an initial grouping of interrelated science concepts from the NGSS focused around Earth and space science and the life sciences and connected them to the stages of the 5E Learning Cycle model—engagement, exploration, explanation, elaboration, and evaluation (Bybee, 1989). Learners participate in activities that introduce and teach introductory concepts related to the sun, earth, and moon system (SEMS) and related patterns that impact day/night hours, seasons, plant life, etc. This content was selected in part because of persistent, generalized misconceptions about the content by teachers and the general public, and because they allow broad coverage of the NGSS.

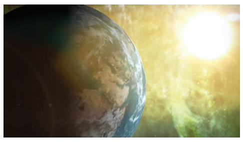
The game was designed around the 5E model (Bybee, et al., 1989), which focuses on cycles of instruction through 5 phases: Engagement, Exploration, Explanation, Elaboration, and Evaluation. Each of these phases corresponded to different parts of the game. The Engage phase led to the development of a narrative that comprises 3 videos (Figure 1). The game begins with our heroine, Talia, being recruited by a league of scientists to help protect Earth from sudden climate changes created by the villain who wants to wipe out certain kinds of plant life. The exact mechanism by which he is doing this is unknown to Talia and the agency in the beginning, so Talia is tasked with determining which plants could survive under which kinds of climates so scientists can ensure survival of the species (the Explore phase). Primary game play occurs on a map-driven board that shows the Earth's continents distributed across latitudinal and longitudinal lines (Figure 1). Students explore characteristics of various plants and must drag, drop, and reorder specific plants to create matches that allow the plants to survive in different regions of the Earth based on the changes caused in seasons and day–night hours by the villain's manipulations. The gaming elements (Figure 1) allow the students to practice concepts related to unit topics using a casual game interface and cut scenes that tie back to the overarching narrative. Immediate feedback is built into all gaming activities, and all performance and task data are collected via a robust backend database. After each level, the player is required to provide a scaffolded explanation of what they think is going on (Explain). In the process of conducting her tests, Talia (the player) uncovers patterns related to latitude and longitude and to day and night hours that lead to a deeper conceptual understanding of the Earth and its orbit around the sun. The Elaborate phase does not become fully developed until the latter levels as the positions, plants, and time all combine to elaborate on the central topic of Latitude, season changes, and the day/night hour ratio. This leads her to the realization that the villain is really shifting the Earth in it's orbit around the Sun. Once they know the mechanism the villain is using, the scientists are then able track the device he is using and to ultimately disable it.

Future modules developed in Phase II will expand on this narrative and focus on concepts like angle of inclination, axial tilt, rotation, and the interrelation of these factors as they impact geology, climate, flora, and fauna on the Earth, which is when the evaluation phase comes in. These levels, when fully developed, result in a full-scale inquiry-based learning game that helps the learner solve a bigger science challenge on the interrelation of day–night, latitude–longitude, axial tilt, rotation of the Earth, and the effects on Earth's flora and fauna and society. A mega-level narrative about a villain attempting to cause multiple catastrophes on Earth in a variety of ways, culminating in the destruction of the Earth by an asteroid (near Earth object, or NEO) is introduced at the beginning of the unit and drives all science inquiry and learning across the full game.



Module One: Testing simulation screen

Talia



Earth's orbit threatened

League of scientists

Figure 1: The primary Project NEO game screen and key frames from three narrative videos.

Methods

A mixed model within-subject pretest–posttest and repeated measurement design was used to test the impact of classroom instruction and game play on science content knowledge and attitudes toward science. The video game is intended to be used in PST science education classes as well as a stand-alone product, so knowledge and attitude measures were administered at key points throughout the project to assess the impacts of classroom instruction and the video game itself.

Sample

Twenty-two of twenty-four PST education majors in an Earth and science education course at an upper Midwest university agreed to allow their class assignments (which included playing the game) to be used for research purposes. The class covered science material related to topics of the Earth's layers, rocks and the rock cycle, plate tectonics, weather, energy use, astronomy, planets, and the solar system. Of the 22 who signed consent forms, 14 completed all phases of the study, for a 64% completion rate.

Instruments

Attitudes Toward Teaching Science (ATTS) were measured by using selected items from the Attitudes and Beliefs about the Nature of and the Teaching of Mathematics and Science, or ABNTMS (McGinnis, Watanabe, Roth McDuffie, Kramer, & Shama 1997; McGinnis & Watanabe, 1999). Subscales used included modified version of the Beliefs about Teaching Mathematics and Science (BTMS), the Attitudes Toward Learning to Teach Mathematics and Science (ALTMS), and the Attitudes Toward Teaching Mathematics and Science (ATTMS).

Attitudes Toward Science (ATS) were measured using modified versions of the Beliefs about Mathematics and Science (BAMS) and the Attitudes Towards Mathematics and Science (ATMS) from the ABNTMS discussed in the previous section, as well as the TOSRA (Fraser, 1981) "Inquiry" subscale.

Game Feedback Survey (GFS) is a paper-and-pencil two-item anonymous survey that asks PSTs to rate the extent to which the game helped them learn or better understand science content.

Science and Game Reflection (SGR) was a series of five open-ended questions about the game and the science content it covered. This was administered as a paper-and-pencil take-home assignment.

Science Test (ST) comprised science content items relating to season, axial tilt, latitude and longitude, and position of the Earth in its orbit around the sun. Items were developed by the science educator teaching the course on Earth and space science. Items 1 through 6 are multiple choice questions worth one point each. Items 7 and 8 are open-ended items that test conceptual understanding.

Teachers' Attitudes Toward Games (TATG). There are currently no validated, reliable measures of teachers' attitudes toward games in the classroom. Several studies have reported using different instruments to measure this construct, but they are not available nor have they been validated. Further, none of these instruments appears to be based on an established theoretical framework for measuring teachers' attitudes toward technology as a teaching tool. Therefore, a new survey was developed based on Fullan & Stiegelbauer's (1991) first-order and second-order barriers, later adapted by Ertmer (1999) to apply to adoption and diffusion of technology in K-12 classrooms. Sixteen existing game attitudes and use surveys and several articles that reported findings based on unpublished scales were first identified and the questions, constructs, and/or outcomes were then categorized as first- or second-order barriers. There are 83 Likert-type items on this test that use a 5-point scale.

Procedure

On October 21, 2013, the science content pretest was administered to the participants. During the following week, the students learned about material in class that was related to the content included in the *Project NEO* game. On November 18, the students completed content posttests with the same questions from the pretest in order to measure their learning from the unit in class. After completing the posttest, the students were given instructions regarding how to log in, create accounts, and play the *Project NEO* game. During this time, the students' amount of game play was tracked. On December 9, the intervention phase was closed, and participants completed the posttest surveys.

Results

H1: PSTs will demonstrate more positive attitudes toward science after playing the game. Descriptive statistics and paired T-tests were run to examine this. Attitudes did not go up, which is not surprising given the short-term duration of the intervention. Scores on science inquiry went down by .40, however, which is surprising ($t(12) = 3.128$, $p = .009$). One explanation is that the findings could simply be an artifact of regression toward the mean as a result of a ceiling effect. Pretest scores were 4.16 on the TOSRA scale, which is very high. The chances of these scores going up are significantly less than them going down. Final scores were still positive (3.75 out of 5), indicating that teachers were still positive about science inquiry as a way to teach science

Further, the entire class is focused on the implementation and value of inquiry-based learning and hands-on manipulation of materials to reinforce scientific understanding. Discussion of hands-on–minds-on learning during this course routinely results in positive comments about the value of this approach to teaching science. Analysis of the reflection papers from the elementary classroom visit these students made to deliver inquiry-based science education *during the time the game was being implemented* clearly show that students were very positive about the idea of inquiry-based learning. It may be that the drop in scores is due to the instrument design itself. The five-point Likert-type scale is anchored by Strongly Agree on the left side and Strongly Disagree on the right side. Students may not have interpreted the categories correctly, believing that values to the right of the scale indicated agreement rather than disagreement. This latter possibility and the first explanation (ceiling effect) are strengthened by the students' self-reported overall experience of the game, which was positive.

H2: PSTs will demonstrate better conceptual science understanding after playing the game. Scores on Items 1–6 increased from preinstruction (3.46) to postinstruction (4.53) and postgame (4.69). Scores on Items 7–8 increased from preinstruction (2.38) to postinstruction (5.30), but decreased at postgame (4.76). Gains were generally distributed across all items. Paired t-tests showed that changes in all item scores were statistically significant from pre- to postinstruction. Scores on the same tests (totals of Items 1–6 and 7–8) after the game were also higher, although the differences were not statistically significant, with the exception of Items 2 and 7; Items 6 and 8 actually decreased.

Item 2 focuses on the conceptual understanding of the path of the sun and was directly tied to the animations of the sun in different cities within the game. Item 7 is an open-ended question focused on the relationship of day–night hours and latitude and longitude designed to assess conceptual understanding rather than factual knowledge. Both questions are directly addressed through gameplay. The increase in this score is evidence that students improved in their understanding of these concepts overall.

Item 6 focuses on how long it takes the Earth to turn on its axis, and Item 8 assesses the strength of the learner's mental model of how and why seasons occur in the first place. Because of modifications to the game during the design process, in which planned content had to be reallocated across future games in order to manage learner cognitive, neither of these concepts was directly represented or tested during gameplay. Thus, the decrease in scores on these items reflects the natural decay of knowledge after instruction (i.e., they forgot what they knew about this content from the classroom instruction phase of the study). Science content that was addressed by the game thus negated knowledge decay across the board or increased both factual and conceptual understanding. Further, in many cases, it would have been more likely to observe decreases by virtue of a regression toward the mean. Given the low power yielded by the small sample size (a 52% chance of detecting a directional increase in scores for a large (.5) effect size, and less than a 10% chance for a small (.1) effect size), *any* increases are significant.

Finally, analysis of individual test items and mastery-level scores indicated that there were more people at mastery on all but Item 6 at posttest for the game than at the beginning. Of particular note, the number of people at mastery for Item 2 increased by 24% as opposed to a 14% increase observed from pre- to postinstruction. Likewise, where no increase in the number of people at mastery was observed for Item 3 from pre- to post-instruction, there was an increase of 15% at mastery from pre- to postgame. That none of the class had a perfect score across all items is evidence that the content remains challenging for students and thus is a suitable subject for innovative methods of instruction like game-based learning. Focusing on this content over the course of one or two more games should lead to increases in learning.

H3: PSTs will demonstrate better attitudes toward games in the classroom after playing the game. Surprisingly, PSTs had a more positive attitude toward games at pretest (i.e., they saw fewer barriers) in the classroom than previous literature has suggested. Scores on measures of first-order barriers (those seen as external constraints such as access or support for technology) were in the positive range, meaning that PSTs did not say such barriers were prevalent, although PSTs tended to believe that these barriers could exist. These opinions do not reflect the actual state of affairs in K–12 schools, of course, as PSTs have not had any significant experience teaching at this point in their education. Still, it is encouraging to know that they do not enter the field with strong beliefs that first-order barriers are prevalent. Second-order barriers (those that tend to be related to internal beliefs and attitudes of teachers) at pretest were even more positive overall than first-order barriers.

Another surprise was that posttest scores tended to be lower across the board than pretest scores indicating that the game made PSTs come to believe there could be more barriers to the use of games than they had initially thought. There are two things to keep in mind when interpreting this finding. First, while the drop was *statistically* significant, it was not large (.18), which leaves the rating between "no opinion" and "agree" that such barriers do not exist. Second, because the vast majority of PSTs here are infrequent gamers (Salentiny, 2012; Van Eck et al., 2013), PSTs may have had naive expectations about the challenge and time that playing a game entails. Their initial ratings of barriers are not based on any meaningful teaching experience in the schools nor upon any meaningful experience playing games. Thus, PSTs may not realize how difficult games are and how restrictive classrooms and schools may be. After playing the game, and after teaching four science units in existing schools as part of their Earth and Science course, PSTs may have come to realize that their initial beliefs were not realistic. Games are difficult to play and even more difficult to integrate into the classroom (Van Eck, 2008), which is something PSTs may not realize until they have played games and taught in classrooms.

H4: PSTs will demonstrate better attitudes toward teaching science after playing the game. Overall, participants had positive beliefs about science and teaching science to begin with (tended to “Agree” with positive statement about science), and these did not change over short duration of this study. On average, participants scored between 3.6 and 3.9 on the modified BAMS subscale, 3.3 on the modified ATMS subscale, between 3.8 and 4.0 on the modified BATS subscale, between 3.85 and 4.15 on the ALTMS subscale, and between 3.08 and 3.23 on the ATTS subscale. Paired t-tests indicated none of these differences were statistically significant. Given the high initial scores and the short duration of the game (generally less than 2 hours), it is not surprising to see little change in attitudes. Such changes may be more likely once the full game has been developed and implemented.

Conclusion

Overall, the game appears to be effective. The product is effective in promoting science learning, can be integrated effectively into science education classes, and makes use of a model that is extensible to other science content. Gains in science content were seen for those areas directly addressed by the game, which is the first of several planned games on the topic. These gains were above and beyond what occurred as part of classroom instruction, indicating that the game can be effective as a stand-alone product. For the purposes of this evaluation, the game was kept separate from the classroom instruction in order to test the game’s additive effect on classroom instruction. If the game and the classroom instruction were deliberately integrated and used concurrently, however, there could be a synergistic effect on learning that exceeds what was found in this evaluation. Because the game does work on its own, there is promise for its use in homeschooling and self-study informal learning environments as well.

Whether the game can effect attitude change toward science and games in the classroom is yet to be determined. The small sample size of this study is not sufficient to detect such differences if they exist. Further, attitudes and beliefs often take a long period of time to change, and this intervention was approximately one-fifth of the final planned product. Participants played less than 2 hours in most cases, which is likely not long enough to effect attitude change in any regard. This is especially true given the high (positive) attitude scores of participants at the start of the study, which made changes harder to detect (the effect size would be limited by the upper bound of the instrument to measure attitude change). It remains to be seen whether this sample is atypical in this regard or not. If not, then it may be that future interventions need only focus on having teachers use games like *NEO* to improve their own learning, without having to overcome barriers toward the games’ acceptance in the first place. Likewise, future interventions using games as instructional tools in the K-12 classroom might be able to focus on teaching teachers how to use games for instructional purposes in their classes without overcoming those barriers.

It should be noted that having positive attitudes toward games and science is no guarantee that PSTs will be *successful* in using games or in teaching science. Part of the goal of this project was to address documented shortcomings in PSTs’ conceptual knowledge of science. One’s attitudes toward science are impacted by how well one actually knows the subject. If PSTs don’t have an accurate picture of their own science competence, their attitudes are of less predictive value. In other words, a PST who thinks he or she is great at science but actually is not will be overconfident. While this may lead to PSTs pursuing science lessons as a teacher without trepidation, the PSTs confidence is built on an insecure foundation and will change when he or she is confronted with gaps in knowledge. We do not want to send PSTs out to teach science with positive attitudes unless it is founded on experience and backed by competence.

Elementary PSTs don’t get a lot of exposure to science education once they are done with their general education requirements, so it may be that they have not yet learned how far they have to go. Once they do, their attitudes toward science may shift. We cannot know with certainty where our sample are on this continuum, but even with the observed gains from the class and the game, no students were at mastery level, indicating they may yet have a way to go, regardless of how confident they feel.

Likewise, positive attitudes toward games shows that teachers perceive there to be few external or internal barriers to using games. But here, too, their lack of experience may undercut the predictive value of their attitudes. They have not yet taught in the schools, so they do not know what first-order barriers do or do not exist. And because (at least these) PSTs are lower users of technology than other majors in many regards, including games, positive attitudes toward games at this time (i.e., without experience) may not be a worthy end goal. When it comes to attitudes in PSTs, we may actually need to look for an initial drop in scores as their beliefs become aligned with reality (competence and experience), followed by an increase over time as first competence and then positive attitudes increase. This argues for a multipoint observational protocol, which will be adopted in future evaluations.

Evidence continues to mount that shows the myth of the digital native is just that. Younger college students may be more exposed to technology, but their knowledge is shallow and they need both fluency and literacy training in technology integration. It may well be that the more PSTs are exposed to gaps in their science knowledge and to games as an activity they must complete, their attitudes toward both will change; dropping first as perceptions are aligned with reality, and later becoming more positive as they become more competent with science and games. Interventions like this should include training on games and gameplay and should do so as part of a comprehensive training program that connects the game to both learning (in PST education) and teaching (in K-12 classrooms).

References

Ball, D. L., Bass, H., Sleep, L., & Thames, M. (2005). A theory of mathematical knowledge for teaching. Paper presented at The Fifteenth ICMI Study: The Professional Education and Development of Teachers of Mathematics, 15-21 May 2005, State University of Sao Paolo at Rio Claro, Brazil. Retrieved January 31, 2014, from http://stwww.weizmann.ac.il/G-math/ICMI/ball_ICMI_prop_oct11.doc.

Broussard, S. R., La Lopa, J. M., & Ross-Davis, A. (2007). Synergistic Knowledge Development in Interdisciplinary Teams. *Journal of Natural Resources and Life Sciences Education, 36*, pp. 129–133.

Bybee, R.W. et al. (1989). *Science and technology education for the elementary years: Frameworks for curriculum and instruction.* Washington, D.C.: The National Center for Improving Instruction.

California Council on Science and Technology (2010). The preparation of elementary school teachers to teach science in California. Sacramento: CCST. Retrieved February 5 from the World Wide Web at https://www.ccst.us/publications/2010/2010K-6.pdf

Darling-Hammond, L. (2000). *Teacher Quality and Student Achievement*, Seattle: Center for the Study of Teaching and Policy, University of Washington.

Ertmer, P. (1999). Addressing first- and second-order barriers to change: Strategies for technology integration. *Educational Technology Research and Development, 47*(4), pp. 47–61.

Fraser, B. J. (1981). *Test of Science-Related Attitudes*. Australia: The Australian Council for Educational Research Limited.

Fullan & Stiegelbauer (1991). *The new meaning of educational change* (2nd ed.). New York: Teachers College Press.

Hawk, P. P., Coble, C. R., & Swanson, M. (1985). Does certification matter? *Journal of Teacher Education May 36*(3), pp. 13-15. doi:10.1177/002248718503600303.

Hill, H., Rowan, B., & Ball, D. (2005). Effects of teachers' mathematical knowledge for teaching on student achievement. *American Educational Research Journal*, 42(2), 371.

Jarret, O.S. (1999). Science interest and confidence among preservice elementary teachers. *Journal of Elementary Science Education, 11*(1), pp. 49–59.

Langdon, D., McKittrick, G., Beede, D., Khan, B., & Doms, M. (2011). *STEM: Good Jobs Now and for the Future*. US Department of Commerce, Economics and Statistics Administration (ESA) Issue Brief #03-11. Retrieved November 3, 2012 at http://www.esa.doc.gov/sites/default/files/reports/documents/stemfinalyjuly14_1.pdf

Llewellyn, D. (2002). Inquire within: Implementing Inquiry-Based Science Standards. Thousand Oaks, CA: Corwin Press.

McGinnis, J.R. & Watanabe, T. (1999, Spring). The use of research to inform the evaluation of the Maryland Collaborative for Teacher Preparation. Journal of Mathematics and Science: Collaborative Explorations, 2, 91–104.

McGinnis, J.R., Watanabe, T., Roth McDuffie, A., Kramer, S., & Shama, G. (1997). The Maryland Collaborative for Teacher Preparation: Making sense of the enactment of reform in the preparation of specialist teachers of mathematics and science. In Rubba, P., Keig, P., & Rye, J., (Eds.), *Proceedings of the 1997 Association for the Education of Teachers of Science* (pp. 326–347). Pensacola, FL: Association for the Education of Teachers of Science.

NGSS Lead States (2013). Next Generation Science Standards: For states, by states. Achieve, Inc., on behalf of the twenty-six states and partners that collaborated on the NGSS. Retrieved February 5, 2014, from the

World Wide Web at http://www.nextgenscience.org/next-generation-science-standards.

Salentiny, A. (2012). Analysis of preservice teacher and instructor technology uses and beliefs [dissertation]. Retrieved from ProQuest, #3516806.

Stevens, C. and Wenner, G. (1996). Elementary preservice teachers' knowledge and beliefs regarding science and mathematics. *School and Science Mathematics, 96*(1), pp. 2–9.

Van Eck, R., Brewster, S., Roberts, N., Brown, R., & Triad Interactive Media (2013). *PlatinuMath: Final evaluation report* [unpublished grant report].

Van Eck, R. (2008). COTS in the classroom: A teacher's guide to integrating commercial off-the-shelf (COTS) games. In R. Ferdig (Ed.), *Handbook of research on effective electronic gaming in education* (pp. 179–199). Hershey, PA: Idea Group.

Wu, H. (1999). Preservice professional development of mathematics teachers. (March 1999). Retrieved from http://math.berkeley.edu/~wu/pspd2.pdf