The Impact of a Pre-instructional Digital Game on Middle-grade Students' Scientific Misconceptions

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Rationale

Students' inaccurate understandings of some scientific concepts (often termed misconceptions) are highly persistent, and rarely displaced by explicit instruction in the classroom (Confrey, 1990). Teachers broadly acknowledge the difficulty of teaching topics that are the subjects of some of the most widely recognized scientific misconceptions (Driver, Squires, Rushworth, & Wood-Robinson, 1993; National Research Council, 2011). The middle grades offer a high-risk, high-reward opportunity to challenge and potentially shift these pre-existing concepts, because students in this age group are increasingly required to reflect on and reason about their own mental models of complex phenomena that are not available for empirical observation, such as the molecular processes underlying photosynthesis, the probability dynamics of genetic inheritance, and the behavior of energy flows through material systems.

This focus on increasingly abstract and not empirically observable phenomena coincides with the emergence of new cognitive capacities to engage with and reflect on counterintuitive and abstract concepts. These cognitive skills, however, require repeated rehearsal and cultivation if they are to become robust, reliable strategies for scientific thinking (Kuhn, 2009). A range of research has demonstrated that educators cannot rely on middle-school students to draw accurate inferences about multivariate systems spontaneously (Kuhn, 2001, 2009; Schauble, 1996) or emergent dynamics (Chi, Roscoe, Slotta, Roy, & Chase, 2011) in the course of instruction about new scientific concepts. Rather, like many adults (Schneps, Sadler, Woll, & Crouse 1989), we can anticipate that, absent a familiar grounding for constructing a new, emergent understanding of the target phenomena, students will continue to draw on pre-existing knowledge and experience to guide their understanding of the unobservable, sometimes counterintuitive, systems underlying these difficult topics.

This project sought to test the potential of portable, digital games as a way to provide this type of preparatory, pre-instructional experience. It draws on Bransford and Schwartz's "preparation for future learning" instructional model (1999), and positions digital gameplay as an activity that engages middle-grade students in repeated interactions, through core game mechanics, that are structurally analogous but nominally unrelated to the target concepts (as do sandbox play or open-ended construction activities for younger children). These repeated, shared in-game experiences then become a source for grounded analogical reasoning during teacher-led instruction. In this approach, digital gameplay becomes a necessary—but not sufficient—first step in an instructional process that includes multiple forms of engagement with the target concepts.

Locating gameplay prior to instruction has the added advantage of making it possible to move gameplay out of core instructional time in the classroom. Lack of flexible access to necessary hardware and software, and competing demands for limited instructional time,

continue to be chronic obstacles to broad, equitable adoption of innovative digital tools for deeper learning (Fox, Waters, Fletcher, & Levin, 2012).

This paper reports on a test of the impact of *Exploring Photosynthesis* on student learning. *Exploring Photosynthesis* is one of four supplementary modules developed as part of a federally funded research and development project. Each of the four modules focuses on one difficult-to-teach topic and includes a digital game and a series of related in-class, non-digital activities.

Description of the Intervention

The *Exploring Photosynthesis* module included the following materials and experiences: teacher professional development; the digital game, called *Ruby Realm*; an instructional PowerPoint presentation about photosynthesis; a kinesthetic classroom activity; a sense-making discussion; and a paper- and PowerPoint-based consolidation activity, called *No Way*! *No Way*! is a collaborative classroom game that invites students to evaluate claims and evidence in fantastic, science-related stories that involve photosynthesis.

Students play *Ruby Realm* for at least 30 minutes, as homework, prior to the beginning of the classroom portion of the intervention. Following gameplay, the teacher conducts classroom activities and discussions designed to help students build analogical connections between the digital game activities and the target concepts about the photosynthetic process.

Because this project sought to explore how relatively low-cost, portable digital devices might be used to support new configurations of technologically rich learning, we chose to develop these games for the Nintendo DS, which can deliver games that look and feel familiar and entertaining to many students, is designed to withstand being transported by children, and is low-cost.

The Current Study

This experimental study compared student performance on a photosynthesis knowledge assessment for middle-school students who study photosynthesis with and without the *Exploring Photosynthesis* intervention. The study poses three research questions.

1. Are teachers in the treatment group able to implement the intervention with a high level of fidelity?
    a. Do students take the Nintendo DSi's home and play the digital game as homework for the minimum amount of time required?
    b. Do teachers report using the various in-class materials and activities provided as part of the *Exploring Photosynthesis* module?
2. In classrooms where teachers implement the *Exploring Photosynthesis* module, do students demonstrate a significantly better understanding of how photosynthesis occurs and how mass and energy are conserved during chemical changes than do students in classrooms where teachers do not use the module?
3. Does the quality of teachers' instruction moderate the impact of the module on student understanding of the target concepts?

Method

This study used a group-randomized experimental design. Implementation of the intervention was staggered throughout the 2011–12 school year because science teachers cover photosynthesis at various points during the school year.

The study sample size ensured that the study would have the statistical power to detect a mean detectable effect size in student assessment scores between treatment and control groups of .24 of a standard deviation.

Sample

      Teacher sample. The final sample of 41 teachers taught in a total of 25 primarily middle-grades schools.

      Student sample. To reduce the data collection burden on teachers and students, for each participating teacher we randomly selected one class to be the "focal" participating class for the study and collected all study data from this classroom. A total of 914 students participated in the study. There were no statistically significant differences in the demographic characteristics or state standardized test scores between the students in treatment and control classrooms.

Measures

      Student assessment. We administered a 34-item, paper-and-pencil assessment during a regular classroom period of 40 minutes at the conclusion of the unit on photosynthesis. A composite total score was calculated for all students completing more than half of the items, and there was good internal reliability (α=.864).

      Other sources of student data. To support our analyses, we also collected data on prior-year student state standardized mathematics and language arts test scores, student demographic characteristics, student attitudes toward science, and the duration of student gameplay.

      Quality of instruction. We used the Classroom Assessment Scoring System-Secondary Edition (CLASS-S) observation framework to measure the instructional quality provided by each of the participating teachers during a typical day of science instruction (Pianta, Hamre, Hayes & Mintz, 2011).

      Teachers' implementation of the *Exploring Photosynthesis* module. Teachers in the treatment condition completed a log detailing aspects of the intervention that were implemented.

Data analysis

We investigated Research Question 1 using descriptive statistics. To answer Research Questions 2 and 3, we conducted two-level regression analyses using HLM 6 software (Raudenbush, Bryk, & Congdon, 2004). The HLM model conducted for this study includes student-level data in the Level 1 equation and teacher-level data in the Level 2 equation.

Results

Research Question 1: Implementation of the *Exploring Photosynthesis* intervention

For the students with gameplay data available (77.4% of the treatment group), the average gameplay time was 47.4 minutes (SD = 31.5), and ranged from 1 to 168 minutes. We also computed means and standard deviations for each of the four scales describing the self-reported fidelity of implementation of the *Exploring Photosynthesis* module. Teachers' responses on the *content coverage* subscale showed that on average they implemented 11.55 of the 12 items (SD = 0.8). The *student engagement* composite consisted of four questions and yielded a mean of 3.2 (SD = 0.8) with a range of 2–4. The *technical difficulties* composite consisted of 11 questions and yielded a mean of 3.2 (SD = 1.51; range 1 to 6).

Teachers' responses to items on the *making links between science content and the game* subscale indicate that of the 28 opportunities to link the game to science content, as outlined in the implementation log, teachers reported making 21.1 of the links on average (SD = 4.0, range 14 to 28).

Research Question 2: Impact of the *Exploring Photosynthesis* intervention on student outcomes

We used a multi-level regression to estimate the impact of the intervention on students' photosynthesis assessment scores. The Level 1 (student-level) model was:

$$Assessment_{ij} = \beta_{0j} + \beta_{1j}(StateMath_{ij}) + \beta_{2j}(StateLangArts_{ij}) + \beta_{3j}(TOSRA_{ij}) + \beta_{4j}(Male_{ij}) + \beta_{5j}(Age_{ij}) + \beta_{6j}(Minority_{ij}) + \beta_{7j}(IEP_{ij}) + \beta_{8j}(ELL_{ij}) + \varepsilon_{ij}$$

Because this is a teacher-level intervention and the study randomized teachers to the treatment and control groups, the test of whether the *Exploring Photosynthesis* module intervention had an impact on students' assessment scores is specified in the Level 2 (teacher-level) model:

$$\beta_{0j} = \gamma_{00} + \gamma_{01}(Treatment_j) + \gamma_{02}(PercentFRPLj) + u_{0j}$$

$$\beta_{1j} = \gamma_{10}$$

$$\beta_{2j} = \gamma_{20}$$

$$\beta_3 = \gamma_{30}$$

$$\beta_{4j} = \gamma_{40}$$

$$\beta_{5j} = \gamma_{50}$$

$$\beta_{6j} = \gamma_{60}$$

$$\beta_{7j} = \gamma_{70}$$

$$\beta_{8j} = \gamma_{80}$$

The results of the HLM analysis showed that the estimated value of $\gamma 01$ was not significantly different from zero, indicating that the photosynthesis assessment scores of students whose teachers were randomly assigned to use the *Exploring Photosynthesis* module were not significantly different from the scores of students whose teachers were assigned to the control group.

Research Question 3: Quality of teachers' instruction as a moderator of student outcomes

The results of this exploratory multi-level regression analysis indicated that while CLASS-S scores were not associated with students' assessment scores, there was a trend toward statistical significance for the *Treatment X CLASS-S* interaction term (p = .07) (See Figure 1). This finding suggests that implementing the *Exploring Photosynthesis* module in a way that positively influences students' learning may require that teachers are typically capable of providing higher-than-average instructional quality.

Figure 1
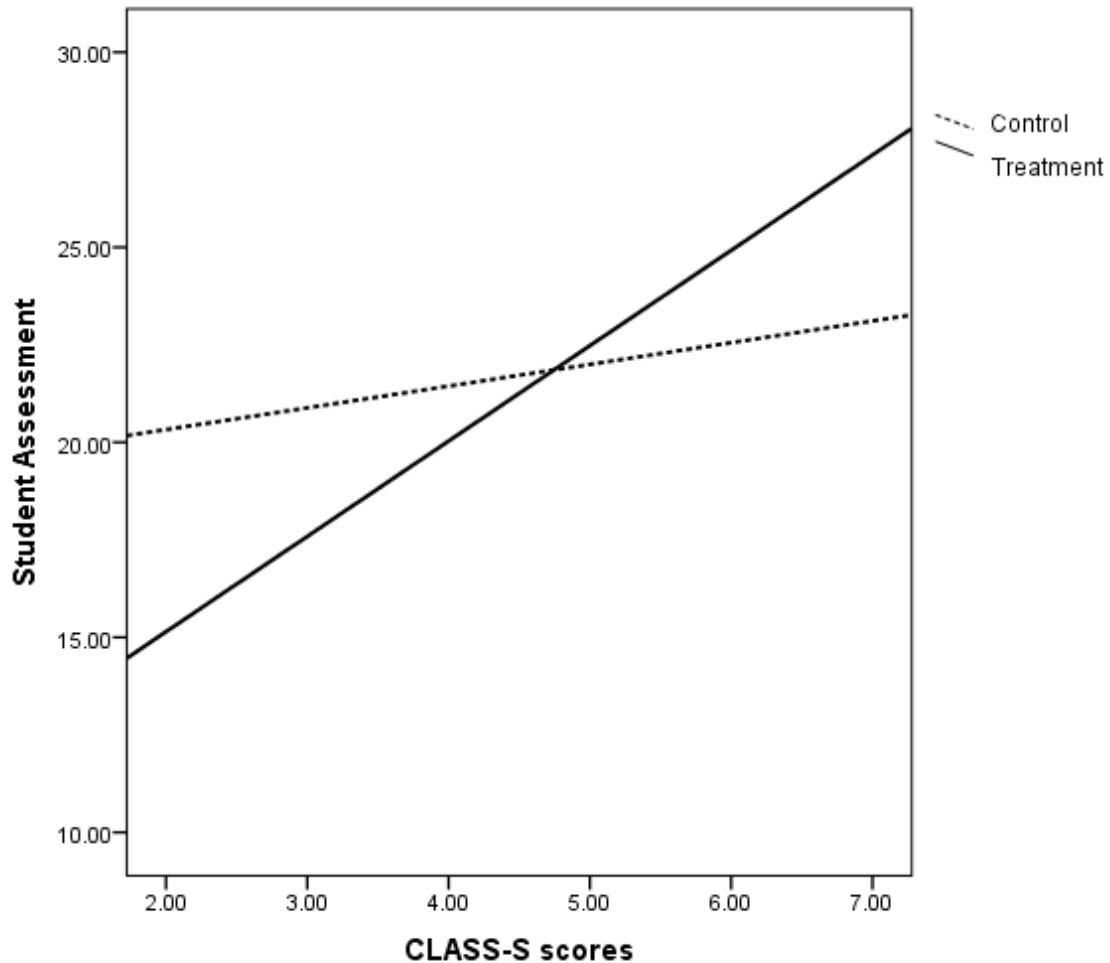
Discussion

This trial tested the impact of a supplementary intervention on student understanding of a particularly difficult scientific concept—that the photosynthetic process allows plants to use energy from the sun to convert gases and liquids (carbon dioxide and water) into glucose, a solid that is the building block of plant matter. The results of this study demonstrate that the module was implemented with a high degree of fidelity, and that the module did not have a significant impact on the quality of students' conceptual knowledge about photosynthesis and chemical change. It is important to note that this project sought to shift student understanding about a topic that has been documented to be the subject of persistent, lifelong misconceptions (Driver, Squires, Rushworth, & Wood-Robinson, 1993).

To investigate whether the project achieved this goal of creating a low-entry, truly accessible intervention, we used the CLASS-S observation tool to measure teacher instructional quality (Pianta, Hamre, Hayes, & Mintz, 2008). Our analyses of these data show that instructional quality was a significant moderator of student performance on the assessment used in this study. Across both treatment and control classrooms, students in classrooms led by more-accomplished teachers (as defined by the CLASS-S) performed better on the photosynthesis assessment than did their peers with less-accomplished teachers.

Conclusion

This randomized control trial was a first test of the impact of new curricular resources, including a digital game, and a specific instructional model on middle-school students' understanding of a notoriously difficult topic. The study design supports the conclusion that, in their current form, these supplementary materials do not have an impact on student outcomes as measured by an objective assessment closely aligned to the goals of the intervention. The study findings also show that teacher instructional quality played a meaningful moderating role in determining student outcomes across the sample as a whole. This study suggests that even when provided with a carefully constructed pre-instructional experience, middle-grade students need teachers to play a critical role as translators of these experiences.

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