Rethinking science learning, a needs assessment

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There has been much discussion about the narrowing pipeline in science, both from the perspective of cause and solution. A number of well-publicized documents have drawn attention to this problem nationwide with varying frames of reference: business, research, development etc (National Science Foundation, 2001; Grigg, Lauko, and Brockway, 2006; Committee on Prospering in the Global Economy, 2007). Due to the technological bent of today's children, the over-used "digital natives", one approach has been to investigate the potential for simulations and games to engage and teach this 21st century, tweeting and facebooking student.

In their white paper for this meeting, Clark, Nelson, Sengupta and D'Angelo have created a very comprehensive review of what simulations and games can do in education. Using the NRC publication, Taking science to school, Clark et al created a framework for categorizing the current development and research on simulations and games based on four themes: conceptual understanding, process skills, epistemological understanding, and attitudes and identity. Their definition of those categories, examples of simulations and games within each, and identification of empirical research is thorough. Their approach is similar to many innovators in that they present strong evidence to why we need to rethink how we conduct science education. Their argument is persuasive.

However, let me approach this differently. If simulations and games are a tool as Clark, et al state, then before we know whether we need that tool we need to know what is the task in front of us. Clark et al rightfully recognize that historically, technology has been touted as a panacea for educational ills, the next best thing to the proverbial sliced white bread, but they do not pursue how we should evaluate the appropriateness of current technology tools or where we should concentrate future research. I would like to reframe the question from "what can simulations and games do" to "what do we ***need*** simulations and games" in science education? This keeps the emphasis on how we can best improve science education, and helps the larger community decide whether to implement or not.

In this paper, I step back from simulations and games as the starting point and instead, begin instead listing two of the major known problems in science education and then discuss what research can tell us about possible ways to address those problems. I will then look back at Clark et al's paper to see how simulations and games might or might not provide unique solutions to those problems, based on the current evidence and where we need more research.

Methodology

A cautionary note about data seems appropriate at this point since this is the response paper to the evidence white paper. Clark et al do a thorough job of outlining the research in each section, but do not evaluate the validity of that research. It is crucial that we do so, in order to learn what works and does not work. This is particularly important for a field emerging from entertainment and trying to set standards for rigor. I'm not suggesting that there is a proper methodology for this research, only that our conclusions should reflect our questions and design. Arguing over whether simulations and games can do something better than we are doing now requires that we define "better". For example, while little of the research on games presented in the white paper is comparative, approximately one-third of the reported controlled studies used a comparison group of vastly different pedagogy (e.g., inquiry-based technology versus lecture), or compared environments based on different theories of learning. This makes one wonder whether the results are due to the technology or to the design theory in which the curricula are embedded or even more likely, to some combination of theory and technology. I do want to underscore the comment in the white paper, echoed in other papers, on the importance of a balance between exploratory and large scale implementations, and add to it the need for meta-analyses that would synthesize and compare results of small and large studies.

One issue that the emerging field of game-based curricula faces is that of understanding what to assess and how to assess it. I've been in classrooms where students and teachers are engaged with scientific games. I have felt the engagement, the 'minds-on' attitude and the interest of the participants. There is something real here. But what is it? That is what we, as a field, are still struggling to understand. I have also been in a presentation where the speaker exhorted the audience to "just use second life" – the reason wasn't important. We must move beyond that to investigating not what games can do, but how, when, to whom and even where they ***should*** do it.

Science Education Needs

Science educators have become very good at teaching the 'formalized knowledge structures' (e.g, in chemistry, the organization of the periodic chart) as Clark et al state, and very good at assessing those, but what do we do poorly? I want to concentrate on two areas: career interest and conceptual understanding. We interest far too few students (hence the narrowing pipeline analogy) in scientific careers, and we produce adults with poor conceptual understanding of science (Committee on Prospering in the Global Economy of the 21st Century, 2007). As a result, we live in a society of individuals with naïve understandings of science (Pew Research Center and AAAS, 2009). This has wide-reaching implications for business success and for our country's global relationships as detailed in numerous reports in the last five years ((Business Higher Education Forum, 2005; Coble and Allen, 2005). For example, the McKinsey Company (2009) suggests that achievement gaps in education have a direct negative impact on our GDP.

Science education need: Career interest in science

Interest in a scientific career starts early and clearly is an important precursor for improving the number of scientists we produce. Students who do not view themselves as interested in science in middle school begin to opt out of science classes as early as high school, thus effectively limiting their career options in their early teens. Tai, Liu, Maltese and Fan (2006) found a strong correlation between 8^{th} graders who wanted a science career and those that graduated with a college degree in science. We need therefore to think carefully of the early years in considering how to improve the number of scientists we produce.

Research indicates several factors that are associated with increasing students' career interest in science. First, students with higher self-efficacy, belief in their abilities to do the work, are more likely to pursue a career in that field (Lopez and Lent, 1992). Second, students who participate in scientific inquiry, whether in formal or informal learning environments, appear to improve their interest in science as a career (Gibson and Chase, 2002; Ketelhut, Savage, Varnum, and Stull, in preparation). Clark et al note the importance of scientific inquiry but imply that scientific inquiry is a new standard to science education and therefore requires new pedagogies to address. While I do not disagree that new pedagogies might be needed, the call, indeed the clarion call, for scientific inquiry in the classroom is nearly as old as the field of science education. For example, Herbert Spencer in 1860 wrote: "Children should be led to make their own investigations and to draw their own inferences" (Spencer, 1860/1896). The fact that we are still 'calling' for it as if it were a new idea indicates how difficult it is to recognize and apply in the classroom.

Science education need: Conceptual understanding in science

Conceptual understanding in science, the second science education need, refers to students' ability to understand the big cross-cutting ideas in science, such as evolution and energy. While we organize science courses generally around these issues, the day to day lessons tend to focus more on the facts (e.g., the structure of the earth) that come together to describe the big ideas and less on the synthesis of those facts into the big ideas (e.g., geological change). As a result, we delude ourselves into thinking that good grades on tests indicate students' conceptual understanding. Physicist Eric Mazur of Harvard University (personal communication, 2009) states that students' intuitive understanding of physics based on their interactions in the real world is often in opposition to the physicist's understanding of the model- and formula-based world. This disconnect inhibits students' ability to learn the science behind their real world experiences.

How does a student move from their naïve or pre-science conceptions of the world to one that is governed by a conceptual understanding of science? Studies indicate again that exposure to scientific inquiry can help mediate this transformation (Bybee 2000). Scientific inquiry experiences allow students to create and examine 'discrepant events' in which their expectation based on their private theories are called into question by experiments they themselves have designed and run. These powerful contradictions force students to rethink their understanding of the topic (Piaget, 1985).

Scientific Inquiry as a problematic solution

Thus, both career interest and conceptual understanding in students are enhanced by having scientific inquiry experiences. This need for emphasizing scientific inquiry is recognized by various groups such as the AAAS, NSTA and NRC plus many state policy makers in their standards documents where scientific inquiry permeates the recommendations. Clark et al make this case well in their paper.

However, simply concluding that we all agree that science education needs to be more fully organized around scientific inquiry is not enough (for that matter, we do not all agree with this as I will discuss later). If it were, then I would argue that there would be little need for games and simulations because scientific inquiry has no intrinsic reason for being conducted through computers. Indeed if we define it as the work of scientists, then scientific inquiry has been going on for as long as long as there have been scientists, far longer than we have had computers.

Instead, various groups, scientists and educators have seen a need to improve science education by continually suggesting for the last 150 years that scientific inquiry needs to play a larger role in science education (DeBoer, 1991). Even now, new reports (for example, the National Science Education Standards, Project 2061, and America's Lab Report) continue to call for integration of scientific inquiry into the classroom as if this were a new idea.

Why is integrating scientific inquiry into the classroom such a tough assignment? I suggest that the reasons for this center first, on poor understanding of what inquiry is and second, on who should do it. This is the arena in which I believe simulations and games could play a substantial role. In the following sections, I will discuss the obstacles, the possible role that simulations and games might play and then indicate where more research is needed.

Obstacle to scientific inquiry: what is scientific inquiry?

The first issue is in understanding exactly what constitutes scientific inquiry. Various groups seem to define this differently (Nelson & Ketelhut, 2007). For example, many high stakes tests classify this as being able to define 'hypothesis' or 'scientific method' (NRC, 2005). As a result, in some situations the advent of high stakes tests has caused a documented move away from inquiry as experimentation (Falk and Drayton, 2004). In contrast, Duvall (2001) describes the inquiry-based scientific classroom as including both student-designed investigations into their own questions as well as learning content in service to understanding their investigations. This description mirrors that in both the National Science Education Standards (NSES; NRC, 1996) and Project 2061 (AAAS, 1993) of scientific inquiry.

One possible role of simulations and games, therefore, can be to provide models for teachers of scientific inquiry, as described in Duvall, the NSES and Project 2061. Using the four strands from the NRC report, Taking Science to School (NRC, 2007), Clark et al thoroughly outline the various simulations and games that could model scientific inquiry as so defined. However, as can be seen in their report, simulations do not always provide an opportunity for student-based questions or student-designed experiments, what they refer to as 'targeted simulations.' The PhET simulations provide a good example. These are identified as targeted simulations in Clark et al, but with the potential for inquiry. A quick perusal of the PhET website shows that for middle school students about 50% of the teacher-designed lesson plans do not use PhET in an inquiry-based manner. These simulations then have a role in helping students understand difficult concepts, but are not strong models of scientific inquiry experiences for inexperienced teachers. To contrast this, the game, Quest Atlantis, has modeling scientific inquiry for teachers as one of its goals. I suggest that the emphasis needs to be placed on designing scientific inquiry-based simulations and games with more research into whether simulations or games can impact teacher pedagogy long term.

Obstacle to scientific inquiry: Equity of access

The second issue with implementing scientific inquiry is that of access. Students in low-level science classes or attending schools with high percentages of non-Asian minorities have far fewer opportunities to engage in scientific inquiry (NRC, 2005). The reasons for this are complicated, and include limited resources, a view of students as needing basic content first, and high percentages of inexperienced teachers (Marshall and Dorward 2000; National Research Council, 2005; Windschitl 2004; Roehrig and Luft 2004).

Clearly, simulations and games can provide access to scientific inquiry for all if the only problem were lack of resources as most simulations and games only require a computer interface which is available throughout schools today. Where issues of equity of access stem from reasons beyond resources as identified above, the solution is less clear. For example, in my own work on the game, River City, my colleagues and I have seen traditionally poorly performing students equal and indeed sometimes exceed their traditionally more successful and more content knowledgeable peers on selected measures of performance (Ketelhut, Dede, Clarke and Nelson, 2007). Whether this would change teacher and popular view of what these students are capable of is unknown. Perhaps the new research into using games as a 21st century assessment, as outlined in Clark et al, will create a platform to showcase the understanding of students who do not perform well on current assessments, allowing us to refrain from wide-sweeping categorization of students. Much work, however, needs to be done in this area, thinking through how to provide validity for these assessments as traditional validity measures will not work if the purpose of the game-based assessment is to uncover different patterns of understanding from traditional tests.

Obstacle to scientific inquiry: Teacher education

The last obstacle to providing students with access to scientific inquiry is the teacher. Current research indicates that the number of inquiry experiences that a student has is associated with their teacher's knowledge of content and experiences with inquiry (Windschitl 2004; Roehrig and Luft 2004). This becomes a vicious cycle: if teachers are not trained with both content and inquiry, then their students will not be educated with both and when some of them become teachers, the cycle repeats. Unfortunately, too often only the need for content knowledge is heard, not the concomitant need for inquiry. Can games play a role in interrupting this pattern? The answer is a tentative yes. Projects like WISE, one example outlined in the white paper, create scaffolds for both students and teachers for scientific inquiry embedded with content.

But, we also need to consider the preservice teacher. Use of simulations and games in the science and science education classroom could provide a venue to improve both the content understanding of pre-service teachers and the level of scientific inquiry experiences they so badly need. For example, Zacharia (2007) used inquiry-based physics simulations with undergraduates. In comparison to those that did the same experiments physically, those in the simulation group exhibited fewer scientific misconceptions on the post test. In a case study of preservice teachers using Whyville as part of their science methods course, I have found that the impact of the game varies based on expertise levels. Students with an experience and expertise in science, teaching, or technology appear to favor the use of Whyville, while those who were novices in these areas were less likely to see the value for it as a science learning environment (Ketelhut, 2009). This is still a burgeoning area and more research into understanding this is needed.

Discussion

Based on this analysis, it would seem that there is a role for simulations and games in the classroom in providing models of good scientific inquiry, equity of access, and improved teacher education. However, the white paper indicates that simulations and games encompass a much wider arena than this. For example, games can be categorized into a spectrum of student-centered design. Some games offer interactivity that masquerades as inquiry. The game, Wonderville (http://www.wonderville.ca/), advertises as an engaging interactive science environment. However, as players investigate the town, much of what they discover are textbook-like snippets about various structures in the game. Given that science textbooks already confuse hands-on with 'minds-on' inquiry, adding a game that mimics this confusion hardly seems necessary. To contrast this to another internet-based game, Whyville offers players a stronger inquiry experience in exploring whypox as detailed in the white paper. During an epidemic, players must figure out how to protect themselves and others from the spread of the disease (Galas, 2006). There is an added impact for students to conducting scientific inquiry in an environment such as

Whyville as these environments allow students not only to conduct scientific inquiry but also to take on the role of a scientist, a powerful overlay to scientific inquiry. Beginning research into this role play seems to indicate a strong impact on students (Ketelhut, Clarke, Nelson, & Dukas, 2008). More research into whether this impacts career interest is needed.

Therefore in terms of evidence for the use of simulations and games in science education, we need to carefully consider what is needed in the classroom, whether a simulation or game could provide this, and how to gather evidence towards that claim. In this paper, I have suggested that any poorly resourced classroom could benefit from simulations and games to improve what they do. Beyond that, we should focus on simulations and games that center on scientific inquiry as the proper tool to address the issues of career interest and conceptual understanding. We need to more fully identify when a simulation or a game is more appropriate, what design factors are associated with increased outcomes, and how they are integrated in the classroom.

However, I caution that this discussion is embedded deeply in one about the purpose of science education for which there is little agreement. The researchers that find evidence promoting didactic teaching over scientific inquiry would be uninterested in simulations and games that are based on inquiry as they have different goals from mine for science education. Until the field determines whether the purpose of science education should be, for example, to create a citizenry that knows the structures of the discipline or to produce large numbers of scientists, then discussing what we are doing poorly or well is meaningless as we have no firm goal towards which to measure progress. Until we agree on the overarching purpose, we are unlikely to agree either on the methods for achieving our goals or our process for assessing how well we are doing. Perhaps, children can see through this larger debate more clearly. A third grader states that the way we can help her learn science better is by making sure she has good science teachers and working computers (Netday, 2006). I would concur that both our needed.

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