Benefits and Limitations of iPads in the High School Science Classroom and a Trophic Cascade Lesson Plan

Nicholas D. Ward,[1,a] Rachel J. Finley,[2] Richard G. Keil,[1] and Tansy G. Clay[1]

ABSTRACT

This study explores the utility of a set of tablet-based personal computers in the K–12 science, technology, engineering, and mathematics classroom. Specifically, a lesson on food-chain dynamics and predator–prey population controls was designed on the Apple® iPad platform and delivered to three sophomore-level ecology classes (roughly 30 students per class with six iPads). Questionnaire feedback indicated that most students greatly enjoyed and were engaged in the activity. Further, student understanding of core concepts generally increased after participating in the tablet-based activity. Here, the iPad was essentially used as a data generator for a calculation-based activity, which is one of many potential applications of a class set of tablets. The collective results of this study indicate that student engagement and concept building is enhanced by immersive, tablet-based activities and a lesson plan that can be readily used in K–12 science classrooms is provided. © *2013 National Association of Geoscience Teachers*. [DOI: 10.5408/13-008.1]

Key words: tablet, iPad, mobile, STEM, K–12, ecology, food chain, trophic cascade, lesson

INTRODUCTION

Innovations in personal electronics technology are seldom driven by the needs of educators but by the desires of retail consumers. However, there is great potential to connect with learners on a more-personal level as mobile devices become increasingly interconnected with our daily lives. Technological innovations provide novel tools for educators to connect and communicate with students. Implementation of these tools may allow for major, positive transformations in our perceptions of the traditional, lecture-based pedagogy (Bransford et al., 2000), but it is important that educators consider both the benefits and the inherent limitations of a platform before adopting it throughout an institution. Further, in some cases, the utility of a platform is limited by school policy, highlighting the need for educators and administrators to work together when adopting new technology in the classroom.

The most-obvious benefit of using innovative technology in the classroom is the ability to spark student interest and to provide a seemingly personalized educational experience. Student motivation, an important factor in deep learning, is thought to be enhanced by educational programs crafted for individual student needs (Deci and Ryan, 1985). For example, incorporation of computer-mediated communication has been successfully used to foster constructivist and individualized learning programs (Abrami and Bures, 1996; Muir-Herzig, 2004). Rau et al. (2008) observed that communicating with high school vocational students about assignments via mobile Short Message Service (SMS) generally increased student extrinsic motivation without causing higher pressure. Additionally, communication on a digital medium has been shown to enhance a student's likelihood to ask for help from instructors because of a greater sense of anonymity and decreased intimidation by social cues (Bures et al., 2000). Several studies have indicated that using technology in the classroom adds complexity to learning tasks, which encourages peer coaching and collaboration (Baker et al., 1990; Dwyer, 1994).

The current generation of western K–12 students has been immersed in mobile communication technology since birth. Student familiarity with the use of mobile and touch screen devices is highly prevalent, especially in urban schools. The use of cutting-edge consumer technology in the educational setting has great potential for connecting with young students on a more-personal level and for embracing individualized learning but is often hard to adopt on an institution-wide basis because of high entry costs and fears of obsolescence. The compact, flexible nature of modern tablet personal computers (PCs) has the potential to drastically transform both student and instructor immersion. As availability becomes more widespread, educators are beginning to unravel the utility of tablets in the classroom. For example, tablet PCs have been successfully implemented as mobile presentation platforms for instructors in a lecture setting (Anderson et al., 2004). Further integration of tablets into university-level courses has allowed students and instructors to share handwritten notes taken on personal tablet devices, fostering increased student participation (Golub, 2004; Anderson et al., 2007). Increasingly, the utility of tablets in engaging young students is beginning to be recognized (Couse and Chen, 2010).

Although the use of tablets by instructors has become increasingly widespread, there has been little development in the use of class sets of tablets in K–12 Science, Technology, Engineering, and Mathematics (STEM) classrooms. Here, we developed a high school ecology lesson, using the iPad (Apple, Cupertino, CA) tablet platform in combination with more-traditional media, and evaluated changes in student understanding. The primary goal of this study was to detail both the benefits and limitations of the iPad platform and

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[1]School of Oceanography, University of Washington, Box 355351, Seattle, Washington, 98195-5351, USA
[2]Garfield High School Science Foundation, 400 23rd Avenue, Seattle, Washington, 98122, USA
[a]Author to whom correspondence should be addressed. Electronic mail: nickward@uw.edu. Tel.: 206-616-5394.

provide our firsthand account of implementing an iPad-based lesson in a high school ecology classroom.

STUDY DESIGN AND LESSON PLAN

Student Demographics

This study was performed at a local Washington state high school (grades 9–12) in the Seattle urban area. Three separate ecology classes of varying size were given the lesson described below in an effort to examine the effectiveness of tablet-based education in the high school science classroom. Students who are enrolled in this ecology course are typically in their second year of high school and have taken an introductory biology course during their first year. Students who are most likely to enroll in Advanced Placement (College Board, New York City, NY) science courses will typically enroll in chemistry instead of this ecology course. Most students in this study ($n = 49$) were in 10th grade. The gender distribution was nearly equal, with 49% and 51% female and male students, respectively. The high school is made up of a diverse student population, with a school-wide distribution of 37.6% white, 30.2% black, 22.1% Asian/Pacific Islander, 21.9% Asian, 7.7% Hispanic, and 0.8% American Indian/Alaskan Native students; 41.3% of the student body qualifies for free or reduced-cost meals, 6.2% are enrolled in special education programs, and 5.6% of the students are transitional bilingual.

Students involved in this study had taken the Washington State–administered High School Proficiency Exam (HSPE) the year before being enrolled in ecology, an exam used to gauge grade-level proficiency in reading, writing, math, and science. Of the students who participated in this study, 67% had below-proficient scores (e.g., 2 or less out of 4) on the science portion of the HSPE, whereas 33% of the students had satisfactory or greater scores (e.g., scored 3–4).

Learning Goals and Washington State Standards

In Part I, students collected and recorded ecological data in an effort to reconstruct food-chain models based on observations and quantitative data. Students explored the concept of energy transfer through trophic levels and the loss of energy via respiration/metabolism.

In Part II, students interacted with a dynamic predator–prey population model in an effort to visualize and identify the linkage between predator and prey populations. Students were then able to identify examples of top–down and bottom–up population controls.

Skills:

- Data collection
- Models/data representation

Washington State Standards:

- Standard performance expectation code: 9–11 LS2C
- Short description: Limitations on population growth
- Long description: Population growth is limited by the availability of matter and energy found in resources, the size of the environment, and the presence of competing and/or predatory organisms.

Activity Logistics

The lesson plan was conducted during a 2-h laboratory period, and a debriefing was conducted during the next day's standard 55-min period (Fig. 1).

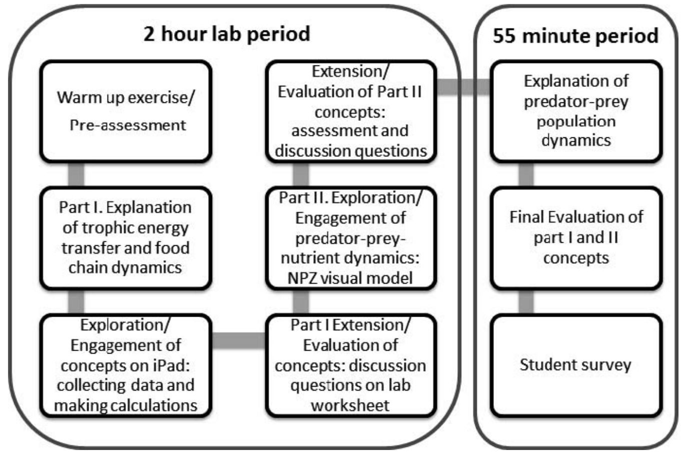

FIGURE 1: Timeline for a two-part lesson on trophic energy transfer and predator–prey population dynamics. The activity was conducted during a 2-h laboratory period with a debriefing and final assessment in the next 55-min class period.

Part I: Food-Chain Dynamics and Trophic Energy Transfer

The class period began with a warm-up exercise both to gauge the initial level of student understanding and to promote student engagement early in the class period. Students were asked to explain why a person would or would not gain one pound of body weight if they were to eat one pound of food and to explain some of the ways that their bodies use and store energy. Student responses were later scored on a scale of 0–3 for concept understanding (see Table I). That score was used as the preassessment for the concepts explored in Part I. Students were also asked several similar questions on the laboratory worksheet (Supplemental Material), which was scored with the same rubric. The students answered these questions after completing Part I of the lesson, and their scores were used as the postassessment for the Part I concepts.

After the warm-up exercise, a brief 5–10-min lesson on basic food-chain construction was given by the instructor. Basic concepts concerning the fixation of energy by autotrophs, the consumption of lower trophic levels by heterotrophs, and the loss of energy between trophic levels via respiration were discussed. Following the short lesson, the students were given the laboratory worksheet and laboratory instructions to read over before starting the activity (Supplemental Material). Students were asked to explain the laboratory instructions to the class before choosing groups of two to four, depending on the class size. After everyone was clear on the instructions, each group was given one iPad tablet (Fig. 2).

The iPads were loaded with the *Food Chain—The Game* application (app; developed by Lukas Biewald and available at: http://filedir.com/ios-games/educational/food-chain-the-game-for-ipad-1013863.html), a simple game in which the player controls a crab in an effort to avoid predators and consume prey (Fig. 3). The crab advances up trophic levels, eventually eating its previous predators. Once eaten by a predator, the app displays how many of each animal type was eaten by the crab and also the final mass of the crab. Students were asked to use the *Food Chain—The Game* app

TABLE I. Student score rubric for preassessment and postassessment.

0: Student either made no attempt to answer the question or did not show an understanding that the mass of food consumed does not equal the mass of weight gained by an organism.
1: Student showed a vague understanding that the mass of food consumed does not equal the mass of weight gained by an organism but is unable to explain why. Student does not mention energy use/storage.
2: Student showed a clear understanding that the mass of food consumed does not equal the mass of weight gained by an organism and that food is used by heterotrophs for energy.
3: Student showed a clear understanding that the mass of food consumed does not equal the mass of weight gained by an organism and that food is used by heterotrophs for energy. The student recognized that metabolism/respiration is a sink for energy.

to collect those data for additional calculations and considerations (Supplemental Material). Finally, students reconstructed the food chain of the game based on their observations of the different trophic levels.

In its original design, this lesson used the iPad for every aspect of the lesson (including Part II described below). For example, students would enter their data into preformatted Excel (Microsoft, Redmond, WA) spreadsheets, and food-chain diagrams would be drawn and saved on the iPad using one of many whiteboard apps. However, because of the constraints of the iPad platform and school Internet-security compliance issues, these parts of the lesson were done on paper and, in the case of Part II, the classroom projector (additional discussion of limitations to follow).

Part II: Population Dynamics

After all groups finished the Part I calculations and questions, the iPads were collected, and students returned to their desks to complete Part II as a class. The goal of Part II was to explore the influence of predator and prey populations on one another and examine several examples of bottom–up and top–down population controls. The instructor gave a demonstration of, and guided students through, the Nutrient–Phytoplankton–Zooplankton (NPZ) model visualization developed at the University of Washington (Banas, 2011). Model results of phytoplankton and zooplankton population sizes, nutrient levels, and detritus sinking and remineralization rates are displayed in this program in a graphic user interface. The user can control numerous parameters and observe how population sizes change. In particular, the instructor-guided students examined the influence of changing phytoplankton and zooplankton maximum growth rates. Top–down and bottom–up population controls were then explained in the context of this model (e.g., bottom–up control occurs when the phytoplankton population size was altered and affected the zooplankton population, and top–down control is when altering the zooplankton population affected the phytoplankton population). Students were also given several other typical examples of predator–prey population dynamics, such as the linkage between kelp, abalone, and sea otter populations.

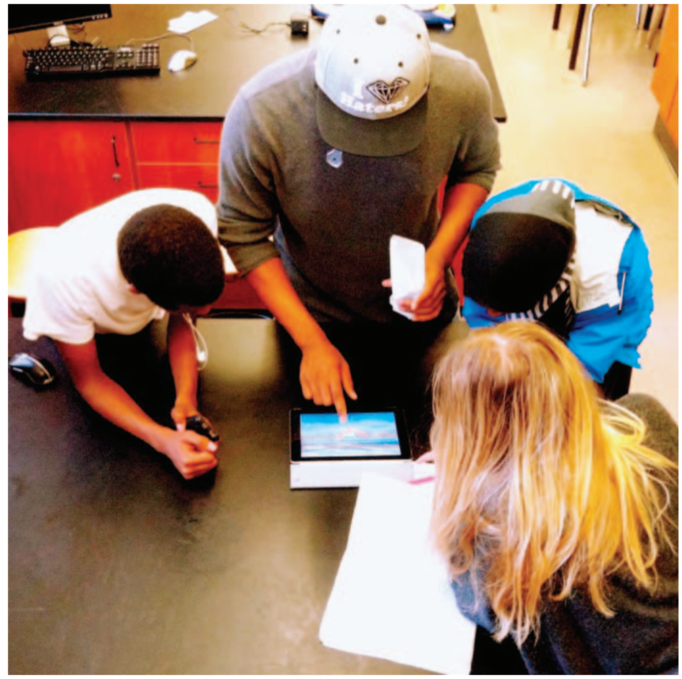

FIGURE 2: Students were given one iPad per group of three to four students.

Students filled out the Part II questions on the laboratory worksheet Supplemental Material while discussing the concepts (Supplemental Material). Originally, answers to these questions were intended to be used as a preassessment for the concepts explored in Part II, and the quiz described below was to be used as a postassessment. However, the Part II laboratory questions had minimal utility as a preassessment of initial student understanding because they were answered as part of a class discussion guided by the instructor. Alternatively, comparing student performance on the Part II laboratory questions versus performance on the quiz was a useful measurement of short-term (next day) concept retention.

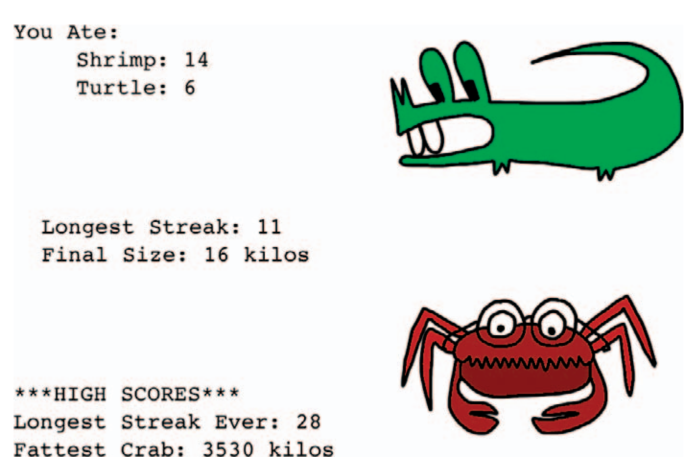

FIGURE 3: During Part I of the activity, students collected ecological data while playing the *Food Chain—The Game* iPad application.

Debriefing and Final Assessment (55-min Period)

The following day, the instructor gave a formal review of the key concepts discussed during both parts of the laboratory exercise. Students were then given a quiz, asking them to analyze a scientific plot of predator–prey populations changing over time (Supplemental Material). This assessment was compared with student scores on the guided Part II questions in the laboratory worksheet to assess how well students retained information presented to them as a class discussion. Preassessment and postassessment scores for Part I, on the other hand, were a useful measure of a student's increase or decrease in concept understanding during an interactive, exploratory type lesson. Finally, students were given a questionnaire asking for feedback and to rate certain aspects of the lesson (Supplemental Material).

We present data from these assessments in an effort to gauge the success of this lesson in terms of student learning. However, we do not attempt to quantitatively compare the effectiveness of our iPad-based lesson to a similar lesson using a more-traditional medium. Rather, our primary goal is to outline the benefits and limitations of the iPad for educators who are considering adopting the platform.

RESULTS AND DISCUSSION

Assessment of Understanding

Initial student understanding of the Part I key concepts was measured at the beginning of the class period with a written warm-up exercise (Part I preassessment). Similar questions were asked on the laboratory worksheet during the lesson and were used to gauge changes in student understanding (Part I postassessment). For both assessments, the student's level of understanding was scored from 0–3 (see Table I). Students generally scored low on the preassessment, with an average score of 1.1 ($n = 49$), with 22% of the students ($n = 11$) showing no understanding (i.e., score = 0 score), 47% ($n = 23$) showing minimal understanding (i.e., score = 1), 29% ($n = 14$) showing adequate understanding (i.e., score = 2), and only 2% ($n = 1$) showing an exceptional level (i.e., score = 3) of understanding.

To assess changes in student understanding, a student's score on Part I, Question 1, of the laboratory worksheet (see Supplemental Material) was subtracted from their score on the Part I preassessment (scores based on the Table I rubric). The relationship between a student's initial understanding (e.g., preassessment score) was then compared with their relative change in understanding (Fig. 4).

Students who showed a strong initial understanding of the concepts (i.e., scored 2–3 on the warm-up; $n = 15$ [31%]) generally retained the same level of understanding after the lesson. In general, students who had the lowest initial understanding (i.e., scored 0–1 on the warm-up; $n = 34$ [69%]) showed the most improvement in understanding after the tablet-based lesson (Fig. 1). All students (100%; 11 of 11) who showed zero initial understanding improved by at least 1 point and generally improved to an adequate understanding (i.e., scored 2 on postassessment). Students who showed minimal initial understanding (i.e., scored 1 on the warm-up) varied from showing no improvement to improving by 1–2 points. These results show that the lesson was successful in engaging students at the lower end of the initial understanding spectrum. However, from this alone, it is not possible to determine what role the technological novelty of using iPads played in enhancing student learning.

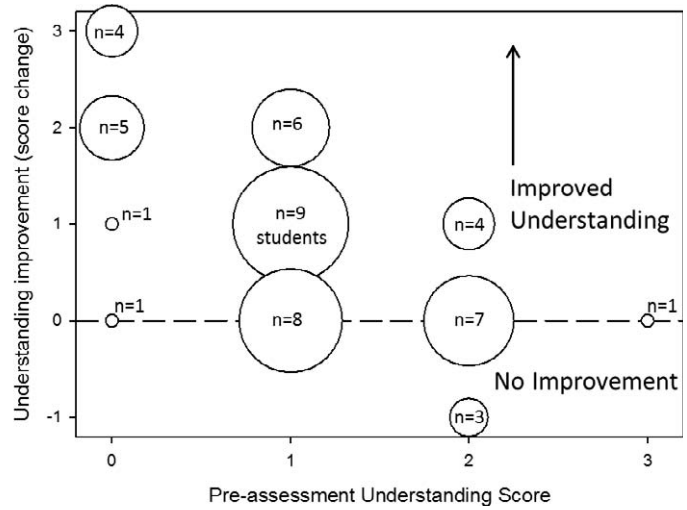

FIGURE 4: The relationship between a student's score on the warm-up exercise (preassessment) and their improvement in understanding (i.e., differences in postassessment and preassessment scores). A student's understanding was assessed on a scale from 0 to 3 ($n = 49$; see Table I for rubric scale).

Responses to Question 2 on the laboratory worksheet (see Supplemental Materials) were used to assess a student's level of critical thinking. During the data collection and calculation portion of the laboratory exercise, students were asked to calculate "growth efficiency" as the ratio of their average crab weight to their average weight of food eaten. However, students were never previously given a formal definition or any instruction on the meaning of *growth efficiency*. Students were then asked to rationalize and explain the meaning of *growth efficiency*, based on their knowledge of how it is calculated and given a score between 0 and 2 (see Table II for rubric).

Critical-thinking scores were compared with students' improvement in understanding to determine which types of students showed the greatest improvements (Fig. 5). Those students who received a score of zero on the critical thinking question showed no improvement over their preassessment level of understanding. On the other hand, students who performed well on the critical thinking question showed a greater improvement in understanding. These results imply that students who were uncomfortable or unable to answer an unfamiliar question were less likely to change or improve on their previous knowledge of the concepts, whereas those students who were able to rationalize or at least attempt to solve the unfamiliar question were more likely to change or improve their understanding throughout the lesson.

Part II of the lesson examined predator–prey population dynamics by exploring the NPZ model as a class. Because of constraints of the iPad platform (more discussion below), this part of the lesson was done on the classroom projector with the instructor walking students through the model. Students were closely guided through the questions on the laboratory worksheet (Part II "preassessment") and generally scored high, with an average score of 5 out of 6 (range =

TABLE II. Student score rubric for critical thinking assessment.

0:	Student either made no attempt to answer the question or did not display or address any of the terms in the *growth efficiency*
1:	Student showed a vague understanding that *growth efficiency* was related to how much biomass an organism fixed relative to the mass of food consumed. Student addressed the terms used to calculate growth efficiency and attempted to rationalize a definition from those terms.
2:	Student showed a clear understanding that *growth efficiency* was related to how much biomass an organism fixed relative to the mass of food consumed and that the difference between biomass consumed and biomass fixed was energy lost to respiration and metabolism. Student was able to rationalize the meaning of growth efficiency by examining the terms used to calculate it.

1–6; $n = 49$). Students were given additional lesson debriefing and a quiz (Part II postassessment) the following day with similar questions. In general, students who scored low on the laboratory worksheet increased their score on the quiz, and those who initially scored well either performed similarly on the quiz or scored one point lower on the quiz. The increase in low-performing student scores is likely a result of the additional debriefing given before the quiz; however, it would be interesting to see how well students retain information given to them in this type of formal lecture setting alone.

Student Survey

One to 2 d after the laboratory exercise, students were given a questionnaire asking them to rate various aspects of the lesson (see Supplemental Material). The three different class periods ranged in size, with student group sizes

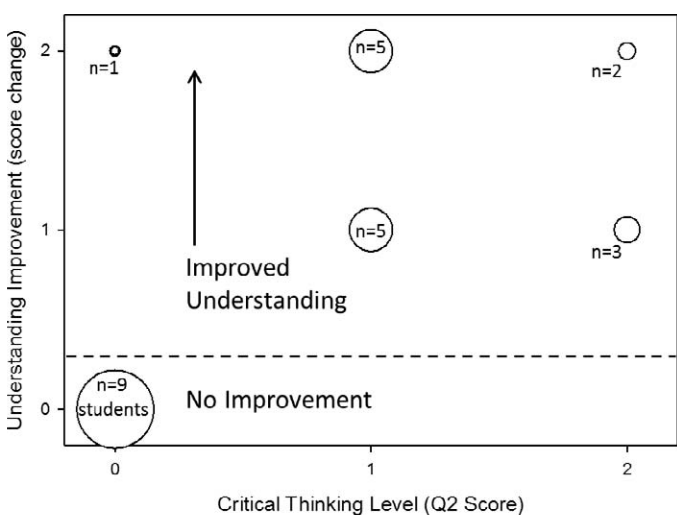

FIGURE 5: The relationship between a student's improvement in understanding (i.e., difference in post-assessment and preassessment scores) and their critical thinking level. Critical thinking levels were determined by a student's ability to rationalize and explain the meaning of *Growth Efficiency*, a term that they have never heard before, but were instructed how to calculate during the lesson ($n = 28$; see Table II for rubric scale).

ranging from two to four. Students in groups of two to three all responded that they felt like they were able to spend enough time using the iPads in their groups, whereas roughly 10% of the students in groups of four responded that they would have liked more time to use the iPad.

When asked how much fun they had with the activity (from 0–5), student responses were, on average, 4.5, with a range from 3–5 ($n = 49$). When asked how difficult the lesson content was, student responses were, on average. 1.6, with a range from 0 to 3. These results suggest that student engagement in the activity was high and, perhaps, this enhanced student engagement resulted in student perception of the content difficulty to be low. In other words, if students have fun they may perceive the lesson content as "easier."

When asked how much they thought they learned, students responded 3.8, on average, with a range from 3 to 5. Although students perceived the content as "easy," they also acknowledged that they learned a significant amount throughout the lesson. Students rated their preference for a tablet-based lesson compared with a "traditional lesson" as 4.6 on average, ranging from 2 to 5, and 98% of the students (48 of 49) responded that they enjoyed Part I of the laboratory exercise (i.e., tablet portion) more than they did part II (phytoplankton model demonstration). In general, students responded that their favorite part was playing the game and their least favorite part was performing calculations and answering questions.

Clearly, the students were engaged by the novel experience of using a tablet PC, and that engagement likely enhanced student involvement in the more-rigorous aspects of the lesson. Anecdotally, students who typically showed little to no involvement in regular classroom activities were much more engaged during this activity and showed large improvements in their concept understanding. Contrary to typical laboratory exercises in this particular classroom, every student completed the entire laboratory worksheet and provided meaningful responses to the synthesis questions.

Logistical Considerations for Instructors

By far the most important consideration when designing a tablet-based lesson is strategizing the desired time frame for tablet use to maximize student productivity and minimize off-task behavior. In this study, the students participating in the first class period of the lesson were given more freedom to finish the laboratory at their own pace. Only a handful of students stayed on task and completed the calculations and questions in a timely manner, whereas many students did not begin any of the calculations until the iPads were taken away from them. Another problem arose when students were asked to calculate averages for their entire group. When performing calculations as a group, typically one student did all of the work, and the others engaged in off-task behaviors. The activity was barely finished by the end of the 2-h class period.

The next two class periods to perform the lesson were given stricter instructions on the lesson time frame. Groups were given only 20 minutes to complete their data collection on the iPad, then given a discreet timeline on when they should finish the calculations and move on to the questions. Student productivity enhanced greatly with these explicit timelines. Interestingly, students in these class periods moved on to the calculations as soon as they were done collecting data (before the 20-min time limit). Whereas students in the class without discreet time limits were distracted by holding the iPads when they should have been performing calculations, the students in classes with time limits did not need to have their iPads taken away to make progress on the laboratory worksheet. The class periods with time restrictions were able to finish the lesson with roughly 20 to 25 min of class time to spare and were rewarded with free time to explore the other iPad apps. These two class periods were also instructed to calculate averages of their own data only, rather than group averages. Students appeared to work much more diligently and put more thought into answering questions when asked to do so individually.

With the above considerations in mind, an instructor can take additional steps to minimize off-task use of the iPad. There are a handful of apps that allow the instructor to determine which apps or Web sites students are able to access. For example, *Guided Access* (Apple) allows an instructor to allow only one designated app to be used. *Padlock* (Mizage, available at: http://mizage.com) and *KioskPro* (Kiosk Group, Frederick, MD) are useful apps for limiting users to specific Web sites. Although these and similar apps can enhance student productivity, they may also help the iPad fit within the restraints of school Internet security policies discussed below.

Considerations and Limitations of the iPad Platform

The lesson was originally designed to be carried out completely on the iPad, including the calculations (to be performed and plotted in Excel spreadsheets) and Part II of the lesson, exploring the NPZ model. However, constraints of the iPad platform and school Internet connectivity guidelines made an entirely tablet-based lesson problematic. First, the high school (and most other schools consulted in the area) would not allow the class to connect to wireless Internet on the iPads because of Internet security issues. Unfortunately, many iPad features and apps require an Internet connection, so we were somewhat limited from the start. Ideally, students would have performed all of their work on the iPad and saved it to an online storage space such as *Dropbox* (Dropbox, San Francisco, CA) or *Google Drive* (Google, Mountain View, CA) shared with their instructor.

Second, the iPad platform is somewhat limiting in itself. For example, the NPZ model, developed by University of Washington researchers, is displayed as a Java (Oracle, Redwood Shores, CA) applet in a web browser. Internet connectivity issues aside, the iPad restricts viewing both Java and Adobe (San Jose, CA) Flash-based Web content. There are ways to get around this limitation by using apps such as *Cloud On* (Palo Alto, CA), which access remote servers to view the iPad-restricted content. However, testing of many of these apps was unsuccessful because they are typically designed for viewing videos rather than interactive Web sites. Many educational tools that are currently being developed or have been developed already by scientists use these older programming languages. Thus, Apple has severely limited the utility of the iPad in an educational setting by restricting the use of Java and Flash-based Web content. A tablet PC with fewer content and application restrictions, such as Android-based (Google), would have fewer potential drawbacks in the educational setting.

It is important that educators are aware of these types of limitations. More important, instructors should design lessons and uses for the tablet that amplify the benefits of the platform, rather than those that highlight its limitations. For example, a great tool that could be used every day in the classroom is *Type on PDF* (Tipirneni Software, Glendale, AZ), which allows students to write on portable document format (pdf) copies of laboratory worksheets, instructions, readings, and more. There are numerous apps with tremendous utility for classroom management such as *Desire2Learn* (D2L, Baltimore, MD) and *Blackboard* (Washington, DC). Apps such as *Dropbox* and *Google Drive* are incredibly useful for sharing files, such as projects and homework assignments, and are typically integrated into other functional apps.

CONCLUSION

The feedback from students was highly positive regarding the tablet-based lesson, with most asking when the next iPad lesson would be. Student engagement was anomalously high, especially among those students who typically struggle to participate in regular classroom activities. Here, we took the approach of using a game to collect data and open the floor for discussion on some basic science concepts. Most students related well to the gaming aspect; however, caution must be taken to ensure that the lesson content is taken seriously using this type of approach. Classroom management is central to a successfully run lesson, regardless of platform. Managing when students have access to the tablets and setting explicit timelines for each part of the lesson proved useful for maximizing student productivity.

Many different approaches can be taken to integrating a tablet PC into a K–12 STEM classroom. An institution should assess the different approaches they hope to use before purchasing large class sets of tablets. Hardware and software limitations of specific tablet platforms should be considered to determine whether a specific tablet is the right choice for a class set. For example, the camera function can be a nice tool for student projects based on observing visual changes over time or for constructing oral/video presentations. With proper wireless Internet connectivity and an appropriate software package, a class set of tablets could also be used to replace desktop computers in the classroom, which are most often used for Internet research and word processing. In addition to saving laboratory counter space, the tablet seems to be more intuitive for the current generation of students. If using tablets as computer replacements, however, it is incredibly important to have an effective theft-prevention strategy because the tablets are desirable items and much more mobile than desktop computers.

The utility of a tablet PC in providing novel lessons, such as the one presented here, is mostly limited by the availability of content. There are many free applications such as the game used for this lesson. However, increased development of applications specifically designed for educational purposes would greatly raise the viability of tablet-based education. The lesson presented here used an application built purely for fun as a data generator, but with more attention to educational applications by software developers, the tablet PC could prove to be a useful source of content in the K–12 STEM classroom.

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SUPPLEMENTARY MATERIALS

Supplementary materials, including the worksheets and examples used, are available online at: http//:dx.doi.org/10.5408/13-008s1 or by contacting the corresponding author at nickward@u.washington.edu.