Towards Research-based Strategies For Using PhET Simulations In Middle School Physical Science Classes

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Abstract. The PhET Interactive Simulations Project at the University of Colorado Boulder has begun a new effort to develop and research simulations ('sims') for middle school physical science. PhET sims have typically been aimed at the college level, but many sims are used in middle school classrooms. Thus, we aim to study the use of PhET sims at this level more systematically, particularly investigating elements of effective sim design and classroom implementation. Over the past year, we have collected observations of middle school students and teachers using PhET simulations. These observations include more than 80 student interviews as well as classroom implementations from 5th-8th grade by 4 different teachers. In this paper, we present initial insights that are emerging from these observations and propose several strategies for designing and implementing simulation activities. We include concrete examples of activities where these strategies have been used effectively.

INTRODUCTION

The middle school (MS) science classroom is not reaching its full potential. National studies show that 41% of 8th graders score below the basic level in science, with larger percentages among minority and low socioeconomic status students [1]. The Horizon report, *Looking inside the classroom: A study of K-12 mathematics and science education in the United States*, estimates that only 15% of MS math and science lessons are high in quality, while 59% are low in quality [2]. They note an emphasis on factual knowledge and procedures as well as a pervasive lack of emphasis on sense-making [2].

At the same time, Robert Tai's longitudinal studies show that students' interest in science by 8th grade correlates with their likelihood to major in science [3]. Thus, improvements in MS science education are critical to fulfilling the objectives in STEM education now echoed by multiple national reports [4].

The Horizon study, as well as the NRC's recent 2007 *Ready, Set, Science!* publication, describe several characteristics of high quality lessons aligned with research on learning [2]. High quality lessons actively engage students with the science content – e.g. they "invite students into purposeful interaction with the content through experience of phenomena, real-world examples…" They emphasize the process and dynamic nature of science – refinement of "understanding through conjecture, investigation,

theorizing, and application." They provide "multiple pathways for students to engage" and develop "conceptual connections among related phenomena and representations."

Interactive simulations are powerful educational tools [5] with the potential to support and enable teachers in crafting and delivering these high-quality lessons. They have the ability to make the invisible visible, to be dynamic and highly interactive, to scaffold and cue inquiry by what is displayed and what is controlled, to provide multiple representations, to embody causal relationships, and to allow safe (both physically and psychologically) access to multiple trials and rapid inquiry cycles. They can actively engage students and make learning fun and relevant. For English language learners and struggling readers, these rich, dynamic visualizations can embody key science concepts, bring textbook and spoken words to life with minimal text, and improve student-teacher and peer communication with shared visualizations.

With funding from the NSF and the O'Donnell Foundation, the PhET Interactive Simulations project has begun a new effort focused on studying the design and use of interactive simulations in middle school. We knew, through teacher reports and activity submissions, that many of the 100 PhET simulations were being used with MS students; however, all of the formal research and testing around the simulations had been conducted with college students [6]. Thus, over the past year, we have conducted numerous student interviews, observed dozens of classroom

implementations, and collaborated directly with MS teachers. In this paper, we present an overview of the project activities to date and report on initial insights and preliminary strategies for simulation use emerging from that work. We describe the data which inform the ideas reported here; detailed analysis of the data will be presented in forthcoming publications.

DATA COLLECTION AND METHODS

Student interviews, in which individual students are asked to think-aloud while freely exploring the simulation, are being used to study effective simulation design as well as to provide insights into how students in this age group learn from simulations. We have conducted over 80 individual interviews covering 14 different simulations, to date. Students range from 4th to 8th grade, and are mostly recruited from local Boulder youth soccer fields or school announcements. They include a balance of males and females and a small number of minorities (mostly Hispanic). All interviews are videotaped, and many include simultaneous screen capture recording. Shortly following each interview, summary notes are prepared. In analysis, these notes are reviewed to identify common patterns and themes.

Classroom implementation studies have been conducted in collaboration with 4 teachers in two Dallas-area charter schools. These K-12 schools focus on preparing all students for college-success and are open to the public through lottery. The student population is over 90% Hispanic with 70-90% 'at risk'. Over this past year, the teachers implemented 11 different simulation-based activities in a total of 24 classes ranging from 5th-8th grade. The activities were developed through collaboration between the PhET team and one or more of the charter school teachers. As discussed below, this collaborative relationship evolved over the course of the year with the PhET team having a larger role early in the year and transitioning to a more equal partnership or teacher-led activity development in the spring. Together, the activities span 12 different simulations (one activity used 2 sims) and typically included a pre-lab and post-lab to gauge learning.

Each activity was implemented over 1 to 2 days of class time, and most often integrated as part of a unit with other hands-on activities, worksheets, or discussions taking place before or after the simulation-based activity. Students worked in pairs – either with each having their own laptop or sharing a laptop. In some classes, teachers had access to a Smartboard which allows student and teacher interaction with the simulation on the board. Collected data includes video of the classrooms, field notes, student work, and (for a limited number of classes) screen-capture recording on up to 5 screens. For many of the activities, we also collected feedback from the teachers on the activity design and implementation after the activity – either as a written email or a recorded conversation.

INSIGHTS FROM INTERVIEWS

While this paper focuses on strategies for using PhET simulations in the classroom, student interviews have provided a few key insights that have proven useful for guiding activity development.

• **MS students engage with and enjoy using PhET sims.** Generally, students begin to use the sims seamlessly, pose questions (to themselves or the sim) which they answer using the sim, and are directly engaged in learning science from the sims. When students struggle with the ideas in the sims, they generally do not get discouraged and often express great joy in "figuring something out" after a bout of struggle and sense making. These students spend 40-60 minutes using a sim, and often need to be asked to stop because they appear to be so immersed in it. Students tell their parents they had fun and ask to come back. *Implication for using PhET:* Students will engage with simulations in a learning mode and enjoy it, if the lesson plan, activity, and facilitation enable and foster that outcome.

• **PhET-style sim controls are generally intuitive for MS students.** MS students have no issues with general controls like play/pause, dragging objects, using sliders and buttons. In some cases, MS students appear to be less inhibited about trying things and asking questions than college students. With a couple of sims, we've found that MS students can be overwhelmed by too many controls. Where possible, we plan to tackle this issue by sim redesign for MS – rather than through activity design. *Implication for using PhET:* In general, students do not need explicit directions on how to use the simulations.

• **MS students tend to create games and challenges**, even when the simulations were not explicitly designed as games. For instance, in Circuit Construction Kit, getting the bulb to light is a challenge built into the sim that all students find and try to achieve, and in Gas Properties, they work to blow off the lid and then try to get all the particles out. Some game-like behavior is not aligned with learning goals – like creating a smiley face out of isotopes or grabbing a planet and drawing with it. Where possible, unproductive play modes are designed out of the simulations. *Implication for using PhET:* Classroom activities can capitalize on students' tendency for and enjoyment of game-play, and channel that play towards productive learning.

EMERGING STRATEGIES FOR
MS CLASSROOM IMPLEMENTATION

Several effective strategies for the use of PhET simulations in the classroom have emerged through our collaborations with the 4 MS teachers implementing PhET simulations in their 5th-8th grade classrooms. These strategies are informed by the insights from interviews and by 1) direct observation by our team of field researchers, 2) in-person conversations with teachers, eliciting their reflections on what is working and what to change, and 3) discussions with students about how they use the sims and what they find valuable to their learning.

Of course, strategies for classroom activity design and implementation will depend on the goals for the activity. In addition to specific content learning goals – which vary across the activities – the activities aim to address some broader science process skills, nature of science, and affective goals. These include: *Scientific process skills* (students engage in exploration, asking questions, making hypotheses, gathering evidence, and controlling for variables); *Evidence-based reasoning* (students collect and use evidence for making scientific arguments and drawing conclusions); *Abstract thinking* (students learn and use abstractions, such as algebraic thinking, scientific reasoning, and making sense of expert models); *Representation* (students learn, coordinate, and use multiple representations); *Measurement* (students use tools such as voltmeters, measuring tapes, scales, and graphs to take measurements and become familiar with this scientific process); *Communication and argumentation* (students engage in scientific forms of argumentation with other students and the teacher); *Affect* (students learn that science can be fun and interesting to them, and that it is within their grasp).

Through the iterative process of teacher input, classroom implementation, observation, and teacher reflection, we identified several elements that appear to foster productive exploration and learning for MS students. Here we focus on two of these elements – that are consistent with the interview findings above – and present related strategies informed by this work.

#1 - Student Ownership: Fostering student ownership of the sim and the knowledge that they gain through interacting with the sim appears to lead to more authentic experiences around scientific process skills and evidence-based reasoning and improves argumentation and affect.

Associated specific strategies:
- **Allow 5-10 minutes of free-play** with the simulation at the start of the activity – before asking any specific questions (especially questions that could be perceived to have a "right answer"). For example start with: "Explore the *Build an Atom* simulation with your partner. See what you can do and what happens. Talk about what you find with your partner." During this time, we see students explore many aspects of the simulation, collaborate and point out features to their partner and neighbors. They find many controls and discover some of the ideas that they will explore later in the activity. After this experience, students demonstrate confidence and facility with the tool – with many students volunteering to share their findings with the class – and apply that knowledge of the tool to investigating and answering the questions that follow. This strategy also appears to decrease unproductive play during the rest of the activity.
- **Avoid explicit direction on how to manipulate the simulation** – that is, avoid instructions like "What is the effect of the sun and earth mass sliders?" or "Change the distance between the sun and earth by grabbing the earth", and instead ask a question like "*Explore* the simulation to find out how you can change the force of gravity and observe what happens." When students are told explicitly in the activity which controls to use or not use, we see students focusing on following the directions correctly, sometimes blindly – not deviating from the exact instructions even when required. This obstructs exploring and learning from the simulation. Indicators such as pictures in the activity of specific control settings or occasional teacher suggestions can help students without triggering the 'direction following' mode, but these should only be used when necessary.
- **Provide opportunities for group sharing time with student demos.** We observe that allowing students to share what they have discovered in the simulation increases their ownership of simulation use, focuses attention on what and how they are learning from the simulation (rather than on what their answer is for a particular question), and creates a collaborative environment where students can help each other explore and expand on ideas and even troubleshoot with each other. This facilitation approach also allows the teachers an opportunity to ensure that all students are on the "same page" by having the entire class discuss a particular idea or notice a particular control while maintaining a student-centered approach.

#2 – Games and Challenges: MS students have a strong tendency to make and enjoy games and challenges within the sims. Thus, games or challenges that are simultaneously aligned with learning goals can be effective for engaging students to use the simulations to explore a concept, increasing classroom discussion and stimulating student questions.

Associated specific strategies:

- **Use built-in games.** In some simulations – Build an Atom, Balancing Equations, Build a Molecule – we have built in either explicit or implicit games that engage students in testing their knowledge. These games are simple, but they embody the learning goals of the sim. They can create productive and engaging learning opportunities for students.

- **Create challenges that foster productive discovery** – that is, craft the challenge so that it creates "play" that is aligned with a learning goal and is conducted with thought or reasoning. In the Circuit Construction Kit, for instance, the activity challenges students to make a working circuit with the fewest components, and then later with the lowest (and highest) possible amp reading. From classroom observations we saw that this framing of a goal helped students focus on the important concept the teacher wanted to draw out, and they were primed for class discussion about what was found. The teacher had the students build their circuits on the Smartboard, and students were eager to find out how other students had approached the challenge. Challenges can take many forms, such as "find all the ways that …", "find the best strategies for …", "develop a procedure for …", "make the lowest, highest, slowest, fastest, biggest, smallest…", etc.

- **Ask students to discover the rules.** Games have "rules" and framing activities as "discovering the rules" leads to productive engagement and learning for this age group. In Build an Atom, for instance, the activity asks students "What is a rule for making an atom with 0 extra charge?"

We briefly touch on a couple of other insights that have emerged. First, our teacher-collaborators report having an easier time facilitating activities when the activities build in opportunities for flexible, teacher-facilitated class discussions. Our classroom observations corroborate their reflection. One strategy is adding suggested discussion stopping points or ranges in the teacher version, but not the student version, so that the teacher can select the right moment for discussion. Second, shorter activities (in terms of number of questions asked and formatted to 1 sheet front-back) have had some observed benefits. They are less intimidating to MS students, and they give the teacher more time and flexibility to facilitate and respond to rich student discussions and observations.

CONCLUSIONS AND FUTURE WORK

In summary, we have found that PhET simulations are generally useable, engaging, and effective learning tools for MS students. We have identified several strategies for creating and facilitating activities that acknowledge and take advantage of key characteristics of this age group – their tendencies to explore and play games – to engage and empower MS students in science learning.

One challenge that the PhET project now faces is how to best convey insights such as the ones collected here to teachers who use or want to use PhET. Many thousands of teachers find the PhET simulations online, so any strategy for providing teacher professional development (PD) must have a strong online component. Regardless of the approaches we use to provide these PD resources online, the use of those resources by teachers and their influence on PhET use in the classroom needs to be an active area of research going forward.

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