A Research Agenda for Developing and Implementing Educational Computer Games

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The Need for a Research Agenda

Video games have exceeded U.S. box-office in the annual sales (Tran, 2002) and emerged as the most frequently used interactive media among children (Kirriemuir & McFarlane, 2003). Game-based learning advocates (Gee, 2003; Prensky, 2001a) argue that this powerful medium can and should be utilized for laudable educational outcomes. However, although teachers and administrators acknowledge the positive effect of computer games on students’ collaboration, discussion, and thinking skills, they are not convinced that games can be used as part of the school curriculum (McFarlane, Sparrowhawk, & Heald, 2002). Instead, the type of educational games that schools are familiar with is edutainment, which usually focuses on the motivational effects of games typically employing game-like drill and practice activities to achieve lower level learning goals. Many of the edutainment endeavors, which use the entertaining elements in video games to make learning fun, failed to produce anything either educational or entertaining (Kirriemuir & McFarlane, 2003; Okan, 2003; Prensky, 2001b). Additionally, researchers have limited experience designing or implementing effective game-based learning, especially with educational computer games. Although there exists 40-years of research on educational games, the research community is small and many research issues remain unresolved.

What research should be conducted to build a knowledge base that supports the design and implementation of educational computer games? Hannafin and Kim’s (2003) critique of web-based teaching research can inform researchers interested in educational computer games. They criticized web-based teaching research as being too diffuse and contradictory; many studies reexamined design issues that have already been investigated in similar media in the past. They argue that web-based teaching research should explore whether existing theory and research provides guidance to web-based learning, which principles are relevant, and which inquires should be conducted to build a knowledge base for web-based learning. They advocate that researchers should examine the unique attributes of the web to develop teaching and learning processes that are philosophically different from traditional approaches. We believe this advice is valuable for researchers interested in educational computer games as well. As a research community, we need to examine relevant learning and instructional theories to identify guidance for designing and implementing educational computer games. We should also review previous research on educational games, whether they are electronic or non-electronic, to determine what has been studied and what issues remain to be addressed. In addition, rather than focusing on all design issues related to educational computer games, it is probably more productive to examine educational affordances unique to computer games. It is in this spirit that we initiated our own research on educational games and developed a research agenda to guide our future work.

To provide guidance for our own development and implementation of an educational computer game, we examined current learning and instructional theories and the affordances of video games to identify design guidance that leverages the strengths of video games and various theories such as problem-based learning (Barrows, 1996), situated cognition (Brown, Collins, & Duguid, 1989), cognitive apprenticeship (Collins, Brown, & Holm, 1991), to name just a few. We distilled several main principles for designing our own educational computer game (Ma, Williams, Richard, Prejean, & Liu, 2006): 1. situating problems in a rich context in order to engage students in scientific inquiry that reflects the way experts work; 2. present problems in all their complexity and offer tools, resources, and scaffolds to make complexity manageable; 3. provide learners with increased power of agency; 4. provide opportunities for authentic assessment of student performance. How do these guidelines work in educational computer games? What new strategies or new theories should be developed and tested to guide educational computer games? This paper presents a research agenda that explores these issues.
Potential Research Areas

The first four research areas listed below are related to the four design guidelines we generated from the literature. The rest of the research areas concern other important factors impacting the use of educational computer games.

Problem Presentation

Many contemporary theories on learning environments are built around a central problem in a rich context (Barrows, 1996; Hannafin, Hill, & McCarthy, 2000; Jonassen, 1999; Schank, Fano, Bell, & Jona, 1994; Spiro & Jehng, 1990). Modern video games provide opportunities for immersive and authentic representations of problems with the use of rich narratives, 3-D environments, real-time cinematics, as well as stirring audio effects and music. What media components should be used to present the problem context in a certain game? How do these different media components in problem presentation impact learning? Pre-rendered movies or real-time cinematics are two common strategies used to present the context in commercial computer games. Is one strategy more appropriate than the other for presenting certain problems in the educational computer game?

In some commercial computer games, problems or tasks are presented to the players when they approach a non-player character (NPC) to receive a quest or quests. These NPCs may serve as pedagogical agents (Baylor & Ryu, 2003) in educational computer games. What roles can a pedagogical agent play in educational computer games? In addition to using a NPC as a pedagogical agent, can a teacher play as an agent when the need arises? Could the facilitation and scaffolding role be shared between the agents played by the teacher and NPC? What scaffolding tasks are more appropriate for NPC? What tasks are appropriate for teachers? What impact does a pedagogical agent have on learner performance and motivation in educational computer games?

In computer games, problems are organized either in a structured “quest” or an unstructured “sandbox” format. What format (“quest” or a “sandbox”) is more appropriate for a particular type of problems, learning outcomes, or content areas in educational computer games?

Facilitation Strategies

In the learning and instructional theories cited in this paper (Barrows, 1996; Hannafin et al., 2000; Jonassen, 1999; Schank et al., 1994; Spiro & Jehng, 1990), the role of the instructor shifts from the “saint on the stage” to the “guide on the side.” Facilitation strategies are the key component to enable learning in educational computer games. For example, Egenfeldt-nielsen (2005) found that teachers play a critical role in helping students make a connection between game playing and scientific concepts. He found that although educational computer games provide experiences needed for students to construct knowledge, the deep understanding of the scientific concepts does not come automatically. Although students may develop spontaneous concepts themselves; developing scientific concepts requires the facilitator to help make the connection. The two facilitators in his studies were overwhelmed by the responsibilities and failed to deliver the assistance needed by students. This study reveals that despite the fact that educational computer games have great potential to benefit education, there are many challenges for facilitation.

What support do students need to maximize the educational benefit of computer games? What facilitation strategies should be provided in educational computer games? Learning and instructional theories suggest various facilitation strategies (Barrows, 1996; Brown et al., 1989; Collins et al., 1991; Schank et al., 1994; Spiro & Jehng, 1990). For example, cognitive apprenticeship recommends strategies such as modeling, coaching, scaffolding, articulation, reflection and exploration (Collins et al., 1991). How are these strategies used in educational computer games? How can support and scaffolding be built into the game to alleviate facilitators’ responsibilities? How effective are these strategies? Moreno & Mayer (2005) found that guidance in the form of explanatory feedback resulted in improved student learning in an interactive game, but reflection in the form of asking students to give explanations for their answers did not affect learning. New findings from cognitive and learning sciences may also suggest strategies for use in educational computer games. For example, researchers who study analogical encoding (i.e. learning by comparing two cases) found that teaching students to compare cases side-by-side improves knowledge acquisition and transfer (Kurtz, Miao, & Gentner, 2001). Analogical encoding aids students in attending to the deep underlying structures (i.e. principles) of cases thereby reducing potential distraction of surface features. Our team is developing an anagogical encoding tool in an educational computer game to scaffold how to draw analog from two cases in order to solve new problems (Williams, Feist, & Ma, October 2006).
Computer games have unique characteristics that may afford innovative approaches to implementing facilitation and scaffolding strategies. For example, who should provide modeling in educational computer games? Should some modeling be provided in the game by a NPC or some by an agent played by the teacher? What modeling tasks are appropriate for NPCs and what are appropriate for teachers? How do these strategies impact learning? Moreover, many games have Heads Up display (HUD), status monitoring tools, resources, community building tools, and tutorials (Pellegrin, Ma, Williams, & Kunnel, 2006). How can these tools add to or enhance the tools and resources described in various computer-based learning environments (Hannafin et al., 2000; Jonassen, 1999)?

Narratives are a key component in many computer games. By and large, the conventions of western narrative are founded on aesthetic principals advanced by Aristotle, who argued that, at its best, narrative has the capacity to be both entertaining and edifying. Character and plot are two key elements in this convention. Characters act to pursue the object of their desire or motivation. In the course of their pursuit or quest, characters encounter obstacles or problems that interfere with achieving their goal. Characters seek solutions to problems and take action to overcome obstacles. This narrative structure has much in common with stories and cases, key elements used in learning and instructional theories such as learning by design (Kolodner et al., 2003), goal-based scenarios (Schank et al., 1994), and analogical encoding (Kurtz et al., 2001). What role should narrative play in educational computer games in light of these theories? For example, goal-based scenarios (Schank et al., 1994) emphasize the use of stories not only to present the problem, but also serve as tools to facilitate reflection, as a resource to provide advice, and to provide feedback to show consequences of actions.

Formative Assessment

Formative assessment plays a critical role in effective teaching (Brandsford, Pellegrino, & Donovan, 1999). It reduces the learning time needed, better motivates students (Corbett and Anderson cited in Koedinger, 1998), and leads to strong learning gains (Black & Wiliam, 1998). It is believed that immediate feedback may contribute to the experience of flow (Csikszentmihalyi, 1991). Despite its effectiveness in bringing about learning gains, formative assessment is lacking in schools (Black & Wiliam, 1998) because it is extremely time consuming and it places high demands on the teacher.

Video games offer many opportunities to monitor and assess players’ performance that goes beyond those typically found in traditional learning environments. The processing speed and networking of modern computers allow players-as-characters to interact with their simulated environments and circumstances, and with other players, in real time. Not only does this increase the plausibility of the fiction and allow the players to immerse themselves further in the character and plot, but it also reinforces the connection between decision-making and outcome. Moreover, interactions among multiple players provide opportunities for peer feedback, collaborative problem-solving and community building (Kolo & Baur, 2004; McFarlane et al., 2002). In addition, video games allow players to retain and access great volumes of data, either through quantitative measurements such as score-keeping, through item acquisitions, increases in abilities and aptitudes, verbal record-keeping devices, and mapping. The persistence of data is a key feature of the medium, allowing players to assess their own performances against that of the system or of other players. This feature may also become a critical tool for performance assessments by external observers such as a teacher. Video game techniques and technologies may provide more frequent and effective means to assess students’ performance. What tools can be built into educational computer games to conduct formative assessment? Computer-based formative assessment tools have used sophisticated multiple choice questions (Hunt & Pellegrino, 2002) or natural language processing techniques such as latent semantic analysis (Landauer & Dumais, 1997) to assess learning. These tools can be integrated into educational computer games. However, current technologies may not have the intelligence to replace teachers for all formative assessment tasks required. What formative assessment should be conducted by teachers? How can the results of assessment be used to customize an individual’s learning experience? In one study, Squire, Giovanetto, Devane, and Durga (2005) found that a key role the facilitators played was to constantly monitor and assess students’ game playing. When the game was too complex for students, the facilitators had to create simplified, customized game scenarios on the fly. This type of assessment and facilitation requires high facilitator ratio, which might not be feasible in many situations. More research is needed in this area.

Learner Agency

Learner agency is a key factor that may contribute to intrinsic motivation (Malone, 1981) and flow (Csikszentmihalyi, 1991). Video games provide the players with increased power of agency. Simulations are found
in many video games. They enable the players to transcend the constraints of time and space to explore the dynamics of a real or imaginary system (Alessi & Trollip, 1991). Players manipulate variables and test hypotheses to construct mental models of a domain (Rieber, 1996). Moreover, in video games, simulations are embedded in interactive storytelling (Murray, 1997). In traditional storytelling, audiences are simply spectators to the drama, passively observing the motives, decision-making, and actions of characters onstage. In video games, however, the players identify fully with a character, act on the plot, and experience the cause-and-effect of their actions. Additionally, cutting-edge AI technologies offer players a choice of roles and tasks, and challenge them with tasks appropriate for their ability level. This allows the player to have control over their experience and to engage in problems within their zone of proximal development (Vygotsky, 1978).

Video games may provide players with increased power of agency. What strategies can be used to enhance a sense of agency in educational computer games? How do these strategies impact learning and motivation? For example, one question concerns learner agency and academic achievement. Players have preferences in terms of the types of activities they would pursue in games (Bartle, 2005). Some are more aspired to win the game; some enjoy more to explore the world; some spend more time socializing; and others focus more on dominating competitors. In educational computer games, how to help children with different preferences to achieve academic goals but still give them a sense of agency by allowing them options and freedom to pursue their interests?

Settings for Educational Game Use

Several researchers suggested that using regular school hours for educational games might be a problem, because of the time schedule and the existing script for work and roles that occurs during regular school hours (Egenfeldt-nielsen, 2005; Saegesser, 1981). Computer games may last for hours, yet regular school hours are divided into small class periods. It is difficult to confine game play within a short period of time. Moreover, classroom teaching is usually teacher-centered and schooling is considered work, whereas games are more player or learner-centered and games are perceived as play. Research on the use of computer games has taken place in regular school hours in the classroom setting (Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005; Egenfeldt-nielsen, 2005; Ketelhut, Clarke, Dede, Nelson, & Bowman, 2005; Rosas et al., 2003; Zheng, 2006), in afternoon school programs in youth facilities outside of school (Squire et al., 2005), or in learners’ homes (McFarlane et al., 2002). Different settings have different dynamics and social cultural rules. What strategies are needed to implement educational computer games in varying settings? How should teachers and administrators be involved and supported? Are some games more appropriate for one setting than another?

Facilitator Knowledge, Attitude, Roles

Previous research on educational games indicates that the facilitator is a key factor impacting the outcome of educational use of games in the school setting (Bredemeier & Greenblat, 1981; Egenfeldt-nielsen, 2005). Facilitators’ attitude toward games and their knowledge about games as well as the subject matter makes a significant difference in students’ learning. Egenfeldt-nielsen (2005) found that the facilitator who has more experience with computer games and who has a view of history as more than historical facts tend to be more successful in facilitating history learning from a computer game. In a study described by Squire and colleagues (2005), facilitators were expert players of Civilization 3.

Existing research shows that facilitators play various important roles in learning environments enhanced by computer games. For example, in an after-school program in which student participants played a strategy game Civ 3 to learn history (Squire et al., 2005), facilitators played the role of teachers and cheerleaders at the beginning of the program, and they became more like mentors or expert players as students gained more competence. The facilitator sometimes played the game along with the students. Egenfeldt-nielsen (2005) also found that teachers play many roles. They had to solve computer problems and helped students playing the game. At the same time, they had a critical role of helping students appreciate and explore historical information and dynamics as well as make the connection between game playing and scientific concepts. Facilitators may need help to acquire the knowledge and skills required to perform their roles. What support do facilitators need? How should the support be provided to facilitators? For example, should it be provided through training, just-in-time tutorial and resources, or a combination of different strategies?
Addressing Learner Differences

Computer games are arguably the most popular media among children. However, there are many individual differences when it comes to educational computer games. Squire and colleagues (2005) found that middle class boys reported dreams to become game designers, whereas children with lower social-economic backgrounds were challenged by games and did not have game design aspirations. Similarly, in Denmark, Egenfeldt-nielsen (2005) found that some students had little experience with computer games. They gave up on the educational computer games played during the study. Only a few students succeeded in this class. Those that succeeded in the class generally had more experience with computer games, liked history, and had extra energy to engage in learning. Learners in educational computer games may have different levels of experience, skill, and self-efficacy with games. How can educational computer games be designed and implemented to meet learners’ varying needs? Lai, Ma, and Williams (October 2006) generated some design guidelines to improve learners’ self-efficacy in educational computer games. How effective are these strategies? More research is needed in this area.
Methodology

Design-based research may provide a framework for an effective methodology in researching educational games. Design-based research emphasizes the design of innovative learning environments based on theory and empirical research through an iterative process of design, implementation, analysis, and redesign (Design-Based Research Collective, 2003). The purpose of this iterative process is not only to enhance the particular intervention being investigated but also to develop theories to account for the impact of the intervention and to create models to inform the design of other innovations. Design-based research requires collaboration among practitioners, researchers, and technologists (Reeves, Herrington, & Oliver, 2004). This emerging methodology has been used to inform the design and investigate the impact of such innovative educational programs as The Adventures of Jasper Woodbury (Cognition and Technology Group at Vanderbilt [CTGV]) and GenScope (Hickey, Kindfield, Horwitz, & Christie, 2003).

To address the research issues presented in this paper, both qualitative and quantitative methods may be needed to guide data gathering and analysis. These methods are appropriate for different stages of design-based research (Bannan-Ritland, 2003; Design-Based Research Collective, 2003; Kelly, 2004; Shavelson, Phillips, Towne, & Feuer, 2003). Qualitative methods are especially helpful during the exploration phase of a design-based research project (Kelly, 2004; Shavelson et al., 2003) when models (Sloane & Gorard, 2003), conjectures (Sandoval, 2004), or hypothesis (Kelly, 2004) are formulated in the context of real world problems and interventions. Quantitative methods are helpful later when knowledge that emerged from qualitative explorations is validated.

References

References:


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