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14. GAMING TO LEARN

A Promising Approach Using Educational Games to Stimulate STEM Learning

OVERVIEW

This chapter addresses how playing and developing educational games are instructional strategies that could add immeasurably to the contribution ETE programs make to contemporary STEM education.

The introduction to this chapter presents a rationale for game-based learning that addresses the changing perceptions and capabilities of youth in the present era and provides research-based support for the high-interest learning that gaming has the potential to promote.

The promise of playing and designing/developing thoughtfully conceived games is described in terms of increasing student engagement, promoting inquiry-based learning, the effect on self-efficacy, attitudes toward further ETE study and stimulating interest in related STEM careers.

Criteria for game design are proposed that would make games appealing to all learners, including students typically underrepresented in STEM courses and careers.

The chapter concludes with a discussion of the challenges posed by the widespread implementation of gaming to learn strategies. These challenges include: a) the gulf between the promise of gaming in theory and the availability of effective games to use; b) the considerable professional development needs (both pre-service and in-service) that must be addressed; and c) the influence of strategies required for widespread adoption (institutional challenges such as building stakeholder support and changing stakeholder perceptions, and technical challenges such as hardware and software availability, firewall issues, etc.).

INTRODUCTION

Even before the landmark study *A Nation at Risk* was published in 1983, policy-makers and educators were addressing the disparity between existing student and worker capabilities and those needed to maintain national pre-eminence (NCEE, 1983). Today, the educational imperative is made all the more daunting by the exponential rate of change in information and communication technology (ICT), the impact of globalization and the uncertainty in the global economy. A bright spot is the multibillion-dollar video and computer game industry, which has a vast global

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audience and is one of the fastest-growing industries in the United States. What is particularly salient for educators is how the facility of today's students with gaming, simulation and interactive communication is reframing their interests and educational expectations.

Our student body has changed more dramatically than in any similar time period in history; for them, interactive learning is the new learning paradigm. Of the total American teen student population (Junco & Mastrodicas, 2007):

- 93% use the Internet and 84% own a cell phone
- 66% use text messaging
- 75% have a Facebook profile and most check it daily
- 34% use websites as their primary source of news
- 44% read blogs and 28% author a blog

According to the Pew Internet and American Life Project, virtually all American teens play computer, console or cell phone games, and the gaming experience is rich and varied, with a significant amount of social interaction and potential for civic engagement. According to this Project (Lenhart et al., 2008):

- Gameplaying is universal, with almost all teens playing games and at least half playing games on a given day.
- Gameplaying experiences are diverse, with the most popular games falling into the racing, puzzle, sports, action and adventure categories.
- Gameplaying is also social, with most teens playing games with others at least some of the time, and it can incorporate many aspects of civic and political life.

DEVELOPING TRANSFERABLE COGNITIVE SKILLS

In response to the ongoing changes required in order to compete in the global economy, employers are demanding transferable skills that are typical outcomes promoted by learning games.

Of significant importance to STEM educators is that the meta-skills (skills that enable gaining more skills) enhanced by game development (knowledge integration, mathematical reasoning, logical and systems thinking, applying ICT skills and programming concepts, applying the design process) are exactly those transferable abilities that are in high demand and can offer students access to promising career and entrepreneurial opportunities (I Support Learning, 2010). An imperative for the use of digital game-based learning in the classroom is that skills such as how to interact with people and collaborate with team members can be embedded authentically in game design experiences.

WHY VIDEO GAMES ARE SO POPULAR

A video game is comprised of three main components: (1) a non-trivial objective; (2) rules; and (3) gameplay. The phenomenal success of entertainment video games is due to the deep engagement that players develop through games that are well matched to player motivation. Within the game development industry, players are identified by type and demographic (Bartle, 1996), and games are designed purposefully to appeal to a given player in a given genre on a given platform. The nature of this engagement can range from a player spending many hours a week joining the millions of players who participate in massively multiplayer online games, such as the community of more than16 million people playing World of Warcraft, or a player spending an equal amount of time playing simple but highly engaging casual games such as Trism (iPhone), Tetris (Web/DS) or Farmville (Web/Facebook).

THEORETICAL FRAMEWORK

Perceptual Control Theory and Flow Theory

Research on human learning helps explain why computer games are so appealing. Perceptual Control Theory (PCT) presumes that humans are essentially intricate control mechanisms and are goal-driven. PCT provides a framework that explains why young people are riveted by games with clear goals, where they recognize that intervention is possible and where their actions provide immediate and understandable feedback (Powers, 1973). Flow theory (Csikszentmihalyi, 1990) describes the state in which people are so involved in an activity that little else seems to matter; the experience itself is so enjoyable that people will do it even at great cost, for the sheer sake of doing it. The two principal characteristics of flow are: (1) total concentration in an activity; and (2) the enjoyment derived from the activity. Flow involves an optimal level of challenge. Tasks that are too difficult create anxiety and frustration. Tasks that are too easy create boredom. Additionally, flow is characterized by control over the environment.

Computer games are captivating because they satisfy PCT and flow theory criteria. They encourage total concentration. Participants can derive great enjoyment and fulfillment from the activities. The level of challenge can be adapted to the user's skills so that the user controls the computer-generated environment and gets immediate feedback. Youth in the Internet generation are demanding educational experiences that involve interactive, motivational online learning activities (Aldrich, 2004), and the learning environment must change to be relevant to students whose use and knowledge of technology is rapidly rendering the traditional classroom obsolete.

GAME GENRES AND PLATFORMS

A video game is widely understood to be a "game mediated by a computer" (Adams and Rollings, 2007). Video games for entertainment have a diverse range of genres, including role-playing (RPG), real-time strategy (RTS), first-person shooters (FPS), action (including a popular type called "platformers"), puzzle, sports, racing and massively multiplayer online games (MMOG), to name just a few. Table 1 depicts game genres by order of popularity ratings by teens who report playing games in that genre (Lenhart et al., 2008).

The games are played on a wide array of hardware platforms, including consoles (Microsoft Xbox 360, Sony Play Station 3, Nintendo Wii), personal computers and hand-held devices (Sony PSP, Nintendo DS). These entertainment games are delivered to the hardware platforms through a diversity of techniques, including retail

Table 1. Game genres in order of teen popularity

Genre examples	*Player popularity rating*
Racing (NASCAR, Mario Kart, Burnout)	74
Puzzle (Bejeweled, Tetris, Solitaire)	72
Sports (Madden, FIFA, Tony Hawk)	68
Action (Grand Theft Auto, Devil May Cry, Ratchet and Clank)	67
Adventure (Legend of Zelda, Tomb Raider)	66
Rhythm (Guitar Hero, Dance Dance Revolution, Lumines)	61
Strategy (Civilization IV, StarCraft, Command and Conquer)	59
Simulation (The Sims, Rollercoaster Tycoon, Ace Combat)	49
Fighting (Tekken, Super Smash Brothers, Mortal Kombat)	49
First-Person Shooters (Halo, Counter-Strike, Half-Life)	47
Role-Playing (Final Fantasy, Blue Dragon, Knights of the Old Republic)	36
Survival Horror (Resident Evil, Silent Hill, Condemned)	32
MMOGs (World of Warcraft)	21
Virtual Worlds (Second Life, Gaia, Habbo Hotel)	10

box sales (DVD, CD, BlueRay), Web downloadable games, Massively Multiplayer Online games (MMO), and mobile/hand-held games, such as those developed for Nintendo DS, Nintendo Game Boy, Sony PSP, Sega Game Gear, Nokia N-Gage, iPod and other PDAs, and mobile phones.

SERIOUS GAMES

Serious games are widely understood to be video games used for purposes other than entertainment. According to Sawyer and Smith (2008), Serious Games are organized by genre and include (among others) education, training, health, advertising and persuasion. The most current generation of Serious Games for education (also described as digital game-based learning) is now almost a decade old and there are a great number of successful "commercial off-the-shelf" (COTS) titles relating to various disciplines, including those shown in Table 2:

Table 2. Examples of serious games for education

Discipline	*Game title*
Biology	*Metablash! Virtual Cell*
Ecology	*Operation: Resilient Planet*
General Science	*Science Pirates: The Curse of Brownbeard*
	Conspiracy Code
	Discover Babylon (fas.org/Babylon)
History	*River City*
	Making History
	Peacemaker
	Global Conflict: Palestine
Health	*Re-Mission*

Table 2. (Continued)

Math	*DimenxianM* for algebra *NIU-Torcs* for numerical methods *Lure of the Labyrinth*
Management	*Virtual U*
Mechanical Engineering	*Time Engineers*
Network Engineering	*Mind Share*
Physics	*Crayon Physics* *Physicus* *Coaster Creator* *Phun*

Over the last decade, Serious Games have advanced as proprietary trainers, and educational researchers have demonstrated that it was possible to leverage the hugely successful design conventions of entertainment games to develop learning games with objectives, rules and gameplay that present complex, situated decision structures where players learn by doing through an ideal use of constructivist pedagogy. Serious games for education are most effective when the game goals and the learning goals are innately meshed. The same is true for the gameplay and learning activities, which are indivisible in effective games. Under these conditions, achievement in the game is directly measurable as the achievement of intended learning outcomes.

Digital game-based learning goals require many important skills, including systems thinking, problem solving, information tracking and resourcing, collaborative information sharing, leadership, teamwork and communication. Effective educational games anchor learning through authentic tasks and environments, and encourage learners to explore and experiment with alternatives, thus deepening their understanding of the concepts to be learned.

Serious games have achieved visibility and traction in education, elevated by significant, though limited, recent research that supports their effectiveness. This includes research that concludes that digital game-based learning can dramatically reduce the learning divide between high- and low-achievers in the classroom (Kebritchi, Hirumi, & Bai, 2010).

THE PROMISE OF SERIOUS GAMES IN EDUCATION

The use of serious gaming is a logical approach in the maturation of curriculum. It can add a riveting, contemporary dimension to engineering and technology education programs, making them attractive to a wider pool of students, including females, and can keep education relevant to students in an age where information and communication technology has become the dominant technological paradigm. Infusing gaming into the school curriculum will promote a contemporary and systemically transformative educational model that would fast-forward the ETE movement.

DimensionM™ from Tabula Digita

The West Virginia Department of Education provided *DimensionM*™ from Tabula Digita to 1,000 students from seven middle and high schools across four counties in West Virginia. Research from the University of Central Florida (UCF) relating to the use of one of the *DimensionM*™ games (Dimenxian) reported that "immersive educational video games can improve students' mathematics understanding and skills, and significantly raise scores on district-wide math benchmark exams." These research findings investigated the effects of modern math computer games on learners' math achievement and math course motivation in public high school settings. In eight studies pertaining to math-related computer games, six were found to positively affect students' mathematics learning and two were found to have "mixed" results (Kebritchi et al., 2010).

In the games, key objectives are covered through a series of highly immersive action-adventure missions. Educational video games contain 3D graphics, sound, animation and storylines comparable to the quality of those in popular entertainment video games.

The UCF study, conducted by a team of faculty and graduate students at the university, consisted of algebra and pre-algebra students and 10 teachers, all from Orange County, Florida. Experimental and control groups were used to test the researchers' hypotheses and were evaluated using pre- and post-study district benchmark exams, game preparation tests, surveys, classroom observations and personal interviews. Students in the experimental group of 193 high school students who played the Tabula Digita video games over an 18-week period scored significantly higher on district math benchmark tests than students in the control group who did not play the video games. In fact, the increase in scores for the test group was more than double the increase in scores for the control group. The higher achievement scores and greater gain scores on the district benchmark tests by students who played the games are particularly significant since a high correlation exists between the district's math benchmark tests and the statewide math component of Florida's Comprehensive Assessment Test (FCAT).

According to the teachers involved in the study, the games were effective teaching and learning tools because they were experiential in nature, offered an alternative way of teaching and learning, and gave the students reasons to learn mathematics to solve the game problems and make progress in the games. The teachers also commented that the games helped address students' math phobias and increased time on task. As one teacher states, "it (the games) makes them want to learn (math)."

Immune Attack from the Federation of American Scientists

With funding from the US National Science Foundation (NSF), the Federation of American Scientists (FAS) developed the video game *Immune Attack* to immerse 7^{th}–12^{th} graders into the microscopic world of immune system proteins and cells. *Immune Attack* is digital game-based learning targeted at improving the understanding of cellular biology and molecular science. Research conducted on the use of this game with 180 students, 7^{th} graders, has shown that students who play it show significant gains in confidence with molecular science-related material and in their knowledge of cellular biology and molecular science (Yarbrough & Fleischman, 2009).

In May 2008, *Immune Attack* was made available for free download on the FAS website (See FAS Website in reference list). *Immune Attack* has been downloaded by over 9,000 people. Five hundred teachers have registered to evaluate *Immune Attack* in their classrooms (FAS, 2010).

Whyville from Numedeon

Whyville is a digital game-based online learning community for children aged 8 to 15. Of these users, 67% are female, a demographic that is difficult to interest in science and math. Numedeon Inc. launched *Whyville* in 1999 and continues to add educational activities based on an inquiry approach to learning, with learner-centered, hands-on learning activities for art history, science, journalism, civics, economics, and more. *Whyville* works directly with the Getty, NASA, the School Nutrition Association and the Woods Hole Oceanographic Institution.

Game Development as an Equitable Instructional Strategy

Gaming is an innovative teaching strategy that can particularly support under-represented student populations in expanding their awareness of and educational preparation for viable, contemporary STEM careers. Properly selected curriculum design criteria (see Table 3) can maximize the appeal of educational games to females, who tend to be drawn to topics and contexts relating to people's needs and concerns, environmental issues, interpersonal relationships and real-life settings (NSF, 2003). Game environments naturally transcend barriers of language, geography, race, gender and physical abilities, and online games will ensure access to all students.

The gender and racial gap in STEM programs appreciably limits the pool of potential workers and is a serious concern threatening the nation's intellectual and economic competitiveness (Mendoza and Johnson, 2000). Because of their interdisciplinary nature, game development programs appeal to a broader array of students, including women (Microsoft, 2008).

Table 3. Curriculum development criteria

Ensuring personal relevance
Including a focus on communication and language skills
Placing emphasis on personal mastery and building self-esteem
Using inquiry- and design-based activities to experience the world
Using real-life contexts
Working in cooperative teams
Promoting interpersonal relationships that build leadership skills

GAME DESIGN/DEVELOPMENT AS A STRATEGY TO DEEPEN UNDERSTANDING

Every truth has four corners: as a teacher I give you one corner;
it is for you to find the other three. — Confucius

In designing and developing games, students delve deeply into the content that underpins the gameplay. For example, in designing the *Year of the Plague* game to support instruction related to Defoe's *A Journal of the Plague Year*, California high school students became totally engrossed in study about the Great Plague. The developers (as learners) had to apply knowledge related to the Plague (symptoms, history, geography of London in 1665, sociology, etc.) to successfully meet game objectives. They immersed themselves in the literature to ensure that the game design and mechanics reflected historically accurate events, characters and backgrounds (Kiggens, 2009).

In their case study of 20 high school students in a game design class in Pennsylvania, El-Nasr and Smith (2006) discussed the learning that took place when students created characters and the 3D setting for a football game. According to the authors, "students developed an understanding of Boolean logic and programming constructs including threading, and event- and rule-based programming. They learned the benefits of iterative design and how to divide work among team members. They gained a better understanding of 3D geometry and vector mathematics. They applied the Pythagorean Theorem and used tangents, vector geometry and 3D transformations. These were difficult concepts to assimilate but by applying them in visual 3D space, students were able to use and understand them" (El-Nasr and Smith, 2006).

Gamestar Mechanic (E-Line Media, 2010) is a digital game-based learning product centered upon the tenet that game design is an activity that allows learners to build technical, technological, artistic, cognitive, social and linguistic skills, and understandings that are ideal for today's world. As a process, game design is an excellent point of entry for learners toward an authentic application of system-based thinking, creative problem solving, art and aesthetics, writing and storytelling, interactive design, game criticism and programming skills. *Gamestar Mechanic* differs from other products that enable game creation by focusing on the act of game development and the art of game design.

Gaming and Computer Science

Game design helps students delve deeper into computer science, and game development has become a favored new major at more than 500 post-secondary schools across North America. According to Moskal et al. (2004), game design programs have rekindled and sustained interest in computer science (CS), and 88% of game design students continued in CS compared to 47% in the control group.

Bayliss (2008) cites several compelling examples of computer science programs benefitting from game design underpinnings. The University of South Carolina implemented a game design curriculum that has increased enrollment in the school's CS department from 52 students in 2005 to 379 students in 2008. At the Rochester

Institute of Technology, the Reality and Programming Together program has been instituted "expressly to reverse the ongoing decline in CS enrollment by taking advantage of ubiquitous interest in computer games." This approach to CS seeks to recruit and retain students, as well as improve instruction, by integrating the basics of CS into designing and building computer games.

IMPLEMENTATION OF GAMING IN ENGINEERING AND TECHNOLOGY EDUCATION

Technology education has been a subject in transition for over 20 years. Its precursors were manual training and industrial arts. Many teachers, trained as industrial arts teachers, are still teaching as they were taught; despite the overarching need for a technologically literate student body and workforce, many school programs are still rooted in crafts teaching. At the same time, there has been an ongoing call from state and national professional leaders in the field to accelerate technology education's transition to a contemporary STEM-based discipline by making it more engineering-based.

According to ITEEA Executive Director Kendall Starkweather, "the idea to develop educational gaming will resonate well with the technology and engineering education community" (Starkweather, 2007). Results of a 2008 survey of technology education state supervisors indicate that 95% would supplement the existing curriculum with SMTE materials, teachers will find Web-based modalities accessible (74%) and necessary computers will be available (79%) (Hacker & Crismond, 2008).

It is increasingly evident that digital game-based learning literacy should be included as a core skill set for ICT readiness for educators in today's technology education classroom. Research data and trend analysis strongly indicate that today's learner is prepared to engage successfully in digital game-based learning. Achieving this new literacy will require institutional change, with a focus on enabling teachers in the classroom with this paradigm. This institutional change will require a shift in allocation of financial resources, but this is just the first step.

Serious Games for education are commercially available and the palette of choices across the curriculum is steadily increasing. Yet, even when there is a commercial game that is closely matched to the needs of a given curriculum, there is more to successful adoption than merely finding the financial resources to purchase the game and improve the technology infrastructure. First and foremost, teachers must be experienced players themselves and be fully inculcated in digital game-based learning pedagogy. This will require an institutional appreciation for the value and effectiveness of digital game-based learning – as demonstrated through strong and continuing professional development support. Additionally, the ecosystem of the classroom must be adapted to suit the emergence of the game-based constructivist learning community. IT policies will need to adapt, acceptable use policies, as well as programs and tools for assessment of learning outcomes will need to be revised, and play as learning must become a value statement for all stake-holders across the institution – administrators, teachers, students, support staff and parents.

As new teachers enter the profession, they comprise a growing demographic that will readily adopt digital game-based education. The average age of a video game player in the United States is 35 years, and 68% of all adults report having played a video game within the last year. Typically, today's teacher does play video games (Entertainment Software Association, 2009). The teacher's role in the digital game-based learning system is paramount. Research clearly indicates that to be an effective instructional strategy, gaming requires the teachers' careful scaffolding and incorporation of the game content into the class curriculum.

The authors believe that if provided with effective Serious Games, teachers would readily adopt them. However, in the face of the many challenges and competition for time in the class day, games must be as or more efficient than traditional instruction in terms of the time required for both teacher preparation and classroom delivery. This parameter is a primary consideration for adoption. Digital game-based learning must justify the cost in terms of classroom time with a return on investment of significantly improved learning performance.

THE VISION – 3D GAMING IN ETE PROGRAMS

Our vision for implementing 3D gaming in ETE programs involves using research on human learning and contemporary educational pedagogy to develop digital game-based learning underpinned by STEM concepts. We are struck by how engaged children are when playing video games; we are also struck by the opportunity that exists to develop digital game-based learning about STEM concepts, where game-based decisions made by students reflects and deepens STEM knowledge. Our vision is to leverage the motivation that is intrinsic to digital game-based learning so that students correctly and joyfully apply STEM concepts to achieve game/learning goals. This is just-in-time learning at its best where students embrace learning in the service of improved game performance.

While there are certainly challenges to realizing the potential of digital game-based learning in engineering and technology education, the early successes clearly demonstrate a roadmap for wide-spread adoption. Implementation can and should occur within the context of a reform-based school environment – rather than be seen as a fleeting, non-academic fad. It is both feasible and appropriate to infuse digital game-based learning in a school setting in such a way as to retain the authenticity and power of video games.

Survival Master: A Case Study of a 3D Game for Middle School ETE Students.

In the *Survival Master* game (see game website) for STEM learning in development with National Science Foundation funding (DRL 0821965) at the Center for Technological Literacy at Hofstra University in New York, 8th grade learners are situated in a survival scenario and are challenged to learned standards-based concepts and demonstrate higher-order thinking skills, including engineering design, problem solving, mathematical analysis, plan formulation and execution, and response to rapid change. This learning game leverages an informed design approach that embeds a design pedagogy developed and validated through several NSF projects conducted by the Hofstra CTL (Hacker, 2010). In informed design, learners are engaged in a progression of knowledge and skill builders (KSBs) – short, focused activities designed to teach salient concepts and skills. KSBs prepare students to approach the design challenge from a knowledgeable base, as opposed to engaging in trial-and-error problem solving where conceptual closure is often not attained. The approach gives the learner first-hand experience with how experts approach problems, as well as valuable experience in team-building.

The game invites students to undertake the design of an emergency survival shelter. It is targeted to 8th grade students who have had some previous exposure to introductory algebra.

Problem Situation: Here's a problem situation that students are asked to consider.

To be understood by students: You are part of a four-person team of engineers and scientists who are studying the effects of global warming in a remote area of Alaska. You have just begun your study of the region when an earthquake strikes and destroys buildings, wrecks power lines, cracks the airport runway, damages roads and triggers a landslide. Even the tent you were using has been ripped to shreds by falling debris. You are cut off from civilization except for the battery-operated radio equipment you have brought with you.

Design Challenge: Here is the design challenge students are asked to undertake. It will require them to apply their science, technology, engineering and math (STEM) skills.

To be understood by students: Your team is 200 miles away from the nearest city and the earthquake has made travel impossible. Your team must build a shelter to keep you warm during the time it will take for a rescue team to reach you.

With temperatures below freezing, your challenge, as one of a team of earthquake victims, is to design and build a rapidly erectable structure that will provide insulation from the cold, withstand the weight of snow (snow load) and the force of wind (wind load), and be built of materials that are readily available locally. Specifications and constraints are provided that detail the temperatures, available heat source, shelter size, and wind and snow loads. Available materials are specified.

Survival Master game goals are driven by desired learning outcomes. The gameplay (as learning activities) is authentic and situated in real-world contexts, yet engages the learner in common entertainment genres and game mechanics that are second nature to the digital native. For example, *Survival Master* has four KSB game levels and each of the levels has a gameplay that leverages a different genre of entertainment gameplay. KSB 1 is a 'puzzle/matching' level designed to teach concepts about surface area and volume of geometric shapes (see Figure 1); KSB 2 is a 'platformer' level that teaches about heat flow; KSB 3 is an 'action' level that focuses on k and R values; and KSB 4 is a 'construction' level focused on structural design concepts.

SMTE Key Ideas

KSB 1: Surface Area and Volume Calculations

Students will know that volume is a measure of filling an object and surface area is a measure of wrapping an object.

To demonstrate their understanding, students will:

1. Given the outside dimensions and the mathematical formulas for the volume of each shape, correctly calculate the volume of four geometric shapes: a cube, a sphere, a square-based pyramid and a cylindrical prism.
2. Given the outside dimensions and the mathematical formulas for the surface area of each shape, correctly calculate the surface area of four geometric shapes: a cube, a hemisphere, a square-based pyramid and a cylindrical prism.

KSB 2: Conductive Heat Flow

KSB2A: Students will know that heat (Q) flows from hot (T_h) to cold (T_c) through a material by conduction.

To demonstrate their understanding, students will:

Given an object with a temperature difference from one side to the other, explain that as the temperature difference (ΔT) increases, the conductive heat flow (Q) increases.

KSB 2B: Students will know that since heat is transferred from a hot temperature (T_h) to a cold temperature (T_c) through a flat surface, reducing surface area reduces heat transfer.

To demonstrate their understanding, students will:

Given objects with different surface areas (everything else being equal), describe how surface area affects conductive heat flow.

KSB 2C: Students will know that different materials conduct heat at different rates depending upon their thermal conductivity. Thermal conductivity is symbolized by the letter (*k*).

To demonstrate their understanding, students will:

1. Given a list of materials with different k values, identify those that are good insulation materials.
2. Given a heat source and two objects of the same dimensions made from different materials, be able to describe how different materials affect conductive heat flow.

KSB 2D: Students will know that heat flow decreases with increasing thickness.

To demonstrate their understanding, students will:

Given different thicknesses of the same material (everything else being equal), explain how thickness affects conductive heat flow.

KSB 2E: Students will know that the formula that relates heat flow (Q) to its determining factors is $Q = kA\ (T_h - T_c)/L$.

To demonstrate their understanding, students will:

Given the heat flow formula and a standard calculator, correctly calculate an outcome based upon manipulation of the variables in the formula.

KSB 3: Relationship between k Value and R Value

Students will know that:

1. k and R values are both measures of a material's resistance to heat flow. k value relates only to the type of material whereas R value also takes into account the material's thickness (L).

2. Since R value takes thickness (L) into account yet is related to k value, R, L and k can be expressed in a relationship. The R value of a material equals its thickness / its k value (R=L/k).
3. The total R value (R_t) of a system of materials is the sum of each of the individual R values ($R_t = R_1 + R_2 + R_3 + R....$).

To demonstrate their understanding, students will:

1. Given k values and thicknesses for several different materials, calculate the R value of each material using the formula $R = L/k$.
2. Solve for heat loss using the formula $Q = A\ (\Delta T)\ /\ R$ given surface area A, R value and ΔT.
3. Given individual R values of several materials, determine the total R value of a system made from layers of those materials by summing the individual R values.

KSB 4: Structural Design

KSB 4A: Students will know that: dead loads, live loads and wind loads are among those that must be taken into consideration when designing a structure.

To demonstrate their understanding, students will:

1. Given information about dead and live loads, define dead load and live load and give some examples of each.
2. Given a representation of wind blowing against a tower on a foundation that supports a platform with a filled water tank upon it, and correctly label the dead load, live load and wind load.
3. After seeing a video of "Galloping Gertie" (the Tacoma Narrows Bridge Collapse), explain why wind loads must be considered when designing a structure in addition to dead loads, which have a constant magnitude (such as the weights of the construction materials), and live loads that change in magnitude and/or location (such as people in a building or cars on a bridge).

KSB 4B: Students will know that structural integrity refers to the ability of individual structural members that comprise the structure (and their connections) to perform their functions under loads.

To demonstrate their understanding, students will:

Given a representation of a tower and its foundation that supports a water tank, correctly identify the components where the lack of structural integrity might affect the item's function or safety.

KSB 4C: Students will know that selecting materials involves making tradeoffs between qualities.

To demonstrate their understanding, students will:

After explaining that structural integrity depends upon the ability of individual structural members that comprise the structure to perform their functions under loads, explain how selecting materials for a structural project involves making tradeoffs between competing qualities such as strength, cost, availability and the ease of working with the material.

KSB 4D: Students will know that: the overall stability of a structure and its foundation refers to its ability to resist overturning and lateral movement under loads.

To demonstrate their understanding, students will:

1. Given the challenge to analyze a representation of a braced tower and its foundation that supports a load, explain that the stability of the structure depends upon its ability to resist overturning and lateral movement under loads.
2. After investigating the design of a water tower, explain why a water tank is sometimes made in a spherical or cylindrical shape rather than a different geometric shape such as a rectangular prism or a square-based pyramid.

KSB 4E: Students will know that structural design is influenced by climate and location, function, appearance and cost.

To demonstrate their understanding, students will:

After reviewing images or models of a variety of structures built for different purposes in different geographic areas (deserts, mountains, icy climates), describe how structural design is influenced by function, appearance, cost and climate/location.

Drawing upon their life experience as gamers, these games are immediately accessible and intuitive for the learner. *Survival Master* culminates in a group multiplayer shelter design challenge, where students work together in teams of four and apply the informed design model to the design of an emergency survival shelter.

Figures 1, 2, 3 that follow are screen shots from the Survival Master game. Three images are displayed that illustrate elements of the game intended to teach skills through the KSBs and the culminating multiplayer design challenge.

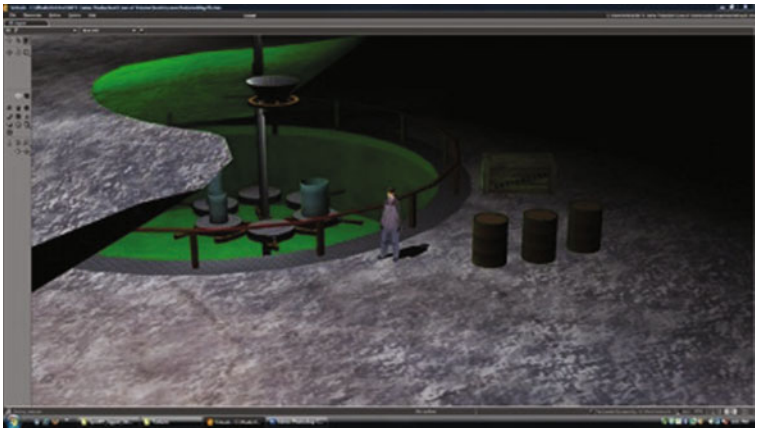

Figure 1. A scene from KSB 1 of the survival master game for middle school ETE. In this figure, a player (represented by an avatar) is walking in the game environment finding geometric shapes (cubes, square-based pyramids, spheres) filled with liquid that will be poured through a funnel into cylinders. The player must choose the cylinder that holds the same volume as the geometric shape.

Figure 2. A scene from KSB 2 of the survival master game for middle school ETE. In this figure, a player moves a platform that models heat flowing from hot to cold.

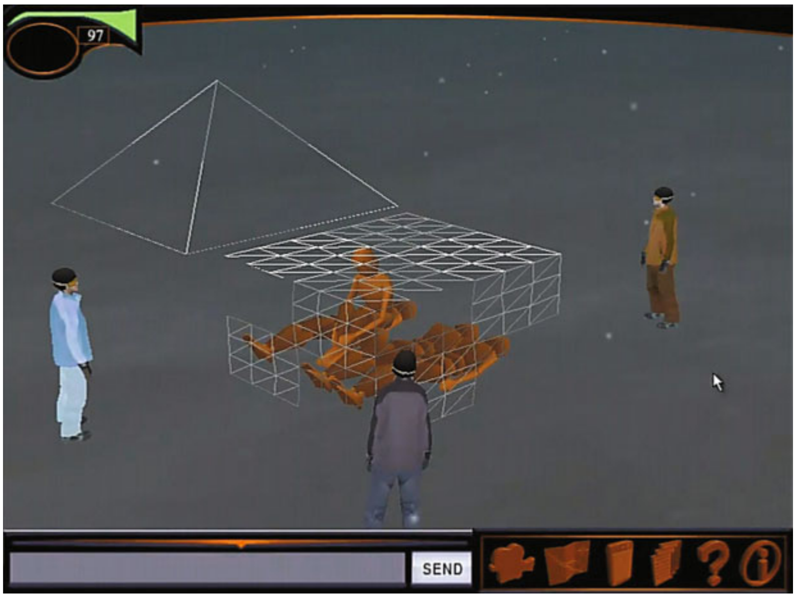

Figure 3. A scene from the multiplayer part of the survival master game for middle school ETE. In this figure, players are designing a shelter to protect them from the Alaskan cold.

Hybrid Modeling

Proponents of situated cognition have suggested that learning is far more meaningful when students can draw on real-world situations, especially situations in which they are personally invested (Lave and Wenger, 1991). Practices of authentic inquiry are best fostered through engagement in activities that are both model-based and situated in real-world activities (Barab, Hay, &Hickey, 2006). A uniqueness of the pedagogical approach taken in the design of the *Survival Master* game is the use of hybrid modeling. The term hybrid modeling characterizes the linking of real-world and computer-based models (Blikstein & Wilenski, 2006). Gameplay alone is an innovative pedagogy, however, hybrid modeling enables students to engage in a virtual design simulation, optimize their designs on-screen and then build functional models to compare physical and virtual implementations. In the *Survival Master* game, the functional physical model can be either full-size or a scale model (teacher's choice). It must meet all the design criteria. Students must consider the tradeoffs in choosing a cube-shaped structure (ease of construction, but high surface area, greater heat loss and increased snow-load on the roof), or a pyramidal or spherical/hemispherical structure (more complicated construction and bracing, but lower snow load and lower wind load in the case of a hemisphere).

The significance of hybrid modeling stems from the value added when students engage in both a virtual modeling and a physical modeling experience. A contemporary engineering and technology education program can propel this innovative pedagogical melding and provide students with the multiplicity of benefits that a synergistic blending of cyber learning and hands-on design and construct modeling can offer. A comparison of the merits of virtual and physical modeling is presented in Appendix 1. For example, using virtual modeling, students can easily vary *geometric* attributes of a shape (e.g., length, width, height) and define the resulting areas, perimeters and volumes. Additionally, they have the ability to make many iterations quickly, which provides a *shameless way* for students to build needed knowledge in a timely fashion and allows them to learn from trying out "what if" scenarios easily.

In developing physical models, tactile and kinesthetic experience of the design complements and improves comprehension of the problem. Physical modeling can convey ideas in unique ways that complement on-screen designs, especially for people with limited visualization skills. Additionally, a physical model better captures the irregularities and vagaries of a complex, real-world environment.

IMPEDIMENTS TO IMPLEMENTATION

In ETE, there are impediments to the adoption of gaming that relate to: (1) the image of video games as entertainment alone; and (2) the present state of teacher education that relies, to a large measure, on the comfort level of the present, traditionally trained professoriate. In ETE, pre-service training is still largely focused on materials-based technology, even in an age where ICT has become the dominant technological paradigm (Hacker, 2009). For example, using the experience gleaned through the development of *Survival Master*, it has become clear that teachers who are traditionally trained as industrial arts or crafts teachers have difficulty with the mathematics demanded by players in the game, even though the mathematics is at an elementary algebra level. Gaming, we have found, requires teachers to reorient their instructional practice. In gaming, students are the active partners in the educational transaction. The role of the teacher changes dramatically from presenter to guide, and many teachers are more comfortable in a role where they actively instruct. It has also become apparent that teachers are not always able to address firewall issues that must be solved in order to enable students to download gameplay elements.

We see three primary challenges to the implementation of educational gaming on the institutional level relating to the plethora of curriculum mandates: a general tendency of policy-makers to fear or mistrust video games as pedagogy and a prevailing lack of digital game-based learning literacy on the part of senior level teachers.

Regional and state curriculum mandates create the same difficulty in leveraging commercial off-the-shelf (COTS) learning games as they do with regard to every other genre of instructional media and courseware. One approach to this challenge is to enable teachers to repurpose COTS learning games through ‘modding,’ which is a common feature of current video games whereby the developer has included in the game purchase the toolset required to develop the game so that the end-users can use that toolset themselves to “modify” the game. This capacity has a new dynamic with the rise of open source or free development tools in use in the video game production industry that allow the teacher and/or learners to use the same tools to modify the game’s content.

To redress the issue of teachers’ fear and mistrust of video games, one promising model is to nurture their ability to become involved in game-based learning development. Across the US, a diverse range of digital game-based learning projects are actively seeking interested teachers to assist with educational game development. In this model, teachers then bring new skills and experience to their institution and serve as professional developers. The power is in the game. Avoiding or hiding the word game is a mistake and a disservice. Embracing the video game as integral part of the student’s life presents an opportunity for the institution to link its capacities with one of the learner’s most important self-identifications – his existence as a gamer. The institution has the infrastructure and resources to do so; all that is missing is the bridge – much in the manner that institutions welcome external communities of learning such as museums, scouting, sports, etc.

New teachers and new millennium learners at every level come to an institution with literacy in gaming that is largely misunderstood and most often underappreciated by senior faculty and administrators. This gaming literacy remains an untapped resource, one that can be effectively and efficiently enabled to become digital game-based learning power. This can best be accomplished with a “bottom-up” approach with a professional development investment aimed at the digital natives in the institution. These digital natives are poised to become a first wave of adopters, forming a cadre of peer mentors for teachers and learners alike. This is an especially inviting aspect for institutions that are in the process of evaluating new possibilities for pedagogy, the role of the teacher and learning communities.

A PROPOSED MODEL FOR INSTITUTIONALIZING GAME-BASED LEARNING

Teachers learn about educational gaming most effectively when it is presented as just another curriculum innovation. In earlier evolutions where computers were first brought to the classroom, followed by Web applications, a successful model for local implementation emerged that is still a good fit today. A model for implementing and institutionalizing game-based learning should include a focus on the following elements:

- **Professional Development**. Provide pedagogical and technical enhancement to pre- and in-service teachers to increase their capability and disposition to develop and implement game-based instruction in the ETE classroom.
- **Learning Communities**. Establish and support learning communities of natural alignments of intra-discipline, early adopters within the institution that work together to resolve local challenges.
- **Leadership**. Encourage leadership from the bottom-up. While it is important for support and leadership from the administration, the long-term success is dependent upon a widespread grass-roots initiative.
- **Support and Resources**. Hardware and software are needed. But, there must also be a deep institutional commitment to ongoing professional development training and support.
- **Celebrate Success**. Promote the early projects. Measure and report on the effectiveness. Involve the learners and their parents.
- **Renew**. Bring in experts and researchers. They provide new directions and help provide new energy to propel the projects beyond the early adopters to institution at large.

SUMMARY

Digital game-based learning is evolving from a promising prospect to a gender equitable, vitally engaging, core instructional strategy to be integrated into ETE instruction. The promise of playing and designing/developing thoughtfully conceived games can increase student engagement, promote inquiry-based learning, positively affect self-efficacy and attitudes toward further ETE study, and stimulate interest in related STEM careers.

Recent commercial successes of Serious Games products have demonstrated that digital game-based learning has a maturity and suitability for STEM learning that warrants serious consideration at all levels of education.

Institutions need to consider how they could transform their organizational systems and instructional practices to take advantage of educational games. This may require fundamental changes in attitude, management and models of organization. This may best be accomplished through bottom-up, grass-roots communities that privilege learning initiatives.

Teacher education should include both the technical and pedagogical means for teachers to implement game-based learning. Educational policy-makers should be helped to envision and support the potential of game-based learning. This will require an institutional commitment to provide new methods of professional development training that will support digital game-based learning as essential teacher training.

Institutions should engage digital game-based learning researchers and development communities to take advantage of the ongoing opportunities to participate in the development of new digital game-based learning products and research initiatives.

To effectively sustain efforts in reform and transformation, institutions should celebrate each small success achieved by early adopters as they lead their peers in embracing this new educational paradigm. These efforts should be measured and broadly reported to the educational community-at-large.

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APPENDIX 1: MERITS OF VIRTUAL VS. PHYSICAL MODELING

Virtual Modeling – Unique Advantages

Pedagogy

- Matches the preferred learning style of many of today's students
- Enables students with limited drawing skills to render successfully
- Helps students capture interim versions of their designs
- Helps teachers assess the evolution of students' ideas and their progression of learning
- Allows students to communicate by generating rendered design ideas for projected or printed PowerPoint presentations
- Eliminates waste of material resources
- The ability to make many iterations quickly provides a *shameless way* for students to build needed knowledge in a timely fashion

STEM Content Knowledge and Skill

- Permits students to easily vary *geometric* attributes of a shape (e.g., length, width, height) and define resulting areas, perimeters and volumes
- Scaffolds students' ability to visualize 2- and 3D shapes
- Allows for easy repetition to support development of skill in using the software
- Enables the use and integration of other software (e.g., Excel, PowerPoint)
- Enhances the ability to use (and understand the use of) software as a powerful modeling tool

Design

- Fosters creativity and higher quality through iteration
- Allows for trying out alternatives without additional costs (in terms of time, capital, materials, equipment)
- Allows students to learn by trying out "What if" scenarios with little risk
- Easy editing and duplicating of complex virtual objects, angles and shapes
- Provides instantaneous visual feedback to help make more informed design choices
- Permits precise scaling and dimensioning of geometric shapes and elements
- Rapidly calculates geometric areas to help students check calculations

Social Networking

- Students can share virtual models over networked computers
- Work can continue in other places such as at home

Other Advantages (not necessarily unique to virtual modeling)

- The software offers specific features, including ease of editing and replicating shapes and angles, providing students access to an almost unlimited supply of clip art and other online resources, and representational reality.

- Reinforces key concepts and skills learned in class (e.g., modeling, design, ratio and proportion, scale, making and interpreting “nets”)
- Develops higher-order thinking skills (e.g., synthesis, analysis, evaluation) in the context of solving engaging problems
- Consistent with contemporary design methods
- Supports creativity through a vast library of already-rendered objects, capacity to save versions and return to them later

Physical Modeling – Unique Advantages and Added Value

Pedagogy

- Students feel significant ownership of their constructed model
- Tactile and kinesthetic experience of the design complements and improves comprehension of the problem
- Physical model conveys ideas in unique ways that complement on-screen designs, especially for people with limited visualization skills
- Doing physical measuring reinforces measuring skills
- Geometry is experienced in a more meaningful, real-world way

STEM Content Knowledge and Skill

- Skills in using hand tools and machines and in processing materials are developed
- Promotes skills in effective management and use of limited materials to achieve a specific purpose
- Errors in math and design thinking are made visible by making the physical model
- Physical model provides a reality check to screen-based modeling (e.g., gravity can be absent in screen-based modeling)

Design

- Building a prototypical physical model is an essential component of the design process
- A physical model provides additional feedback to designers, i.e., it informs designers where the virtual model may not be accurate and keeps the virtual design honest
- A physical model better captures the irregularities and vagaries of a complex, real-world environment
- Working with a 3D physical model is a necessary complement to working with virtual models (e.g., it is sometimes easier to view the impact of changes in object placement in the physical model)
- A physical full-scale prototype permits testing designs under real-world conditions
- Allows testing of prototype qualities not easily modeled on the computer. An example is *ergonomics* (the “fit” between the design and human users)

– Contributes added realism for purposes of visualization, presentation and marketing
– Promotes creative thinking in that students may find it easier to create and develop their ideas when handling physical materials

Social Networking (not unique to physical modeling)

– Enhances communication skills through group discussion and planning
– Students recognize that teamwork is a necessity to get the job done effectively and on time