# Learning Context: Gaming, Simulations, and Science Learning in the Classroom

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This white paper provides an overview of the opportunities and challenges that pre-college classroom settings offer in using games and simulations to promote learning and engagement in science. This study is not a comprehensive review of all the games and simulations schools have implemented and all the findings that resulted, nor does the discussion cover broader issues of integrating other types of learning technologies into the science classroom, although many of the same opportunities/challenges apply. Online games and simulations in science are emphasized, since this is still an emerging form of learning technology more widely applied in informal learning (Mayo, 2009), and results of classroom usage may be unfamiliar to many readers.

The advantages and disadvantages of in-school contexts are often not distinct from one another, so effective implementation is not a matter of building on opportunities while eliminating totally separate challenges. Rather, as discussed below, the strengths and limits of classrooms as sites for educational games and simulations are often interwoven, and strategies for use involve managing various tradeoffs.

Where possible, this paper draws on empirical evidence based on large-scale studies, but much of its content draws on pilot data or anecdotal data. This suggests areas in which more research is important to further elucidate the themes in this paper. The findings that follow are grouped to address four questions:

1. How can teachers integrate Internet-based games and simulations with more conventional forms of instruction and assessment in science?

2. What constraints and opportunities exist because of the science classroom setting?
3. What opportunities for deep, individualized learning do science classrooms provide?
4. What opportunities for psychosocial learning and motivation do science classrooms provide?

The paper concludes with recommendations for a research agenda on the use of games and simulations in classroom-based science teaching.

<u>How can teachers integrate simulations and games into conventional science classrooms</u>?

Research shows a wide range of individual learning styles and strengths (Dede, 2008; Dieterle, 2009). To be effective, teachers – regardless of what approach to instruction and assessment is most prevalent in their classroom – should create a learning "ecology" with niches that have various forms of pedagogy that speak to students' needs and preferences (National Research Council, 2005; Spires et al, 2009). As one way of achieving this, science teachers can use games and simulations as a supplement to traditional or project-based instruction (e.g., at the beginning of a curricular unit to build engagement or to document relevance, at intervals for formative assessment, and in conclusion for summative assessment). For example, a teacher could use the science game *Electromagnetism Supercharged!* in such a manner to combine the strengths of conventional and game-based instructional strategies (Squire et al, 2004). Another illustration is a teacher using the simulation *Betty's Brain* to help students learn causal relationships in whatever science topic they are studying (Chase et al, in press)

As an alternative way of creating a learning ecology, a science curriculum unit can center on an extended game or simulation, such as Quest Atlantis (Barab, Sadler, Heiselt, Hickey, & Zuiker, 2007; Hickey, Ingram-Goble, & Jameson, in press) or Whyville (Neulight et al, 2007) or BioLogica (Buckley et al, 2004), with more conventional instruction and assessment as a complement. For example, in the case of the Taiga Virtual Park in Quest Atlantis, teachers can support an eleven year old in taking on the role of a scientist who uses disciplinary understanding of water quality to, in the context of a virtual world, solve an authentic program and observe the consequences of his or her choices; thereby providing an element of experiential consequentiality not usually possible in the classroom (Barab, Zuiker, Warren, Hickey, Ingram-Goble, Kwon, & Kouper, 2007). Comparison studies (Arici, 2008; Barab et al, in press) show learning and motivation gains over traditional science curricula.

Such an approach can involve cross-disciplinary instruction to build skills across the curriculum, as with the pilot “augmented reality” (Klopfer, 2008) learning experience, *Grey Anatomy*, in which students use mathematics, science, and English/language arts skills in determining why a virtual whale has beached itself outside their middle school (O’Shea et al, 2009). Teachers of other subjects may even choose to use science curricula if these are powerful for engagement and learning in their subject area. As an illustration, an English/language arts teacher used the *River City* curriculum (Nelson et al, 2007) for several weeks in her classroom because she felt this built literacy and critical thinking skills.

In classroom use of a science game or simulation, students often request access outside of school; this can increase immersion, enhance engagement, and more closely align science instruction with students’ informal learning strategies. However, complementing science learning in the classroom with assigned or voluntary access to games or simulations outside of school presents several challenges, unless that learning is supervised as in a club or a camp setting. Students who have ready access to the technology infrastructure needed have a differential advantage over those who do not. Further, if the game or simulation is multi-user, then the possibility exists of students engaging in inappropriate behavior when unsupervised (e.g., cyberbullying, swearing), Although informal communities like *Whyville* rely on peer pressure to enforce positive social norms, to guarantee a safe setting my colleagues and I restricted use of the *River City* curriculum to in-school settings (class, lunch period, before or after school) in which an adult was present as monitor. We also built an automated "swear checker" that would respond to the use of bad words in student chat, reminding them to watch their language. Moreover, we provided teachers each morning with chat logs of their students from the previous day, so that they could closely monitor student activities to encourage appropriate, on-task behaviors (Clarke & Dede, 2009a). Students quickly realized they were more closely monitored in the multi-user virtual environment (MUVE) than in other types of project based learning, in which the teacher could not closely supervise every group's work simultaneously. [Many illustrations in this paper draw on our experiences with design-based research on the River City curriculum, which is described in more detail in an Appendix for readers who may be interested.]

In summary, teachers can integrate games and simulations into the science classroom in a number of ways, depending on their instructional goals and pedagogical preferences. However, extending multi-user science learning games/simulations into situations where students are unsupervised is potentially problematic, given that teachers are held accountable for anything students do connected with schooling.

<u>What constraints and opportunities exist because of the science classroom setting</u>?

Science classroom settings are infused with at least six intermingled opportunities/constraints for educational games and simulations. First, classroom settings offer the opportunity to design and implement the game or simulation with the science teacher as a resource, as well as the intertwined constraint of teachers who do not implement the game/simulation in the manner its designers intended, inadvertently undercutting student learning (Dede, 2005). As an opportunity, even experienced designers often find student behavior unpredictable, so having feedback from science teachers on student misconceptions inadvertently generated by games and simulations is valuable.

For example, a teacher was very happy with the *River City* curriculum, but informed us that a team of students once spent substantial time repeatedly using the mosquito catcher (a virtual tool to help students assess the local prevalence of insects who serve as a vector for malaria), well beyond what was needed for statistical sampling. When she investigated, the students believed they could reduce illness in the simulation by "catching" enough mosquitoes to block the disease. Such a strategy was neither practical at scale in our simulation, nor in fact would the underlying model have recognized such activity as changing the level of mosquitoes. So, we modified our instructions so that students would not have this misconception.

As an example of the related constraint, we observed some teachers who inadvertently undercut the guided social constructivist pedagogy underlying *River City* as a means of learning science inquiry (Ketelhut et al, 2008). They instead used the learning-by-doing simulation as a "controlled laboratory" experienced to demonstrate "correct answers" the teacher provided in advance. To aid with this and similar issues, informal teacher learning through experience with a curriculum can help their effectiveness in using a science game or simulation. For example, the amount of teacher experience with using *River City* (e;g,, novice implementers as contrasted to teachers who used the curriculum again in subsequent years) was significantly correlated with both greater teacher comfort with the curriculum and better learning outcomes for students.

Professional development is an important method of reducing issues with fidelity of implementation. Over the last two years of our project, 94% of participating teachers rated as useful our four-hour online pre-implementation training via Elluminate. Our in-field *River City* trainers reported fewer problems with teachers undercutting intended pedagogy in those educators who invested time in either our face-to-face or our online professional development.

Our *River City* research documents that the type of professional development a teacher received (face-to-face or distance) was a statistically significant predictor of students' learning outcomes. Further, our studies of scaling up show that delivering effective professional development across distance can increase students' educational performance. For example, in our sample of novice River City instructors, students of teachers who were trained online (using the webconferencing tool Elluminate) performed significantly better on the post-test, on average (controlling for gender, SES, reading level, and pre-test performance), than students whose teachers were trained face-to-face, even though face-to-face training was longer in duration.

Research has established that a range of models for online professional development are effective in aiding teachers with content knowledge, pedagogical processes, and a variety of other knowledge (Dede, 2006; Falk & Drayton, 2009). Both Web 2.0 interactive media and immersive interfaces offer many opportunities for professional development to help teachers adapt science games and simulations for effective use in their particular situation (Dede, 2009b). Over the next few years, "next generation" teacher professional development models are likely to appear that will take advantage of these emerging technologies (Dede et al, 2009). For example, science teachers could not only experience the game or simulation directly in their initial online professional development, but then could voluntarily participate in an online community of practice bolstered by Web 2.0 tools, gaining insights about effective use and adaptation to local conditions. Further, the game or simulation developers could then provide the opportunity for advanced professional development in which science teachers serve as co-designers (e.g., having teachers experienced in a MUVE meet in-world to share situated insights about possible improvements).

Returning to discussing the opportunities/constraints of the classroom, as a second factor beyond science teachers' interpretation of the learning experience, school settings frequently have the constraint of inadequate technology infrastructures, as well as offering the intertwined opportunity of student technical support. For example, in our *River City* curriculum a chronic implementation problems in classroom settings was teachers' access to an adequate, reliable technology infrastructure. In schools with technology labs as their mechanism for 1-1 student-computer ratios, teachers using the *River City* curriculum sometimes complained of resentment from other teachers who were competing for access to that scarce resource. When schools instead created just-in-time classroom infrastructures using laptops on carts, we found that precious time was lost each session in activating the network among machines and the server.

Further, for reasons of security, student safety, and privacy, districts often have idiosyncratic, flawed ways of enabling network access to outside resources, some as extreme as simply blocking everything external. For example, districts with an extreme interpretation of the Child Internet Protection Act (CIPA) may disable by default many of the Internet capabilities that might be built into a game (e.g., chat), a situation technically, logistically, and organizationally difficult to remediate. In these contexts, games and simulations must be completely closed environments (e.g., no external URLs). For implementations of the *River City* curriculum in hundreds of schools during the 2008-09 academic year, our project team included a quarter-time technology specialist to handle, sometimes school by school, bizarre and dysfunctional network configurations.

That said, once the network was configured properly, the *River City* application was robust and seldom experienced technical difficulties; this is in general true for games and simulations built with a modern authoring shell. Further, when technical problems arose, our science teachers reported that often their students were adept at resolving those issues, providing onsite support as well as modeling a nice role reversal in who were the classroom “experts.”

Third, in using games and simulations in science classroom, the responsibility of the teacher to grade students is a double-edged sword. With the *River City* curriculum, our human subjects’ agreement prohibited teachers from using our research pre/post measures for grading. Some teachers used other measures for assessment; others saw the learning experience as enrichment not included in grading. Both students and teachers reported that, when the learning experience was evaluated by the teacher as part of the course grade, some students took the game or simulation more seriously, while others lost engagement because of this.

In general, paper-and-pencil item-based tests do not measure learning from science games and simulations as accurately as do performance assessments, such as a “letter to the mayor” students wrote at the conclusion of our *River City* curriculum documenting their insights and recommending steps to reduce disease in the city (Ketelhut et al, 2007). This is true even when researchers spend years crafting traditional tests to improve their validity. Research has documented that higher order thinking skills related to sophisticated cognition (e.g., inquiry processes, formulating scientific explanations, communicating scientific understanding, approaches to novel situations) are difficult to measure with multiple choice or even with constructed-response paper-and-pencil tests (Resnick & Resnick, 1992; Quellmalz & Haertel, 2004; National Research Council, 2006; Clarke & Dede, in press). These tests also demonstrate limited sensitivity to discrepancies between inquiry and non-inquiry based science instruction

(Haertel, Lash, Javitz, & Quellmalz 2006). Until valid, reliable, and practical virtual performance measures are available – as my colleagues and I hope to develop with Institute of Education Sciences funding using a MUVE interface (http://virtualassessment.org) – students may rightly perceive traditional measures of learning in games and simulations as somewhat bogus, undercutting their engagement.

Fourth, classroom settings offer the opportunity to reach students unlikely to use science games and simulations for informal learning, as well as the interrelated challenge of gaining acceptance of the game or simulation in an schooling system dominated by high stakes tests. Each year, an increasing proportion of students experience online, console, and handheld games outside of school for fun, developing learning strengths and preferences for using interactive media (Dieterle, 2009). This reduces the teacher's overhead required in preparing students to do an "outside the box" activity in science classrooms and builds learners' motivation for educational games and simulations.

However, as Warschauer and Matuchniak (in press) document, research shows that a substantial proportion of students do not have experience with computer-based games and simulations; of those that do, not all are enthusiastic about them. Games and simulations are no more a silver bullet for education's woes than any other single medium or form of pedagogy (Cuban, 2001; Dede, 2008). That said, as our case studies of the *River City* curriculum document, some students who enjoy gaming for entertainment, but shun educational games, find that assigned experiences in classroom with science simulations are unexpectedly fascinating, building their interest and self-efficacy in school (Clarke, 2006; Ketelhut, 2007).

Most students never have the opportunity for such a discovery, unfortunately, because the current emphasis on high stakes testing poses barriers to integrating games and simulations into schools, even for science classrooms in states without a science test. In taking *River City* to scale, our teachers frequently reported pressures from school administrators to stay away from “inefficient” forms of active learning because those took valuable time from presentational/assimilative test preparation. Further, the science curriculum coordinators for three large urban districts refused to allow teachers to use *River City* because an emphasis on science inquiry might interfere with students doing well on the content-oriented high stakes science tests (Clarke & Dede, 2009).

Fifth, classrooms present the opportunity to do controlled studies – pilots, design-based research, and randomized clinical trials – with more detailed pre/post measures and more controlled observations than possible in informal learning settings. In addition, the students in classroom settings are typically more representative of the overall population of learners than those who voluntarily elect to participate in a science game or simulation outside of school, leading to better generalizability for research findings.

That said, getting permission to do research in school settings is typically very difficult. For example, in taking the *River City* curriculum to scale, we had to satisfy a district research committee that demanded three times the documentation that Harvard’s Institutional Review Board (IRB) required, mandated customized changes in our standard letters of consent approved by our IRB, and took almost a year to reach a favorable decision. In another district, we had to arrange special trips to have researchers fingerprinted by that district so that they could gain access to schools, because that state refused to accept fingerprints done elsewhere. Implementation issues because of communications breakdowns among a district’s curriculum, research, and technical organizations was also a frequent problem. Until district and state attitudes and policies change to make classroom settings reasonable testbeds for research, the potential of schools to empower high quality studies will go largely unfulfilled.

Sixth, public schools offer the opportunity to deliver educational games and simulations to the entire population of students, but pose formidable challenges to implementation at scale, as well as to longitudinal studies. (A full discussion of the complex issue of designing for scale is beyond the scope of this white paper, but a quick sketch of strategies and challenges is presented below.) Scale is not only a matter of common sense (Coburn, 2003), such as not spending large amounts of resources on students in each classroom having access to a game development company to build what they design, or not designing simulations that involve high ratios of instructors to learners. Research has documented that in education, unlike other sectors of society, the scaling of successful instructional programs from a few settings to widespread use across a range of contexts is very difficult even for innovations that are economically and logistically practical (Dede, Honan, & Peters, 2005; Vankatesh & Bala, 2008).

In fact, research findings typically show substantial influence of contextual variables (e.g., the teacher's content preparation, students' self-efficacy, prior academic achievement) in shaping the desirability, practicality, and effectiveness of educational interventions (Barab & Luehmann, 2003; Schneider & McDonald, 2007). Therefore, achieving scale in education requires designs that can flexibly adapt to effective use in a wide variety of contexts across a spectrum of learners and teachers. Clarke and Dede (2009) document the application of a five-dimensional framework for scaling up to the implementation of the *River City* multi-user virtual environment for middle school science:

- *Depth:* design-based research to understand and enhance causes of effectiveness

- *Sustainability:* “robust design” to enable adapting to inhospitable contexts, the equivalent of hybrid plants tailored to grow under various types of adverse conditions
- *Spread:* modifying to retain effectiveness while reducing resources and expertise required
- *Shift:* moving beyond “brand” to support users as co-evaluators, co-designers, and co-scalers
- *Evolution:* learning from users’ adaptations to rethink the innovation’s design model

A one-page overview showing various aspects of these dimensions is available at http://www.ciconline.org/c/document_library/get_file?folderId=95&name=THSpr07ProcessofScalingUp.pdf. Readers are referred to the citations above for more detail on the challenges of implementing science games and simulations at scale.

In summary, a myriad of factors influence the effectiveness and practicality of any technology based innovation in school settings (Zhao, 2003). For example, Russell et al (2003) found significant influences from all the factors listed in Table 1.

*Table 1: A Taxonomy of Factors Influencing Effective Instructional Usage of Technology*

| | |
|---|---|
| District | Community Attitudes about Educational Technology<br>District Vision for Technology<br>Leadership of Technology Initiatives<br>Resources for Technology Initiatives<br>Support Services for Technology Initiatives<br>Infrastructure of Computers and Telecommunications<br>Professional Development Related to Technology<br>Relationship Between Technology and Equity<br>Technology-Related Policies and Standards |
| School | Leadership of Technology Initiatives<br>Principal’s Pedagogical Beliefs<br>Principal’s Technology Beliefs<br>Principal’s Technology Preparedness<br>School Culture |
| Classroom | Teacher’s Pedagogical Beliefs<br>Teacher’s Technology Beliefs<br>Teacher’s Technology Preparedness |

| | |
|---|---|
| | Teacher Demographic Characteristics<br>Technology Resources<br>Students' Home Access<br>Students' Home Usage<br>Students' Comfort with Technology<br>Students' Demographic Characteristics |

Optimizing the design and implementation of science games and simulations across this range of variables is certainly challenging (Wilson, 2009).

That said, the educational goal of the game or simulation will influence the difficulty of integrating the learning experience into conventional science instruction. A simulation that reinforces the typical objectives teachers have (e.g., using *Betty's Brain* to deepen students' content knowledge; using a Whyville simulation to illustrate a causal relationship) is less challenging – and less transformative – for the teacher to integrate than a simulation that emphasizes doing authentic scientific inquiry in a complex setting (e.g., *River City*, *Quest Atlantis*). So the extent to which a particular game or simulation encounters the challenges above in integration will depend to some extent on its specific educational goals.

<u>What opportunities for deep, individualized learning do science classrooms provide</u>?

Science classrooms offer at least five ways to individualize and to enhance students' learning using games and simulations beyond what is possible in informal settings. First, teachers can assign students to teams based on detailed knowledge of learners' intellectual and psychosocial characteristics. For example, in all of the immersive learning environments I and my colleagues build, we use "jigsaw" pedagogies in which each team member has access to data others do not, requiring collaboration for collective success (Dede, 2009a). In each of these environments, teachers have reported taking care in team assignments along several dimensions:

- ensuring that collectively the team has students with individual interests in science, in games, and in collaborative leadership
- placing each learner in a role that matches his or her current capabilities (e.g., students who struggle to read English text can aid their teams by gathering numeric data)
- selecting team members so that one person does not dominate the interaction (e.g., sometimes forming teams of all one gender)

Such nuanced composition of learning groups is much more difficult in unsupervised informal settings.

Second, in contrast to relatively unguided learning in contexts outside of school, science teachers can alter their classroom instruction and support based on the feedback educational games and simulations provide. As discussed earlier, in the *River City* curriculum every morning each teacher received detailed logfiles of students' chats and behaviors, as well as students' scores on embedded assessments and their postings in online notepads. 62% of participating teachers felt that the logfiles of students chats and behaviors were helpful in directing their instruction, 76% felt that the online notepad reports helped them keep track of what their students were doing, and 80% felt that the embedded assessments and online notepad reports help them to get a better sense of how their students were spending their time. We also provided teachers with daily updates about individual student's performance on the formative assessments embedded in River City; more than 80% of teachers reported liked receiving these (Dieterle et al, 2008). Overall, as contrasted with informal settings, classrooms offer the opportunity to take advantage of feedback that provides information on how to enhance and individualize learning.

This analysis of challenges to informal settings is not meant to undercut their value in enhancing students' engagement and learning in science. Many of the challenges of usage outside of school described earlier are resolvable by a combination of automated recognition of problems and human oversight in addressing them. However, even with these supports, the vast majority of teachers are likely to view assigning multi-player activities outside of school – where the learners are not directly supervised, but the teacher is still held accountable for any problems – as too high a risk.

Third, science games and simulations are adaptable to students with special needs, allowing them to be mainstreamed in science classrooms. For example, by adding supplementary audio materials my colleagues and I adapted our augmented reality curriculum, *Alien Contact!*, to meet the needs of a student who was visually impaired (Dunleavy, Dede, & Mitchell, 2009). As another illustration, a special needs teacher modified the *River City* curriculum so that her class of cognitively challenged students could complete a substantial part of the curriculum, with very positive effects on their motivation and self-efficacy. Research shows that every learner has strengths and weaknesses and that the Universal Design for Learning approach developed at CAST is an effective method of spanning the range of individual needs (Meyer & Rose, 2005). Classrooms offer opportunities for teachers to extend the supports that universal design for learning can embed in science games and simulations.

Fourth, educational games and simulations can prepare students to take full advantage of real world field trips in science classrooms. As an example, with Institute of Education Sciences funding my colleagues and I are designing and studying virtual ecosystems (Metcalf, Clarke, & Dede, 2009). The *EcoMUVE* curriculum, now in development, is designed to illustrate the complex causality of an ecosystem, with interactive, immersive depictions of plant and animal behavior (http://www.ecomuve.org). Students "collect data" like scientists by placing simulated measuring tools into the virtual environment, exploring the environment, collecting data at different points in time, and viewing phenomena at different scales. We plan to study whether students who experience this simulation are better prepared to take full advantage of their visits to real ecosystems.

Fifth, teachers through their knowledge of students can relate virtual experiences in science games and simulations to what is happening in the real world or in their personal lives. Research documents that games and simulations have many such connections (Stevens, Satwicz, & McCarthy, 2008; Pitaru, 2008). For example, some students in urban settings noted that the tenement houses in *River City* were infested by diseases that, over a century later, still are prevalent in their neighborhoods; immigrant students experiencing *River City* made similar observations about current conditions in their native countries. Other students who had illness in their families could relate to the epidemiological insights that this curriculum fosters. Teachers were instrumental in helping learners make these types of connections.

Overall, science classrooms offer a variety of ways for deepening and individualizing learning from educational games and simulations. Further research is needed on what types of professional development are most effective in helping teachers to realize the opportunities above (Schwarz et al, 2008). Studies of how to achieve related benefits for informal learning in online communities such as *Whyville* are also important (Kafai, Quintero, & Feldon, in press).

<u>What opportunities for psychosocial learning and motivation do science classrooms provide</u>?

In general, games and simulations draw on psychosocial factors to motive and to educate, as documented in a growing research literature (Lee & Peng, 2008; Annetta, Mangrum, Holmes, Collazo, & Cheng, 2009). Further, well designed games and simulations can enhance students' psychosocial development, particularly in adolescence (Durkin, 2006). Beyond all the opportunities discussed above, schools offer at least two mechanisms for leveraging motivation, learning, and psychosocial development from science games and simulations.

First, school provides a context for informal discussions about the curriculum by students outside of classrooms. Research documents the value of online discussions in enhancing learning via games and simulations (Steinkuehler & Duncan, 2008). Teachers can aid in fostering such discussions face-to-face through leveraging proximity. For example, some *River City* teachers were amazed by students' eagerness to spend extra time on the curriculum during lunch hour or before/after school.

Second, school clubs and similar organizations offer fertile ground for science games and simulations. The extensive use of robotics in schools illustrates this potential; unlike virtual environments but similar to augmented reality, this type of "gaming" adds a kinesthetic dimension to learning (Rogers & Portsmore, 2005). Science games and simulations draw on similar motivations, particularly if they enable learner modification of the learning experience (parallel to modifying one's robot). "Modding" is now a capability of modern game engines and is extensively utilized by many participants for fun and informal learning about the models underlying the entertainment experience. Some games (e.g., Little Big Planet, Spore) even require learner design of processes that involve scientific principles, although no support is provided for this. Science teachers can employ modding to encourage students to learn by game/simulation design (Annetta, Minogue, Holmes, & Cheng, 2009).

In summary of all the sections above, classrooms offer a variety of intermingled opportunities/challenges for enhancing learning through science games and simulations. Much remains to be learned about how to design and implement these types of learning environments to maximize engagement and educational effectiveness in classroom settings. This white paper closes with ideas about developing a research agenda in this area.

Thoughts on a Research Agenda for Games and Simulations in Science Classrooms

The next challenge for the field is to move beyond isolated research in which each group of investigators uses an idiosyncratic set of definitions, conceptual frameworks, and methods. Instead, to make further progress, we as scholars should adopt common research strategies and models—not only to ensure a higher standard of rigor, but also to enable studies that complement each other in what they explore. As the materials related to this NRC workshop document, we now know enough as a research community to undertake collective scholarship that subdivides the overall task of understanding the strengths and limits of games and simulations for teaching and learning. Further, through a continuously evolving research agenda we can identify for funders and other stakeholders an ongoing assessment of which types of studies are most likely to yield valuable insights, given the current state of knowledge.

To inform a research agenda for educational games and simulations, I offer brief thoughts about fundamental assumptions for scholarship. In doing so, my purpose is not to propose what the research agenda should be – that is a complex task best done by a group of people with complementary knowledge and perspectives – but to start a dialogue about what such an agenda might include and how it might best be formulated.

I believe that any research agenda should focus on 1) usable knowledge; 2) collective research; 3) what works, when, for whom; 4) more than a straightforward comparison of the innovation to standard practice; and 5) innovations that can be implemented at scale. My first assumption that any research agenda should allocate the majority of its funding towards developing "usable knowledge": insights gleaned from research that can be applied to inform practice and policy. As Stokes describes in his book, *Pasteur's Quadrant* (1997), usable knowledge begins with persistent problems in practice and policy, rather than with intellectual curiosity. I believe in defining research agendas in such a way that scholars not only build sophisticated theories and applied understandings, but also disseminate this knowledge in a manner that helps stakeholders access, interpret, and apply these insights.

My second assumption is that, even though individual studies of creative "outlier" approaches is important, collective research is vital for the further evolution of our field. Fully understanding a complex educational intervention involving gaming and simulation and delivered at scale may require multiple studies along its various dimensions, each scholarly endeavor led by a group that specializes in the methods best suited to answering research questions along that dimension. Further, once efficacy of an intervention is determined via exploratory research, a single large study with a complex treatment is of greater value for research than multiple small studies of individual simple interventions, none of which has the statistical power to determine the nuanced interaction effects described next.

My third assumption is that a research agenda should center on what works, when, for whom, going beyond whether or not some educational game or simulation "is effective" in some universal manner (Kozma, 1994; Means, 2006). Numerous studies document that no optimal pedagogy – or instructional medium – is effective across every subject matter (Shulman, 1986; Becher, 1987; Lampert, 2001). Thus, the nature of the content and skills to be learned shape the type of instruction to use, just as the developmental level of the student influences what teaching methods will work well. No educational approach, including gaming and simulation, is universally effective. The best way to invest in learning technologies is a research agenda that includes the effects of the curriculum, the context, and students' and teachers' characteristics in determining which aspects of educational games and simulations work when, for whom, under what conditions necessary for success.

My fourth assumption is that, even though summative evaluations are important, the scholarly focus in the research agenda should expand well beyond the “is there a significant difference in outcome between this intervention and standard practice?” studies that comprise many of the publications in this field (Fletcher & Tobias, 2006). A vast literature exists documenting the “no significant difference” outcomes characteristic of many such studies (Russell, 1999). Beyond flaws in research design and analytic methods, frequent reasons for lack of a significant treatment effect include an intervention too short in duration to expect a substantial impact or a sample so small that, for lack of statistical power, even a large effect size could not be detected. The use of measures inadequate to detect the significant differences that are occurring is another common problem.

Even when all these issues are overcome, often the population in the study is narrow, the teacher characteristics are optimal, or the context is unrepresentative; each of these generates major threats to generalizability. Evaluation studies provide much more information on whether an innovation works than why it does and should be only a small part of a research agenda, not the preponderance of work, as they typically do not contribute much to theory and do not provide nuanced understandings of what works, when, for whom, and under what conditions.

My fifth assumption is that a research agenda for educational gaming and simulation should privilege studies of interventions that can be implemented at scale. The challenges of scale for science games and simulations were discussed earlier, as were the advantages of implementing at scale. This is not to argue that research agendas should not include studies of unscalable interventions – such research can aid with design and help evolve theory – but I believe that the bulk of a research agenda, to produce usable knowledge, should focus on innovations that can scale. As discussed earlier in the section on scale, this does not mean designing one-size-fits-all science games and simulations, but rather optimizing the adaptability of the learning experience to various types of settings, students, teachers, and instructional goals.

A logical next step in this process for formulating a research agenda is for the scholarly community in games and simulations for science learning to create an electronic forum for sharing ideas. In a recent article in Educational Researcher (Dede, 2009b), I describe how common Web 2.0 tools could be used to create such an infrastructure (page 61):

> A geographically distributed community of scholars studying a particular topic in education might use a research infrastructure mingling many of these Web 2.0 tools to enhance both the pace and quality of their work. At the level of sharing, through communal bookmarking (e.g., http://www.diigo.com/), the group could continuously scan the educational context for resources of interest, including non-archival material such as unpublished papers and YouTube videos. Photo/video-sharing tools (e.g., http://voicethread.com) could enable sharing and annotating research data as multimedia artifacts, such as student products and video records of teaching. A ning (e.g., http://www.ning.com) could provide background information to foster informal professional exchanges among members of this community, empowering the "social scholarship" Greenhow et al. describe. A wiki (e.g., http://writer.zoho.com) could serve as the basis for a negotiated exposition of theoretical principles; the theoretical wiki at the National Science Foundation (NSF)-funded Pittsburgh Science of Learning Center (http://www.learnlab.org/research/wiki/index.php/Main_Page) illustrates the value of this. Mashups (e.g., http://healthmap.org/en) could offer ways to contextualize individual datasets against a larger context of practice.

Through this, we could work to more beyond these preliminary thoughts to a fully articulated research agenda to drive innovation, encourage investment, and realize the opportunities described in this white paper.


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## Appendix: The River City Curriculum

For about a decade, my colleagues and I have studied the feasibility and practicality of using multi-user virtual environments to increase student achievement in scientific inquiry (http://muve.gse.harvard.edu/rivercityproject/), with three rounds of funding from NSF ("Museum-Related Multimedia and Virtual Environments for Teaching and Learning Science," REC-9980464/REC-0296001/REC-0202543, $1,024,161, 2/1/2000-8/31/2002; "Studying Situated Learning and Knowledge Transfer in a Multi-user Virtual Environment," REC-0310188, $784,244, 6/15/2003-5/31/2005; "Studying Robust Design Strategies for Developing Innovations Effective and Scalable in Challenging Classroom Settings," IERI-0532446, $1,780,000, 9/1/2005-8/31/2008). In this research, we have researched how these virtual environments enable students to do authentic inquiry and engage in the processes of science. We have conducted a series of quasi-experimental design studies to determine if virtual environments can simulate real world experimentation and can provide students with engaging, meaningful learning experiences that increase achievement in scientific inquiry. Our results show that these virtual environments enable students to engage in authentic inquiry tasks (problem finding and experimental design) and also increase students' engagement and self-efficacy. In the findings from this work, we have shown that learning sophisticated processes such as inquiry is not a linear learning trajectory and requires extended interactive experiences. We have sketched the potential of immersive virtual environments to help students understand complex phenomena.

The River City curriculum is delivered via a multi-user virtual environment. The middle school science curriculum is centered on skills of hypothesis formation and experimental design, as well as on content related to national standards and assessments in biology and ecology. Our goal for River City is to promote learning for all students, particularly those who are unmotivated or low performing. The storyline behind the curriculum is that students travel back in time to 1878 to help the mayor of River City figure out why the residents are fallen ill. Students log into the computer program and visit the virtual city, which is an historically accurate simulation of a 19th century industrial city. The city is concentrated around a river that runs from the mountains downstream to a dump and a bog. Like most 19th century industrial towns, it contains various neighborhoods, industries, and institutions, such as a hospital and a university (Figure 1).

Figure 1: Map of River City

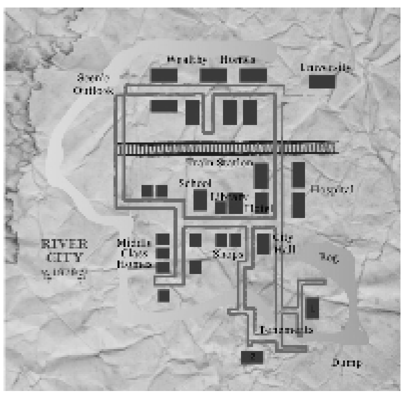
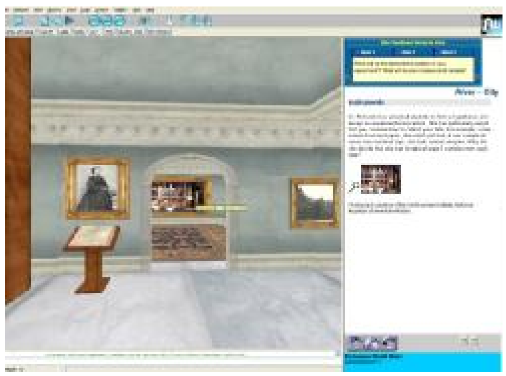
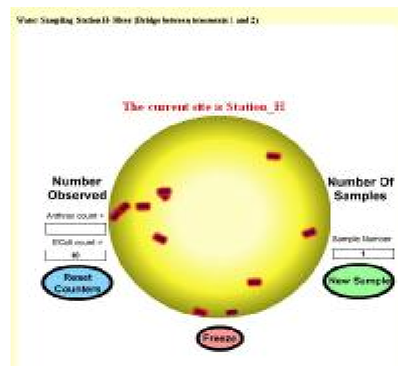



Figure 2: Talking to River City Residents


Upon entering the city, the students’ avatars can interact with computer-based agents who are residents of the city (Figure 2), digital objects (e.g., historical photographs), and the avatars of other students. Students can enter buildings, walk around the city and explore the surroundings. They encounter various visual and auditory stimuli, such as mosquitoes buzzing and coughing, that provide tacit clues as to possible causes of illness. The program interface appears as a split screen with the virtual city on the left and a web-based content driven window on the right. When students click on an object in the world it appears in the right hand screen (Figure 3). For example, when they click on one of the tools, such as the virtual microscope (Figure 4), they can take and visually examine water samples, as opposed to many curricula that just provide students with number counts and no tools or objects to manipulate. Students work in teams of three or four to develop and test hypotheses about why residents are ill. However, the computer ratio is one-to-one; each student sits individually at a computer and navigates his or her avatar in the virtual environment. Teams of students collaborate through using a text based chat interface.

Figure 3: 3-D world with web-based content in RHW. Figure 4 Virtual microscope






Three different illnesses (water-borne, air-borne, and insect-borne) are integrated with historical, social and geographical content, allowing students to develop and practice the inquiry skills involved in disentangling multi-causal problems embedded within a complex environment.