Game Development in a Larger Context\textsuperscript{1}

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Abstract

Games that teach, serious games, have been proposed, among other reasons, to address the growing gap between supply and demand in STEM discipline graduates and to tap into student engagement. We will review briefly the trends and compelling numbers supporting the need to close the gap and proceed with the arguments for how serious games might meet such a challenge.

To develop a serious game agenda, however, we should first examine the value proposition of this novel teaching technology and consider its relatives, for instance in simulation. Metrics for a value proposition should include suitability, cost effectiveness, and a quantification of achieved results. Suitability is a particularly important aspect since here the creative requirements for successful games come into focus. We will illustrate this point with projects currently under way at Purdue and elsewhere.

Computer Science has a special role to play, both in creating serious games as well as in creating entertainment games. This is because game development and game technology are engaging vehicles to communicate numerous CS topics and many other topics for that matter. Consequently, gaming related courses hold promise for attracting more students to CS majors and potentially to more desirable job opportunities for graduates. Moreover, such an expertise or application may attract more students to Purdue and more employers to our students. Topics communicated well by serious game development might be best suited include algorithms, artificial intelligence, graphics, and performance engineering. Similarly, key topics from the sciences and engineering to the humanities and professional school are also in scope, creating a broad intellectual territory in which to operate. Here, a number of strands can come together and suggest that the time may be right to solicit funding for serious gaming when contextualized in the broader vision of computational thinking and novel delivery platforms for information, and motivated by the core problem of putting a sense of excitement into STEM education and potentially providing a novel learning platform that engages our best digital learners and motivates them to persist and succeed in subjects they may feel have been most daunting and/or most uninspired.

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The STEM Problem

People trained in the disciplines of Science, Technology, Engineering and Mathematics (STEM) are increasingly in short supply, yet they are important to the nation's future economic standing. The main argument is historical: since the industrial revolution, the growth of economies throughout the world has been driven largely by the pursuit of scientific understanding, the application of engineering solutions, and continual technological innovation [1]. The current situation is illustrated by forecasts from the Labor Department showing the mismatch between demand and supply of BA degrees in IT, Engineering, Life Sciences and Physical Sciences. As we establish the knowledge economy, computing and computational thinking is becoming an inseparable part of all science and engineering. To-date, virtually every object manufactured is first modeled and analyzed by computation. For example, the Boeing 777 was designed entirely electronically and its design and manufacturing processes were done entirely computationally. Even in the design and manufacture of consumer goods complicated computations are used to design products and their manufacturing and packaging processes.

Computational Science has been called the third leg of science (the other two legs being experimental and theoretical science), yet even here we find that the boundary between computational and experimental science is blurring. In the Compact Muon Solenoid experiment at CERN, a global collaboration in High energy Physics, that is about to begin in the Spring of 2008, $10^{17}$ particle collisions are to be detected and analyzed over 10 years. In this enormous number of collisions, physicists are looking for just 10 “exotic events” predicted by theory; [2]. A Tier-2 site (such as Purdue) will analyze about 1PB of collision event data per year. Similar examples can be cited in astronomy, the life sciences, and many other fields, with data streams coming from sensor networks, instruments such as telescopes, flow cytometry, etc., and from simulations.

So, how is one to close the widening gap between these developing needs and the atrophying supply of young STEM-educated students? And how can we influence the enrollment curves and retention numbers in CS in particular? Currently, many factors complicate this goal: our heroes are singers and sports figures. Science and mathematics teachers are in short supply, and innovations in teaching have not kept up with what we know about student learning. Furthermore, the politics of social conservatism that try to re-assert a retrograde view of science
and evolution are unhelpful, and censoring science because of political dogma has been attempted.

**Education Technology and Serious Games**

Educators continually seek to increase the effectiveness of teaching, and technology changes allow exploring novel methods to impart knowledge. The progression has been something like this:

1. **Blackboard:** The material is developed in real-time by the teacher and has to be copied by the student into note books. On-the-spot changes are easy, but the quality of diagrams is low and color is not necessarily available. Once erased, the information is lost. Device and preparation costs are negligible.

2. **Continuous foil with overhead projection:** This medium essentially simulates the blackboard environment, adding the ability to scroll back and making color more common. Device cost is small and preparation cost is negligible.

3. **Prepared foils with overhead projection:** This medium allows prepared pictures and diagrams in addition. Color is common, changes are more difficult to make. Device cost is small, but preparation time is noticeable since the lecture is scripted, but becomes a one-time investment.

4. **Powerpoint and projector:** The foils are now electronic documents. Changes can be made easily, images and diagrams are simple to incorporate. The availability of laptops, moreover, allows integrating animations and computations/simulations. Device costs have become modest. Preparation time is noticeable since the lecture is scripted and needs to anticipate ensuing discussions.

5. **Immersive worlds:** The teaching now moves towards interactive and participatory learning with a rich sensory engagement. Ideal for simulations and for many topics in the physical sciences, but not deeply explored for abstract material such as exploring abstract manifolds in optimization or other mathematical subjects. Device costs are high as are the preparation costs for the material and the cost of maintaining it, and the development requires a team.

6. **Gaming environments:** Close to immersive worlds in potential and style, but require less expensive devices due to economies of scale. Device costs are modest, cost of preparation is very high since not only are individual scenarios scripted, but players’ responses are fully anticipated.

Given this line-up, why are we excited about serious games? First, games are a medium that match the way this generation of learners leads their lives. Young people today spend an average of almost 6.5 hours a day with media, and eight of 10 online teenagers play video games, according to the MacArthur Foundation’s Digital Media and Learning Fact Sheet [3, 4] Of those who play, estimates are upwards of 22 hours on average spent weekly playing video games This cohort is what Prensky [5] calls “digital natives.” Second, games offer an immersive, participatory experience that does not require expensive VR hardware and software, and third, games are engaging and fun. In fact, the Federation of American Scientists [6] which typically weights in on matters of nuclear weapons and national security, recently published a report and hosted a conference on serious games where many concluded that video games may be the next great discovery. The report noted that “gaming could help address one of the nation’s most pressing needs -- strengthening our system of education and preparing workers for 21st century jobs” [6].

Affordability of producing a serious game is not competitive with multi-media or video. Books, conventional web content, and power point are clearly cheaper learning tools. Indeed, a dedicated
team of talented people is needed to create engaging games, and although the cost is well below the
current cost of creating entertainment games, it remains significant.

So, how can games become more affordable to develop? Only through reuse and by leveraging
other people’s work. For best in breed, moreover, we need compatibility of modules so they can be plug-and-play. So the emergent efforts to construct game engines for educational purpose and make them open source or free license for academic institutions is a necessary step [7, 8, 9]. This would be the way to overcome the stringent cost model for games.

The fact that many young students are digital natives is not necessarily a compelling argument
for delivering learning through serious games [10]. While there is strong evidence that this
generation of learners is media saturated, only about a third of teenagers play games -- but those
who play do so often. There is little hard evidence that those who don’t play will acclimate rapidly to
game environments. We do know, however, that this method of instruction is much more
interactive, bridges context, evidences a high time-on task (one of the best predictors of learning),
helps develops higher order cognitive skills that require complex decision-making, and enhances
problem solving and team building skills. However, we don’t know nearly enough about how and
why learning happens as it does, and these answers bear heavily on CS design decisions for topic
content, structure, and sequencing. We need large-scale evaluation research on the comparative
terms of this instruction method to others and controlled experiments on how simulations
and other advanced media work to transfer the art and technologies of video games to education
and learning systems.

We clearly need to be careful about a-priori assumptions on the suitability of games as teaching
vehicles and need to investigate carefully what they excel at. One related example that has married
sophisticated CS with creative learning applications and systematic evaluation is the Alice project [9].
Strictly not a game, but a story-telling programming system, studies deploying Alice have adduced
evidence that interactive media can be effective vehicle for teaching programming, and that the
environment and style in which the stories are developed are especially suited to engaging young
female students. Similar studies are made for DVTE [11], a project in the military, although detailed
information on the effectiveness is difficult to obtain. Note that the guide [12] does not carefully
distinguish simulation from gaming, a topic to be considered below.

Anecdotal evidence from CS490G, a projects course taught in the Spring of 2007 at Purdue
University, indicated that there are considerable difficulties when designing a serious game as the
primary vehicle to teach a concept in CS. The choice of concept is difficult: Some simple ideas
readily come to mind, such as teaching binary arithmetic, search tree balancing, and basic
comparisons in asymptotic complexity. However, the objective of designing the game in ways that
make playing it engaging and fun runs into the twin obstacles of bringing an abstract concept to life
by concrete analogy and of the implementation effort needed to present the chosen analogy in a
visually pleasing way. The former links back to the question “what are the specific strengths of the
medium as teaching vehicle?” that was raised before. The best project from the course was a maze
puzzle that was designed to have many similarities with recursive function calls and, by playing,
encouraged developing an appreciation of recursion. As elaborated further below, others have
devised game development courses with teams mixing CS students and art students, so separating
the technical development task from the artistic content creation.

While the design of a serious game teaching CS concepts may be a difficult undertaking, teaching
 techniques used in general game development is not and is an excellent vehicle for engendering
enthusiasm among the sizeable subgroup of CS students who dream enthusiastically and
energetically of developing an entertaining game. For CS, this use of game technology in the class room is particularly satisfying since the range of algorithms, data structures and performance engineering issues is very broad. Game development, thus, delivers an appealing frame to teaching those concepts, notwithstanding that the connections of the material to game development in a number of cases may not yet be evident to the students. With this focus, then, game technology can be cast as part of entertainment computing, a broader subject that would include software for music, storytelling and more.

In a similar venture, Ian Parberry has been offering game development courses in the CS Department at the University of North Texas for over 10 years. By his report, the classes are full every semester, enrollment closes early, and CS has witnessed a significant increase in the number of CS majors because of this component in the curriculum. Parberry cross-lists his course with an art class and requires student teams to include members from both departments. There are other courses around the country; for instance, the Alice project developed at Carnegie Mellon and now used extensively on other campuses.

In a bold and innovative move, the Discovery Learning Center at Purdue offered $150,000 in seed money to an interdisciplinary team to convert a course on the books to an on-line gaming format. Faculty and students from Science and Engineering departments were heavily involved in the design and development of proposals. The winner was a gaming course for Introduction to Aerospace Design in the College of Engineering. Once on-line, this course will provide a laboratory for the evaluation research we call for on these new gaming formats designed for learning. At the University of North Carolina at Greensboro, the first such gaming course for credit, Introduction to Microeconomics, has garnered widespread attention from the national news press including NPR and the New York Times. This attention reinforces the enthusiasm for digital game base learning.

In teaching the social sciences, role-playing games such as Second Life [13] can be used study particular situations or the game community itself. History and archaeology can be taught by developing mashups that combine navigable maps with location- and time-aware information. Such information composition can easily be cast in a game context, such as recreating historical battles or other signature events, or simply presenting the teaching material in a more contemporary way, such as the Visible Past project [14].

**Games, Simulations, and eScience**

Simulations are part of many, but not all, games. The relationship between games and simulations can be so close that it could be difficult to draw a clear distinction. For instance, flight simulation systems seek to reproduce accurately the behavior of a plane under simulated conditions of air flow, speed, control settings of the plane, etc. To enhance realism, flight simulations include terrain models of good fidelity. If used for enjoyment, therefore, a flight simulation system can be considered a (high-end) flying game. Conversely, flying games, such as Flight Simulator X [15], incorporate a simplified flight simulator, where the simplifications lie in the fidelity of determining the plane’s behavior under atmospheric conditions, as well as the limited atmospheric conditions that can be assumed. A reasonable distinction might be that a game must include a plot that motivates the player.

In serious games, the emphasis is on training and teaching, and so it is important that embedded simulations be faithful to the subject matter, which means, for the most part, to reality. Whenever the simulation includes the ability to interrogate internals of the simulated system or plot attributes etc, the simulation becomes a useful tool to explain and convey information. Thus simulations and
simulation systems are a valuable part of the educational repertoire and are not tightly bound to the business model of entertainment games. They thus offer stepping stones to the potentially costly development of serious games.

An interesting example of the science-games connection is in biology. Swarms of locust, flocks of birds, schools of fish, all exhibit a collective behavior that appears choreographed by a collective mind, yet can be built from simple rules such as “avoid collisions, stay with the group, and go with the flow.” The work of biologists such as Iain Couzin [15] and others, e.g. [17], uses these rules to explain and predict collective behavior. The rules are derived using Craig Reynolds’ work on boids [18]. While Reynolds starts out trying to build interesting looking collective motion from simple rules, Couzin and Sumpter seek to explain animal behavior by building rule-based behavior models and seeking to validate them from simulations.

Computational thinking is NSF’s way to refer to the trend, sketched before, that computing is becoming an integral part of science and engineering. Related, eScience refers to all projects in science and engineering research that have a manifest computational component. The emergence of eScience and the stress NSF puts on computational thinking motivate consideration of how much Computer Science should be taught to all science and engineering majors, and, conversely, of how literate CS students ought to be in science and, conversely, how literate all students should be in computational sciences. The idea is to prepare both groups for a future of interdisciplinary projects with a strong computational component. Such projects require teams whose members embody a diverse portfolio of skills. Not only do the team members contribute specialized knowledge, they also have to be conversant with each other's field for effective communication. This motivates the inclusion of more science in CS education and teaching CS tools and techniques to science students. Simulations, as well as some serious games are well-suited to this purpose.

Conclusions

Academic work in the area of serious games is novel and not often part of the curriculum. Accordingly, seeking funding for serious games may necessitate looking into novel sources, proposing work with an unconventional agenda. The preceding discussion has identified some connections to entertainment computing, simulation, eScience, the arts, humanities and other areas. Those connections stake out a wide field of possible activities that are eminently respectable in academic and in other communities. For example, many government agencies and politicians make decisions and implement programs that have broad impact and not infrequently include unintended consequences. Serious games and simulations could serve the need to acquaint decision makers better with the full impact of what they are implementing. Moreover, game- and simulation-based training is already a bona-fide part of the military, e.g., [19]. Related sectors benefitting from this approach include emergency response training for man-made or natural emergencies. Whether in education, in defense, in emergency response or in politics, there is a place for conveying complex material in a way that is engaging yet demands and enhances complex skills. Serious games and their technical relatives are appropriate candidates for fulfilling this need.
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