SAPS and Digital Games: Improving Mathematics Transfer and Attitudes in Schools

Richard N. Van Eck

Abstract Many suggest that digital games are a way to address problems with schools, yet research on their ability to promote problem solving, critical thinking, and twenty-first century skill sets appears to be mixed. In this chapter, I suggest that the problem lies not with digital games, but with our conceptualization of what it means to promote problem solving and critical thinking, and how transfer of such skills works in general and, specifically, with games. The power of digital games lies not in some magical power of the medium, but from embedded theories (e.g., situated learning and problem-centered instruction) and from good instructional design (the principles of learning and teaching to which all good instruction must adhere). This chapter describes situated, authentic problem solving (SAPS): a model to explain how digital games can promote transfer and improve attitudes toward mathematics. By examining research on the instructional practices (situated learning) and outcomes (transfer, problem solving, attitudes) that lie at the heart of SAPS, we can chart a path forward for best practices of digital games in mathematics education.

Keywords Situated learning · Authentic assessment · Transfer · Attitude · Attitude toward mathematics · Problem solving · Critical thinking · Engagement · Serious games · COTS games · Integrating COTS games · Games in the classroom

Houston, We Have a Problem

Whether or not our current approaches (hereafter referred to as “traditional”) have ever been a successful way to teach is debatable, but it is evident that they are not working today in United States (US) schools. Based on ACT test scores, only 45% of those who graduated from high school in 2011 were prepared for college-level math. US students continue to score below average in mathematics when compared to other Organisation for Economic Co-operation and Development (OECD) countries. In 2012, the US ranked 31st of 65 countries—a fact made

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R. N. Van Eck (✉)
Department of Teaching and Learning, College of Education and Human Development,
University of North Dakota, Grand Forks, ND, USA
e-mail: richard.vaneck@und.edu

T. Lowrie, R. Jorgensen (Zevenbergen) (eds.), *Digital Games and Mathematics Learning*,
Mathematics Education in the Digital Era 4, DOI 10.1007/978-94-017-9517-3_9

even less encouraging when one considers that this is unchanged from 2009 and that 36 countries have been added to the OECD since 2003, when the US actually was ranked sixth from the bottom (OECD 2012).

Traditional approaches not only fail to teach students mathematics, they also fail to engage them. The percentage of US students intending to major in mathematics has been estimated as low as 0.6 %, and US students account for only 10 % of the world's engineering majors (for which mathematics is a key foundational field) (Lutzer 2002). Because of figures like these, most educators agree that we have to focus on *interest* in mathematics in addition to mathematical thinking and computation.

The Problem Starts with Education

While much of the content taught in school remains unchanged from its origins (Thales of Miletus, ~600 BCE, mathematics; Euclid, ~300 BCE, geometry; François Viète's work, ~1600 CE, algebra), the fundamental *ways* we teach that curriculum have changed, and not for the better. Evidence from the early history of mathematics, shows that knowledge was often derived from observation and manipulations of objects in the real world, most often in service of solving real-world problems (e.g., the height of a pyramid and the number of blocks needed to build it), and the ways it was taught reflected that connection to real-world problems. Beginning with the Industrial Revolution in Europe (e.g., Joseph Lancaster's Monitorial System), when mass education became a government- and economics-mandated priority, education has become "boiled down" to the basics and stripped of all meaningful context or relevance. Consequently, methods of teaching mathematics during the last two centuries have been dominated by a computational focus on mathematics in the abstract, with little or no application to the real world.

Things are no better today; we routinely focus on lower-level skills instead of problem solving and do so in highly abstract and decontextualized ways (Woodward and Montague 2000). In one of the most rigorous, large-scale randomized observational studies of classroom practice to date, Pianta et al. (2007) randomly selected 1000 students at birth and followed them through their first 5 years of school, observing them in 2500 classrooms in 1000 schools located in 400 school districts in ten different cities. Among their findings were that the ratio of teaching basic skills versus problem solving was 5:1 for fifth grade and 10:1 for first and third grades. Mathematics problem solving specifically accounted for 7 % of all classroom time, and 91 % of teachers' methodology was either lecture or independent seatwork.

Back to the Future

By removing learning from meaningful, situated contexts, we have actually created less effective learning *and* a whole new problem: failure to transfer. Students today cannot apply the decontextualized learning they get in most classrooms to real-world problems. Most mathematics education experts now believe that the focus should be more on mathematics as a way of thinking rather than a set of discrete skills (Devlin 2011), and our standards bodies seem to agree.

The US Common Core State Standards Initiative (Next Generation Science Standards Lead States 2013) is a state-led effort to develop standards that provide a consistent, high-quality framework across all public schools. Forty-five states in the US have currently adopted the standards, which include mathematics. While these standards focus largely on the expected computational aspects of mathematics education, one of the six identified characteristics of the standards is that they "include rigorous content and application of knowledge through *high-order skills*" (emphasis added). This focus on high-order skills (e.g., problem solving) is further supported by the organizers' emphasis on connecting mathematics to the real world, or what experts call "thinking mathematically" (e.g., Schoenfeld 1992). Consider the following excerpt from the Standards for Mathematical Practice, which are designed to guide the implementation of the standards themselves (emphasis added):

> The first of these are the NCTM process standards of problem solving…. The second are the strands of mathematical proficiency [that include] adaptive reasoning, strategic competence, conceptual understanding …, procedural fluency …, and productive disposition (*habitual inclination to see mathematics as sensible, useful, and worthwhile, coupled with a belief in diligence and one's own efficacy*)…. Without a flexible base from which to work, they may be less likely to … apply the mathematics to *practical situations*, *use technology mindfully*…. In short [it] prevents a student from engaging in the mathematical *practices*.

The National Council of Teachers of Mathematics (NCTM) has likewise been calling for a renewed emphasis on authentic, real-world problem solving. The 2000 standards make several references to the need for a focus on problem solving and authentic learning (NCTM 2012; emphasis added):

- "Students need to see that mathematics is a human enterprise that, although often abstract, *has tremendous power in explaining and predicting real-world phenomenon*" (p. 29).
- "Active engagement with mathematics is best fostered through … interesting mathematical or *real-world problems*" (p. 35).
- "…[M]odeling and representation are key ideas that must be *anchored in real-world models and phenomenon*" (p. 100).
- "*Real-world contexts* provide many rich and varied opportunities for students to link what they are learning to the world around them and vice versa" (p. 202).
- "Mathematics … should focus on *solving problems* as part of understanding mathematics so that all students … generalize in situations within and outside mathematics … to solve problems and *adapt the strategies to new situations*" (p. 76).

Unfortunately, the standards provide no guidance on how teachers are to achieve these outcomes, and while both allow for, and even advocate, the use of games in mathematics education (e.g., the NCTM lists 25 games on their Illuminations Website), closer examination reveals that most of the games are of the paper-and-pencil variety rather than digital games[1] and focus on computational mathematics at lower

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[1] I use the term 'digital games' throughout this chapter to refer to any game that is developed for a digital environment, to include computers, game consoles, handheld gaming platforms, tablet games, etc.

taxonomic levels. Such games provide no answer to our current need to promote problem solving, transfer of learning, and learning to think mathematically.

We lost something critical 250 years ago when we severed the connection to real-world problems in education, or what I refer to as situated, authentic problem solving (SAPS). We lost something that goes far beyond whether people can “do sums”; we lost the ability to think mathematically. With that, we lost generations of potential mathematicians, engineers, and scientists who never saw the connection of mathematics to their lives and the problems they care about solving. Now, our failing schools and standards bodies demand a solution. How will we meet this challenge?

SAPS: A Roadmap Back to the Future Through Digital Games

It may help to describe the SAPS model and framework I will use before beginning this chapter in earnest. SAPS is a model that integrates several instructional theories and approaches, including situated learning, problem solving, transfer, engagement, and attitudes toward learning. Drawing on years of research in each of these areas, the model explains why and how problem solving, transfer, and positive attitudes can be promoted through instruction, including digital game-based learning (DGBL).[2] SAPS explains the apparently mixed results on the use of digital games in promoting these outcomes and points the way toward an effective way of using digital games in mathematics education. I will discuss this research in some detail throughout the chapter as I provide the rationale for this model, but the essential argument is as follows.

Situated learning is an instructional practice whereby learning and demonstration of learning (testing) are situated within an authentic, real-world environment, simulated or otherwise. Asking a student to solve abstract math problems in a workbook is not situated learning; asking a student to figure out how much wood and material will be needed to build a playground for their neighborhood is. Situated learning is an answer to putting learning back into real-world contexts and allows us to promote transfer of learning.

Transfer is the ability to apply what is learned in one context to another context, and it is rarely done by students. Failure to transfer is a largely self-imposed problem resulting from the decontextualized (non-situated) approaches we use in education today. Problem solving is both an instructional outcome (e.g., students are good problem solvers) and a process that learners engage in (e.g., students solve problems as part of their instruction). Problem solving is an important goal that is currently not met by formal education and which can subsume lower-level skills (e.g., computational fluency), making it an efficient instructional goal for mathematics curriculum. When problem solving (as an instructional process) is integrated

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[2] I use the term ‘digital game-based learning’ (DGBL) to refer to the use of games within an existing lesson, classroom, or other instructional context where the intent is at least as much to learn rather than to (exclusively) “have fun”.

with situated learning, we get transfer of problem solving and improved attitudes toward instruction.

Digital games are ideal vehicles for these processes and outcomes, and SAPS is a way to guide our practice in evaluating, designing, and using DGBL solutions in mathematics education. Many DGBL advocates today have, in my opinion, mistaken the forest for the trees, in part because they fail to account for instructional design, which is what has led to the fragmented, inconsistent nature of many research findings today (e.g., Hays 2005). In this chapter, I will outline the evidence for digital games as educational tools; describe the relevant research in situated learning, transfer, problem solving, and engagement (attitudes) upon which SAPS is based; relate each to digital games today; and conclude by providing examples and guidance for the application of SAPS to mathematics education.

The Evidence for Digital Games

Digital games are immensely popular with children and adults. According to the Entertainment Software Association (ESA 2013), Americans spent more than $20 billion on digital games and related technology in 2012. Video game play by children has been steadily increasing over the last 15 years, from 26 min in 1999 to 49 min in 2004, and 1 h and 13 min in 2009 (Kaiser Family Foundation 2010). Gaming devices now appear in 42 % of homes, with households with children being nearly twice as likely to own them (Pew 2010).

It is not surprising, then, that DGBL is seen by many as a savior for failing education systems today: digital games are able to teach content, change attitudes, and promote problem solving. There is evidence to support such claims. While success varies with the quality of the instructional design used to develop mathematics games, on average, a well-designed game improves learning over lecture by between 7 % and 40 % and can effectively erase the differences between failing students and those working at a "B" grade level (Mayo 2009). Digital games have been used successfully in a wide variety of domains and areas, including spelling, reading, mathematics, physics, health, biology, computer science, spatial visualization, divided attention, surgical skills, and knowledge mapping (Tobias et al. 2011), as well as combat skills (Kent 1999), language fluency (Baltra 1990; Barrett and Johnson 2010), and transfer of mathematics (Van Eck and Dempsey 2002).

Randel et al. (1992) conducted a review of 68 empirical studies on the use and effectiveness of instructional simulation games, with the vast majority of the games being digital, and found that games are effective in teaching social science, mathematics, language arts, physics, biology, and logic, with mathematics making up the majority of instructional game topics. Fifty-six percent of the studies showed no performance difference between games and conventional instruction, 39 % showed an advantage to games, and 5 % favored conventional instruction. Game use resulted in higher performance in mathematics, physics, and language arts, but less in other areas. Overall, Randel et al. (1992) found an advantage for retention and interest for instructional simulation games over conventional instruction.

Hays (2005) reviewed 105 articles on digital games for learning and concluded that “games can provide effective learning for a variety of learners for several different tasks,” including math and attitudes (p. 6). A meta-analysis of 32 studies by Vogel et al. (2006) found “significantly higher cognitive gains … versus traditional teaching methods” for games (p. 233).

So why then do we hear so often that the research on games is, at best, inconclusive? The answer is to be found in our inconsistent application of instructional design. Put another way, games are effective if and only if they adhere to the same instructional design principles as all good instruction. When we think of games as a new means of teaching whose power is inherent in the medium itself rather than a medium that embeds the instructional theories and events we know to be effective, we mistake the medium for the message: “There appears to be consensus among a large number of researchers with regard to the negative, mixed or null findings of games research, suggesting that the cause might be a lack of sound instructional design embedded in the games” (O’Neil et al. 2005, p. 467). Other researchers have come to similar conclusions (e.g., Leemkuil et al. 2003).

Situated Learning

The theory most important to understanding how digital games can improve learning, promote transfer, and increase positive attitudes toward the content is situated learning. Situated learning holds that learning is effective to the degree that it is embedded in a meaningful context (e.g., Brown et al. 1989; Choi 1995; Choi and Hannafin 1995; Lave 1988). Situated learning arises out of a movement in cognitive studies in the 1970s that began to study human cognition in the contexts in which they naturally occur (Cohen and Siegel 1991; Graesser and Magliano 1991; Meacham and Emont 1989). The theory is referred to as situated cognition, while situated learning is the term used to describe instructional methodologies based on situated cognition.

According to situated cognition theory, learning will be most successful if it takes place in authentic environments, using authentic tasks. An authentic environment is one in which the task, process, or concepts are likely to be found in the real world—what Brown et al. (1989) call the “ordinary practices of a culture” (p. 34). Situated learning most often refers to real contexts, but others have extended the concept successfully to simulated, or virtual, contexts. One prominent example is anchored instruction (Cognition and Technology Group at Vanderbilt [CTGV] 1992a, b, 1993). Much of the research on and design of anchored instruction was conducted using videodisc and CD-ROM materials, yet the findings remain relevant to digital games today. In anchored instruction, an environment, context, and story are developed in which the learning events, or “anchors,” are embedded. Anchors must represent authentic tasks, processes, and goals. The most well-known example of anchored instruction is the Jasper Woodbury project (CTGV 1992b). This 12-lesson series of adventures was divided into four main mathematical areas: Complex Trip Planning, Statistics and Business Plans, Geometry, and Algebra.

Students learned about the content through watching and interacting with a video story. Researchers often cite anchored instruction as a means of promoting transfer of learning as well (e.g., Anderson et al. 1996; Choi 1995; Choi and Hannafin 1995; CTGV 1993; Vye et al. 1998). Tests of the Jasper Project supported that research (Sherwood and CTGV 1991; CTGV 1993). So situated learning in real or virtual environments has been shown to be effective in learning and transfer of learning. What evidence do we have for the ability of modern digital games to support situated learning?

Situated Learning and Games

Several researchers from different disciplinary perspectives and, in some cases, using different terminology, have posited that digital games are situated learning experiences. Take James Gee's work on video games (e.g., 2007), which relies heavily on the concept of situated learning from a sociolinguistic or semiotic perspective. As a linguist, he is concerned with how we make meaning from words, symbols, images, and artifacts, which he posits "have meanings that are specific to particular semiotic domains and particular situations (contexts). They do not just have general meanings" (p. 24). His argument is, in part, that situations drive meaning and that meaning cannot be derived without context. Learning, from this perspective, is closely tied to the formation of identities through social–cultural–linguistic interactions in what Gee calls "affinity groups." It might be tempting to conclude that this is "merely" about identity formation or language acquisition, but he connects these principles and others to digital games, arguing that games are semiotic domains that require players to make and interpret meaning within a variety of different situations. While his focus is more about process outcomes than about "content" (p. 46), it should be recognized that mathematical thinking and problem solving *are* processes and that transfer of learning will depend on learners being able to "make meaning" of mathematics based on different contexts.

Digital games today, like role-playing games, simulation games, and adventure games, make perhaps the best use of situated learning of all other instructional approaches outside of actual apprenticeship. Digital games situate problems in meaningful contexts where learning and performance are authentic, which decreases the disparity between how learners learn mathematics and how they apply mathematics to real-world problems (i.e., how they transfer learning).

Transfer

Situated learning potentially removes the self-imposed problem of failure to transfer by making learning and performance contexts identical to the real world. Yet there is much to be learned about transfer that can further guide our use of digital games for promoting transfer. Transfer as a learning concept has its origins in the late 1800s in a philosophy called "formal discipline." Formal discipline held that the mind was like a muscle and that learning, like exercise, would improve the overall function of the mind (muscle). Thorndike (1969) and Woodworth (Thorndike and Woodworth 1901) cast doubt on this theory with their proposed theory of identical elements, which stated that transfer was a function of the amount of similarity, or identical elements, between the learning and performance contexts.

Here we see once again the relevance of situated learning, which also emphasizes the similarity between learning and performance contexts. In a game where transfer of mathematics is our goal, then we might design for situated learning by creating a virtual world that resembles the real-world context in which we want our learners to apply the knowledge in the future. So rather than building a game that allows learners to practice solving abstract equations for volume and area over and over until they reach mastery, we might create a game in which the application of volume is essential to achieving a goal that the learner cares about solving (e.g., building a community swimming pool and calculating the water needed to fill the pool with water, or determining how much water it will take to fill enough water balloons to put the neighborhood bully out of commission). In the case of using a commercial game like Zoo Tycoon, we might design problems like calculating the cost of adding a hippopotamus habitat to a zoo, which would involve many mathematical operations, including volume of water needed for the pool, allowing for the displacement of water by “X” hippopotami.

But transfer is more complex than this. Focusing on problem and context similarities ignores the role of the learner herself. The stance learners adopt prior to, during, and after instruction has as much to do with transfer (or failure to transfer) as the problems do. This is why many researchers have argued that social-constructivist theories of transfer are critical to solving the transfer problem. While even this subfield of transfer is too large to convey in the space allotted here, some key tenets will prove useful later in making the connection to transfer via games. In a recent special issue of Educational Psychologist, devoted to the constructivist approaches to transfer, Goldstone and Day (2012) argue that there are three key themes that emerge from this research: the stance, or perspective, of the learner; the role of motivation; and specific instructional strategies that can promote transfer. Intentionality to abstract knowledge to apply to future learning (forward transfer), or to search memory space for prior knowledge that can apply to a current problem (backwards transfer), may be more important than any other consideration. Consider the case where students are unable to solve a problem but, when prompted to consider prior knowledge, are suddenly able to do so. Motivation plays a large role in determining the learner’s stance as well; intrinsically motivated learners may be more likely to adopt more productive stances for transfer during and after learning. And, of course, the prompting, guidance, scaffolding, and strategies used during instruction serve a metacognitive function in helping learners develop and monitor good transfer strategies and to develop into more intrinsically motivated students. It is no surprise that all three are interrelated features.

Perkins and Salomon (2012) suggest a “detect–elect–connect” framework for understanding the multidimensional nature of transfer, in which learners must first detect the opportunity to transfer (similarity of surface or deep structures of two different problems), elect to engage in cognitive effort to connect the two, and connect the two problems by solving the one under study. We have been talking so far only about the last phase as transfer, yet all three are critical and are impacted by different strategies and approaches. They point out that transfer itself is not uniform, with problems that share surface detail and deep structure (same–same) often resulting in positive transfer, while problems that share surface-level characteristics but differ in deep structure (same–different) promote inappropriate transfer, and problems with different surface characteristics but similar deep structures (different–same) often result in blocked transfer. Each situation is different and requires its own approach to teaching, although it could be argued that the most important form is different–same.

An example of same–same might be when a person who knows how to drive a car is able to maneuver a tractor, even though they have never driven one before. The surface features appear similar and the deep structures are the same, so transfer works automatically. Different–same conditions, in contrast, might be when a student has learned how to calculate the duration, fuel cost, and timing of a space launch to Mars using calculus but fails to recognize that the deep structure of the problem is identical to intercepting an asteroid heading to Earth at a point where there is enough fuel and time to destroy it ("We never studied asteroid problems….").

It is this kind of transfer we are most concerned with in traditional mathematics. The two problems just described actually share more surface level detail in common than traditional mathematics. Formulae are traditionally studied in isolation (learning the formulae themselves), then in the abstract (applying the formulae to workbook-style practice problems, e.g., "2 + 2 ="), and finally in a word problem format. It is this latter format that is supposed to encourage and build transfer skills in mathematics, yet research has shown that transfer from word problems to authentic problems does not occur (CTGV 1992b). We teach abstract computational fluency with a few word problems sprinkled in and then are surprised when, without any further guidance, our students cannot apply mathematical thinking to real-world problems. We have to do more to reduce the disparity between school teaching and real-world performance. Early research on transfer has firmly established that transfer is unlikely without learner guidance on the connection between two different contexts or situations (e.g., Adams et al. 1988; Brown 1989; Gick and Holyoak 1980; Hayes and Simon 1977; Lockhart et al. 1987; Perfetto et al. 1983; Reed et al. 1974; Simon and Hayes 1976; Weisberg et al. 1978), yet far transfer (e.g., from abstract, computationally focused mathematics to situated, real-world problems) is more likely to require additional instructional events. This is where digital games can help, once again. By using situated learning, we can teach the mathematics in (simulated) environments that resemble the real-world problems we envision. In other words, digital games allow us to potentially turn far transfer problems into near transfer problems. This is not to say that there is no place for computational fluency training; it remains the best way to truly master the processes. But by first beginning with the situated problems, we establish a meaningful context for computational fluency training.

Transfer and Digital Games

There is a growing body of evidence that learning in digital games can transfer to other contexts. In one of the earliest post-CTGV/anchored instruction studies of transfer and games, Randel et al. (1992) found that junior high students who participated in an instructional game improved in their ability to select prior knowledge and relevant ideas for solving new mathematics problems (transfer).

Gopher et al. (1994) studied Israeli Air Force cadets using a game (Space Fortress II) versus no game, and found evidence for transfer from the game to actual flights. Similar results were found by Hart and Battiste (1992) with one game, but not with another. Also Brown et al. (1997) compared learning from a game about diabetes to another game (unrelated to diabetes or any other medical condition) and found that learning transferred to behavior in terms of better communication with parents and in self-managing diabetes.

I will discuss another game that I developed to promote transfer of mathematics skills later in this chapter as evidence for the efficacy of the SAPS model, and which also promoted transfer of learning. However, one example here may help to illustrate the power of digital games to transfer to the real world in ways that do not involve specific learning content. Re-Mission (Kato et al. 2008) is a game to help pediatric cancer patients learn to monitor and participate in their treatment plans. The game pits you as a nanobot character inside a human body, against cancer cells and antibodies that attack the wrong things, armed with antibiotics and chemotherapy. Research showed that patients who played the game had both a better understanding of their disease and treatment plan and how they interact, and adhered to their medication schedule significantly more than those who did not play the game (Kato et al. 2008). The situated nature of the learning (taking on the role of delivering the chemotherapy to the cancerous cells) changed perceptions of efficacy. It is hard to imagine a case where the stakes for transfer are higher and the clear evidence that a digital game made the difference.

Overall, the research shows that serious games (digital games designed to teach) are successful in facilitating both near transfer and far transfer “sometimes as well as traditional methods, and sometimes better than comparison modes” (Tobias et al. 2011). Again, this should come as no surprise when we consider that well-designed games will adhere to the same instructional principles that all good instruction does, and thus when paired with practices (e.g., situated learning) that have been shown to promote transfer in other venues, they should produce the same things. When we encounter research that indicates a digital game does not transfer, we are most likely looking at a game that does not adhere to situated learning, good instructional design, or which is measuring transfer improperly. So how can we best make use of digital games for the purposes of transfer?

Most researchers believe that improving transfer requires multiple transfer opportunities over an extended period of time (Quinones et al. 1995; Salomon and Perkins 1989). This is another reason digital games can help promote transfer. Unlike good teachers or tutors, digital games are always ready to teach and, when deployed via the Web, can potentially reach millions of people at the same time.

Like good teachers, however, well-designed games embed the instructional events (e.g., guidance, practice, feedback) to support learning and do so without variation no matter how many times they are played and replayed. Digital games allow us, therefore, to provide multiple practice opportunities, with minor variations in context being possible with relatively little effort.

Perhaps the most important aspect of transfer as it relates to digital games is that it is highly context- and domain-specific (e.g., Black and Schell 1995; Bransford et al. 1989, 1986; Brown et al. 1989; Salomon and Perkins 1989; Perkins and Salomon 1989). Experts in one domain do not necessarily perform better in other, related domains. For example, expert chess players do not possess extraordinary memory for chess positions and board sets, but instead rely on the arrangements of the chess pieces as cues for possible moves and strategies. Similarly, Gee argues that all meaning is situated within affinity groups and semiotic domains (like digital games) and that one cannot learn "general" meanings of things; all meaning is mediated by the environment and situation it is embedded within (2007).

It is this finding that best accounts for the disagreement over whether skills learned in digital games can transfer to other domains. If the question is whether playing digital games (and being exposed to the kinds of situated problem solving and critical thinking skills embedded in their particular semiotic domain) will make students better critical thinkers and problem solvers in the real world, the answer is probably "no." The distance between game contexts and real-world contexts, irrespective of specific domains (far transfer), is too great to see any short-term gains. The better question is whether playing those same games will make us better at the kinds of critical thinking and problem solving that go on in other similar games (near transfer), to which the answer is probably "yes." Does that mean that digital games cannot help us with transfer of skills and content taught in formal settings? No. The key is that digital games must situate the skills, problem solving, and critical thinking of our domain of interest (e.g., mathematics) within environments that mirror the application of those skills in the real world. Even then, this will only happen if we have arranged instructional events so that students make the connection between the two different environments. So the answer to the question of digital games and transfer is "yes, *if*" we do not rely on just any digital game to do it all on its own.

Problem Solving

So far, I have been discussing transfer without regard to the taxonomic level of the outcomes, yet problem solving may be the most logical outcome with which to concern ourselves. We do not do it currently (Pianta et al. 2007), yet it is a critical outcome for our schools, subsumes all lower-level skills so is not an "either–or" decision, and is the easiest to connect to real-world scenarios (situated learning). Research on problem solving goes back at least to the 1930s and Gestalt psychology, and a full accounting is neither possible nor warranted here. I will focus here on the key ideas from problem-solving research that impact how digital games and

DGBL can situate authentic problems in meaningful contexts to promote transfer and positive attitudes toward mathematics.

The first key finding for our purposes is that, just as with transfer, problem solving is context and domain dependent. What this means is that problem solving can only be taught within specific domains and not generically by instructional means (e.g., by digital game playing in general). Getting lots of practice solving problems in one domain does not make one a better problem solver in general (e.g., Anderson et al. 1996; Bhaskar and Simon 1977). Just as in Gee's (2007) conceptualization of situated learning, there is no "general" meaning of words, neither are there generalized kinds of problem-solving skills that apply across all domains and problems.

So, when some researchers speak about the ability of digital games to promote 'problem solving,' they are talking about the transfer of a generalized kind of problem solving that does not, in fact, exist. No matter how many digital games one plays, one will not become a better problem solver, per se. One might become better at solving similar problems, which is to say, better at playing games that embody the same kinds of skills and problems one has faced in a game. But when we talk about twenty-first century skills (e.g., Partnership for 21st Century Skills 2009) in the hopes that gameplay will transfer to real-world equivalencies in the future, we are ignoring a wealth of evidence from transfer and problem solving that suggests otherwise.

A second key finding is that because problem solving lies at the top of the intellectual hierarchy (Gagné et al. 2005), it subsumes most of the other intellectual skills in our learning taxonomies.[3] As Devlin (2011) points out in his book, "Mathematics is a way of thinking about problems and issues in the world. Get the thinking right *and the skills come largely for free*" (p. 1). This means that problem solving is the most challenging outcome to design for but also that doing so allows us to simultaneously address the lower-level intellectual skills.

The third key point for our discussion here is that problem solving is both an outcome and an instructional strategy, the former being the result of the latter. As described earlier, promoting problem solving requires providing students with multiple practice opportunities in solving different problems in different contexts. Any instructional strategy, therefore (including digital games and DGBL, as we will see shortly), must be compatible with problems and problem-centered instruction.

The last key point is about the nature of problems themselves. We will rely on this to make the connection to digital games in the next section. It is generally agreed that a problem has an initial state (the set of information and resources present at the beginning) and a goal state (the information and resources that *will* be present when the goal has been met). Jonassen (2002) also characterizes problems as having two components, but with a critical distinction. They have a goal (goal state), which he calls the "unknown" by virtue of the learner not knowing how it will be reached, and *a value* to the learner in achieving that goal. We will see next

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[3] That is, rules, concepts, and discriminations; the other varieties of learning (cognitive skills, motor skills, verbal information, and attitudes) are independent of problem solving and other intellectual skills.

that games are themselves problem spaces with initial and goal states, with goals/unknowns and a value to the learner in achieving that goal, and that this makes them good vehicles for promoting problem solving.

Problem Solving and Digital Games

If games are compatible with (or are themselves) problem solving, they should exhibit the same characteristics as problem solving. Games are goal driven, which some might argue makes them problem solving by default. One need only pick up any commercial game and read the marketing material or play the first 5 min of a game to see that this is true. Consider the description for *Game Magazine*'s 2013 Game of the Year Award for Bioshock: Infinite (Irrational Games 2013):

> BioShock® Infinite puts players in the shoes of U.S. Cavalry veteran turned hired gun Booker DeWitt. Indebted to the wrong people and with his life on the line, DeWitt has only one opportunity to wipe his slate clean. He must rescue Elizabeth, a mysterious girl imprisoned since childhood and locked up in the flying city of Columbia…. Together, they learn to harness an expanding arsenal of weapons and abilities as they fight on zeppelins in the clouds, along high-speed Sky-Lines, and down in the streets of Columbia, all while surviving the threats of the air-city and *uncovering its dark secret*.

Like problem solving in other venues, playing a game requires us to formulate a problem space for both the overall goal of the game (e.g., to help Booker rescue Elizabeth and discover the dark secret of Columbia) and the subordinate problems along the way (often numbering in the hundreds for adventure games like this). Everything one does in a digital game is problem solving—there is very little "down" time where actions are either not required (as with cut scenes) or where actions have nothing to do with solving the problem (e.g., customizing the look and feel of your avatar). Also, the player rarely has any of the prerequisite knowledge needed to solve the problem. In Jonassen's problem-solving parlance, this represents the "unknown" (how we will rescue Elizabeth, how to use those weapons and abilities, and what the dark secret of Columbia is). Just as clearly, however, there is a *value* in solving this problem as evidenced by the 3.7 million who had purchased it by May of 2013 (Goldfarb 2013). Providing *valued* problems is what games do that so many other examples of problem-solving instruction fail to do.

The problem (and a game is a complex problem made up of multiple problems) itself guides the learning and serves as the impetus and vehicle for learning all of the subordinate intellectual skills (rules, concepts, and discriminations). For example, consider the following scenario from the game Dark Souls (Namco Bandai 2011):

> I awaken in a dark cell with only a broken sword hilt and vague instructions to fight my way out of the dungeon to ring a bell which will get me out of the world of the undead. I know that I have an inventory with some items in it and, if I have played any game before, know that things I find will be useful in some way during the game (cognitive strategy and a rule). I find a key, some "humanity" (which makes me human until and if I die), and additional swords and armor. When I find a locked door, I realize one of my keys may open it, and there I find some pine resin. Examining it in my inventory tells me that it can increase the potency of my weapons temporarily. Later, after dying several times in a row in my

> attempts to beat the boss monster at the end of the first part of the game, I remember the pine resin, use it on my sword, and combine that with an attack from above which I know from experience does triple damage. I have combined several rules in the game, some of which I knew and some of which I had to learn. These rules have helped me formulate a new complex rule: information can be found that can help guide me as I combine useless things into things that will help me solve problems. This new rule will, in turn, help me later in the game (many times).

Yet we must not lose sight of Goldstone and Day's (2012) trinity of the stance of the learner, the role of motivation, and the specific instructional techniques that can make learners better at transferring mathematical knowledge. In the next section, I will talk about the role of situated learning problem solving and the formation of attitudes, and we will see how a game can address all three. But before we do, it might help to describe one more game; one that we are currently developing. Its goal is to promote expert-like thinking in science measured, in part, by the ability of students to solve analog science problems and to promote positive attitudes in girls regarding engineering science. The working title is Eco Adventure, and it takes place in a city where learners encounter three problems of increasing complexity, each of which forms one of the three levels in this game (L1–L3), in authentic ways (e.g., through the media, conversations, and observation). Using the SAPS model described in this chapter, learners solve these problems under the scaffolded guidance of a mentor. Through their interactions with people in the game, including a diverse group of scientists, local government officials, and community members, learners participate in authentic scientific processes while solving problems that deal with water, soil, and air impacting human, animal, and plant ecosystems. Learners set their own subgoals for play by earning badges, including "Green" badges (by choosing eco-friendly options), "Sleuth" badges (by minimizing the number of visits to key resources), and "Hero" badges (by promoting processes that maximally benefit people and animals). Players travel by clicking locations on the map and selecting the method of transport in order to interview people, conduct research, test solutions, or present findings to the elite Eco-Protector Scientists (EPS) group and to citizens. Our game also employs a variety of scaffolding strategies at key points in the problem-solving process using hints and prompts to get the learner to consider what they may be able to learn (their stance, or intentionality) from the current problem that could be helpful later (forward transfer) or how what they have learned might be applicable to a new problem (backwards transfer). The first problem provides the most scaffolding. Once learners solve this problem they encounter a more complex problem, which requires more from them, and which is accompanied by less scaffolding. The last problem requires learners to solve a more complex problem with multiple solutions, none of which is perfect. They receive almost no support along the way for this problem. Automatic, proximal measures such as deviation from the optimal solution path, elapsed time between key problem nodes, and patterns of responses to EPS questions are used to approximate measures of the learner's current thinking and to trigger mentor intervention in science.

So there is evidence that digital games are a kind of problem-solving instruction themselves and therefore should be just as effective as other instructional modalities in supporting problem-solving instruction. As situated learning environments (e.g., we play a specific character in a setting driven by a consistent narrative), digital games should also promote transfer. In the next section, I will talk about how these all work together to also promote positive attitudes toward instructional content.

Situated Learning, Problem Solving, and Attitudes

While we must increase mathematical ability, including at the computational level (where most of the test scores focus), increasing competence is no guarantee of increasing *interest* in the field of mathematics and related disciplines. While we might expect that increasing mathematics skills would result in some people feeling more positive about the field, attitude is formulated only in part by competence and self-efficacy. It is also important to show students that mathematics solves problems they care about, like building bridges, planning a playground, or calculating fund-raising needs to provide meals for the homeless for a year.

Low motivation and low self-confidence in math (Middleton and Spanias 1999) contribute to students' low levels of effort and poor learning outcomes. Research has shown that students who struggle with math are more engaged when math instruction is situated in real-life scenarios (Bottge et al. 2007). By combining situated learning and problem solving, we show students that mathematics solves real-world problems they *value*, which can help them come to see the value of mathematics itself (improved attitude).

We often talk about motivation, engagement, and fun in the same breath, but they are in fact very different phenomena. In my opinion, games (and all good learning) *ARE* about engagement if we recognize that engagement is *less* about fun and *more* about an effortful process that results from full employment of the learner's cognitive faculties (e.g., during problem solving). Recall Jonassen's concept of problems requiring both a goal, or unknown, and a *value* to the learner in meeting that goal. Digital games are "engaging" not because they are "fun" but because there is a *value* in the problems they ask the player to solve. Engagement results in part from problem solving, which is why DGBL should focus on both situated learning and problem solving. Figure 1 shows where I believe engagement is generated during problem solving.

In this model, it is actually failure, not success, that generates engagement. If the primary motivation for playing digital games (or engaging in any other effortful task) was the "fun" of being successful alone, most games would not be fun. As with digital games, most of our time in problem solving is spent in failure and remediation. Failure leads to cognitive disequilibrium, a state Piaget argued that is critical for our ability to "accommodate" new knowledge by restructuring our mental models or schemas. Higher-order learning is more likely to require accommodation, whereas lower-level learning is more likely to require assimilation (the process of "fitting" similar information into existing schemas without modification). When a learner makes a prediction and finds she is wrong, she wants to resolve this disequilibrium quickly and to begin asking questions like, "Why was that wrong? What did I miss?" This, in turn, prompts her to revise her hypotheses, take a new action to test them out, etc. Good *problems* will keep learners in this cycle, while good *instruction* (the events surrounding problem solving in formal learning

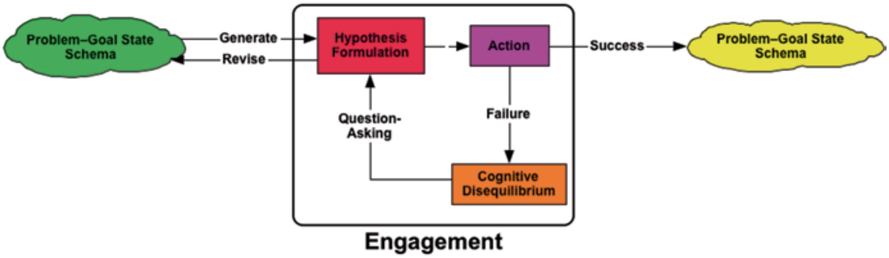


Fig. 1 Engagement as a function of the problem solving process

environments) will provide scaffolding and support so learners are operating at their maximum cognitive capacities, or what Vygotsky (1978) called being in the Zone of Proximal Development.

It is not too much of a stretch to see how the game I described earlier (Eco Adventure) combines both problem solving and promotes positive attitudes. The problems in conservation and ecology rarely seem like “typical” science problems to students, who are used to solving decontextualized problems that bear little resemblance to the things they care about. When the reason a student is solving a problem is to save wildlife, protect habitat, or provide safe drinking water for children, the process (and therefore the content) becomes more relevant. Students are in turn more motivated to solve them and may develop more positive attitudes toward the content areas. Remember that motivation is one of the three key themes in promoting transfer (Goldstone and Day 2012); the motivation from solving these problems in a game may be enough to get over the “elect” hump to which Perkins and Salomon (2012) refer.

So in addition to designing our curriculum around real world, authentic problems that our students find relevant, we have to recognize that our goal is not to make learning “fun” or to find ways for our students to *easily* achieve success. Rather, our goal is to find ways to *engage* them—to make them work at their maximum cognitive capacity and to design problems that make them fail regularly but about which they care enough to want to work through that failure with our guidance and support (scaffolding). Digital games are an ideal vehicle for this, which is why they can be an important part of mathematics education.

SAPS Model, Mathematics, and Games

Putting what we know about situated learning, problem solving, transfer, and engagement together yields the SAPS model for designing DGBL that should, based on prior research, promote transfer and problem solving and improve attitudes toward the content. There are examples and research that show it can be effective. Van Eck and Dempsey (2002) undertook a study to see if a digital game that made use of this model could promote far transfer of mathematics formulae to real-world problems and to improve attitude toward mathematics. In the game, the student plays the niece or nephew of a couple who fixes up houses. The player has been hired to help work on a house and has been assigned the tasks of calculating the amount of paint needed to paint a room and the amount of wallpaper border needed to paper the perimeter. The game is an immersive 2D environment with video avatars of the aunt and uncle, who can be summoned to ask questions as needed. The avatars appear in the doorway of the room when called, and are "embedded" (situated) in the environment as if they had just come in from the other room. No learning or demonstration of learning happens outside of the game or narrative context of the story.

Students who are taught to solve problems of area and perimeter in traditional, decontextualized ways typically fail to transfer those skills to contextually embedded problems. Thus, "calculating how much paint to use" to paint a room seems to many to be something they never learned (far transfer). Providing hints and scaffolding (through the avatar/advisement) helps them see that walls are squares or rectangles, that the vaulted ceiling comprises triangles and rectangles, and that the doors, windows, etc., are also shapes for which the area can be calculated and added/subtracted as needed. The advisement is the explicit instruction regarding the similarity of school mathematics contexts to real-world (in this case, simulated) contexts.

One-hundred-and-twelve middle school children were randomly assigned to one of five conditions formed by crossing "advisement" (contextualized video advisors or text-based advisors) and competition (competing against a character or not). Participants in the control group were given a computer-based tutorial containing word problems that were numerically and semantically identical to those in the program. Transfer of mathematics skills was assessed via a second computer-based instructional simulation identical to the simulation game in the treatment conditions in terms of structure and general content but differing in the setting (a theater instead of a house; near transfer). Transfer was measured solely by the ability to solve the problem.

Participants in the contextualized advisement condition without competition had higher transfer scores (0.82) than participants in the no contextualized advisement without competition (0.25). Participants in the no contextualized advisement with competition condition had higher transfer of mathematics scores (0.78) than those in the contextualized advisement with competition (0.47). It seems that those in the contextualized advisement conditions did best when competition was not present, while those in the competition conditions did best when no contextualized advisement was present.

It may be that the presence of competition creates an affective environment in which contextualized advisement cannot be fully attended to or processed because learners are concerned about the time they have taken (which is displayed on screen) and with beating the competitor. In other words, competition may inhibit metacognitive skills, attention, and elaboration. Further research with this game also showed that the SAPS model can improve attitudes toward the content, even after only 50 min of gameplay (Van Eck 2006). Players who participated in the conditions where the advisors were contextually embedded video avatars (situated advisement) within the game environment showed less anxiety toward mathematics at the end of the game than did those who received help in the form of text (abstract, or non-situated advisement). Results were particularly significant for those who were in the competitive conditions.

While one study does not prove a theory, this is not the only example of evidence for this approach. Research on the use of SAPS approaches has continued to provide evidence that higher-order learning and transfer can be promoted through games. For example, transfer from games to real-world skills has been seen in medical fields (e.g., Dobnik 2004), aviation (e.g., Gopher et al. 1994; Hart and Battiste 1992) and a variety of visual, cognitive, and psychomotor skills (Tobias et al. 2011).

David Williamson Shaffer has proposed a theoretical approach for conceptualizing game-based curriculum that holds great promise for promoting transfer and which reflects current thinking on transfer as a complex, socially situated process. Focusing on content as a way of thinking, he argues for "Pedagogical Praxis," (Shaffer 2004a) in which we design instruction based on the culture (situated learning) of the professions in which our domains are used in the real world. Students are thus encouraged to speak like experts, use the same tools as experts would use, and in other ways behave as experts in the given domain. Shaffer has extended his theory to the use of games ("epistemic games"). He has tested these epistemic games in a variety of domains and with different learners, and has found they can promote higher-order thinking and the development of expertise (Shaffer 1997, 2002a, b, 2004b), including mathematics. Among the key elements in his research with geometry, for example, was that the software was "autoexpressive," meaning that the tool's behavior reflected the student's conceptual understanding of the domain (e.g., mathematics).

The concept of autoexpressivity is perhaps of most significance for our purposes because it is the result of the alignment between the actions in the microworld (simulation game) and the domain of interest. The tool behaves according to underlying rules of the domain, and such, it is a direct reflection of the learner's current conceptual understanding of the domain. The environment and the domain are perfectly aligned, which then provides continuous and consistent feedback to the learner about her own (in this case, mathematical) understanding.

Chris Dede has also done important work that reflects the SAPS approach. One of his most significant efforts in this area is River City (Clarke 2007; Clarke et al. 2007; Ketelhut 2007; Ketelhut et al. 2007; Nelson et al. 2006), which is an example of what he calls a Multi-User Virtual Environment (MUVE). River City is designed explicitly around situated learning principles and has produced results consistent with prior research on situated learning and performance, motivation, and transfer outcomes. This virtual world focuses on a city (River City) where the population is becoming ill. It is unclear what the cause of the illness is, and it is up to the student to solve this problem. The players are "sent back in time" (River City is a nineteenth-century era US town) to explore the town, interact with residents, collect data, conduct experiments, and answer questions in a lab notebook. Through exploring the environment, interacting with the inhabitants, and sharing their results, they discover that economically disadvantaged families are disproportionately affected, and that there are several factors involved, including polluted water runoff to low-lying areas, insect vectors in swampy areas, overcrowding, and the cost of access to medical care. At the end, students write to the mayor of River City describing the health and environmental problems they have encountered and suggesting ways to improve the life of the inhabitants.

River City has been implemented with more than 1000 students in different middle schools and resulted in performance benefits (higher test scores than comparison groups), motivational improvement (attitude toward content, attitude toward domain, and self-efficacy), engagement in school (lower absence rates, reduced disruptive behavior), and perhaps most importantly, evidence for better inquiry (problem solving) and transfer. Students report, and their in-game actions and learning artifacts reflect, feeling more like a "real" scientist, understanding the connection between what they are learning (the domain) and how it aligns with the real world (Ketelhut 2007; Ketelhut et al. 2007).

Barrett and Johnson (2010) describe an approach consistent with SAPS within the context of sociocultural learning theory, which combines elements of Gee's, Shaffer's, and Dede's approaches. They have developed games for learning language (Farsi) in cultural contexts. Rather than learning phrases in isolated, abstract training environments, learners enter a game world in which they learn the language by trying to get around in an Arabic country. They land at the airport, and must interact with customs officials, taxi drivers, hotel staff, etc. In learning the language, they also learn cultural (situated) knowledge about idioms, what to ask first, topics to avoid, etc. Failure results in the behavior that would occur if the player were in-country (e.g., the taxi driver takes you to the wrong place, or is offended by the manner in which you asked to be transported and leaves you at the airport). These games, which rely on artificial intelligence to generate actual conversation, have been tested with more than 50,000 people and found to be effective in learning language, but more importantly, they appear to result in real-world transfer. In studies of the trainees in the field, it was found that the 3rd Battalion of the 7th Marine Regiment did not suffer a single casualty because, in the opinion of the commanders, the training was so effective in learning the language.

One can see in all of these examples both similarities and extensions of the ideas discussed earlier by other researchers. Gee's affinity groups and semiotic domains are echoed in Shaffer's epistemic frames, which extend these ideas to include ways of thinking and behaving within specific professions and domains.

Implications for Mathematics Education

Given our need to improve computational mathematics and problem solving, our desire to promote transfer, and the abilities of games (through situated learning and problem solving) to do all this while also improving attitudes, we would seem to have a blueprint for the future. What does a focus on SAPS approaches to learning mean for those on the front lines of education? In the remainder of this chapter, I will attempt to provide specific advice about putting this all into practice, covering some additional concepts along the way to help complete the picture.

Promoting Transfer and Problem-Solving Skills with Digital Games

Before we talk about specific ways to use digital games for mathematics education, it is important to remember that what makes for good DGBL in this regard is what makes for *any* good instruction—adherence to core instructional design principles. Unfortunately, good instruction is hard to develop. Worse, problem-solving curriculum and transfer are the hardest instructional outcomes to develop for. Add to this that DGBL is the most difficult medium to develop for, and you have a recipe for some of the hardest instruction you can design. We should be sure, therefore, that we are seeking DGBL for the right reasons and that we have the time and resources to implement it. For example, the home improvement game I described earlier that was successful took approximately 1000 h to develop and implement. SAPS is an approach that can be developed with or without digital games in mind, however, so just because a SAPS digital game *can* be used to teach lower-level skills does not mean the effort is always justified.

And when we do find digital games are compatible with the SAPS approach, we have to remember Jonassen's second maxim for problem solving; that the problem should have some *value* to the learner. Too often, we ignore this component, relying instead on our ability to convince students to "trust" us; that it will be useful "someday." Finding problems that our *students* care about (rather than problems *we* think are valued) can be harder than it sounds. Digital games must therefore reflect the kinds of problems our students value, not that we value or think our students *should* value. The best way to find those problems is to involve students in the process—make them co-designers. Students love nothing more than being asked for their opinion.

Finally, the contexts in which we situate those relevant problems must be relevant and transferable to our final domain environments. It can be possible to find a good problem that is valued by students but which does not map well enough to the content. The time it takes to implement good DGBL will only pay off if we address enough of the content under study. So the problems we identify should require enough of the sub-skills we have taught or wish to teach so our students learn to solve problems as well as gain fluency with the computational sub-skills those problems require.

Using Designed Games

The most effective way to use digital games in the classroom is to design the games from the ground up to teach what we want. That way, we can ensure the best content coverage and the most effective application of the SAPS model. Whether designing or selecting serious games for the classroom, there are several things to look for.

First, make sure the game is explicitly aligned with curriculum standards that your school values (e.g., the Common Core). Games in the classroom can be a tough sell to administrators, parents, and even students, so the conversation has to begin and end with achieving instructional goals you cannot otherwise meet easily. Those standards should then be mapped to specific content areas in your curriculum.

Once you know the game meets your goals (and that you can articulate how and why when asked!), evaluate the game yourself as a player. Contact the developer to get access to the game and to any professional development materials they may have, and play the game. Look for things like how well the content (the problems) is integrated (situated) within the game itself and how authentic the problems are. Shaffer's idea of autoexpressivity is key here: does the game require demonstration of the skills and concepts in order to advance, or does it use gameplay to "reward" traditional instruction? The game should be centered around problems that would normally require the application of those skills to solve. Mathematics is itself embedded in a variety of real-world activities rather than being a profession, per se (mathematicians and educators notwithstanding!), so the problems in the game and the processes used to solve them should be situated and authentic.

McLarin's Adventures (K20 Center 2008) is a game in which players use mathematics to help survey a planet they have landed on. While this context is clearly fantasy-based, the process of surveying land (problem solving) is quite realistic (regardless of what the flora and fauna of that world look like!) and, most importantly, the use of mathematics and related surveying, graphing, and mapping tools is highly authentic. Application of mathematics skills is directly relevant to advancement in the game, and the game and tools are autoexpressive in that the students' conceptualization of the mathematics is reflected in the tools and game behavior. The game is aligned with the Common Core mathematics standards and has been used with thousands of students in dozens of schools around the country and has been found to be effective in promoting learning.

Project Selene (CyGaMEs 2007) is a game in which players learn about how moons form by "building" their own moon. They must choose how much matter to accrete over what period of time, while monitoring the geological processes that govern moons versus asteroids versus debris. The context is much more realistic than McLarin's Adventures, in that you are simply in space working with debris. Of course, this technology is not actually possible now, so the setting is still fantastic, but the game and its relation to the domain of interest is still authentic. The game is aligned with the National Science Education Standards, the American Association for the Advancement of Science Atlas of Science Literacy Strand Maps, and the Next Generation Framework for K-12 Science Education. It has won several prestigious awards and has been shown to be highly successful in promoting transfer of scientific knowledge in public school curriculum.

Contemporary Studies of the Zombie Apocalypse (Triad Interactive Media 2013) is a game that is geared toward middle school students and is an adventure game that uses the SAPS model in which players routinely encounter real-world aspects of abstract mathematical concepts (Fig. 2). In addition to problem solving, players learn to think about the world mathematically, with abstract concepts manifested within the game world in visual, relevant ways. Humanity finds itself living underground because of a zombie infestation. Once a year, four children win the lottery

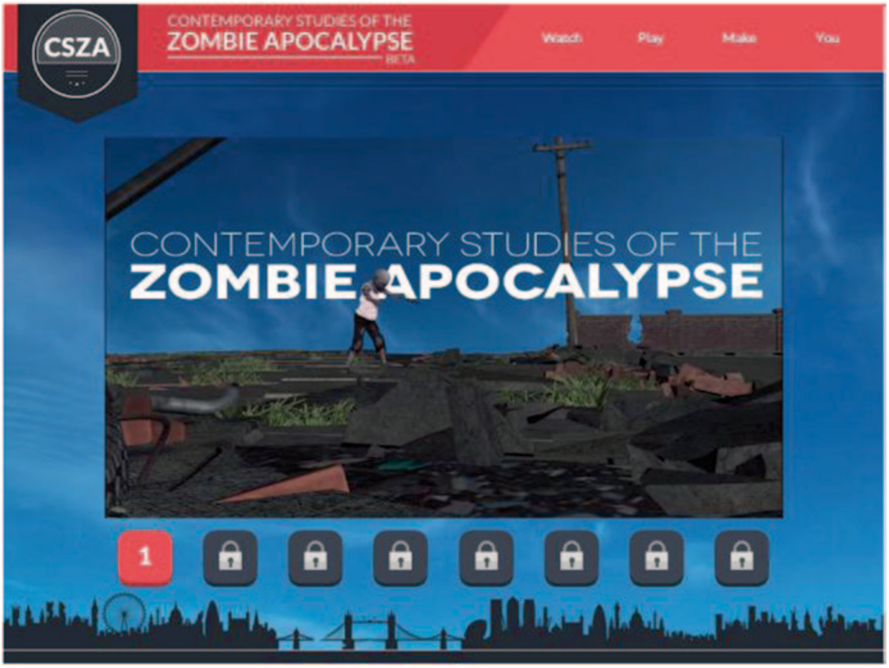


Fig. 2 Home Screen of CSZA

and are allowed up to the surface to scout things out. All is not as the corporate government state would have them believe, however, and through a series of adventures (which require mathematical problem solving, all situated within the context of the narrative), the children come to realize the surface is not all that bad (despite the odd zombie) and decide to live up there. In addition to problem solving and a series of fluency/computational skills learned along the way, this game also has a unique feature in which concepts like convex, concave, linear, and periodic are manifested in visually relevant ways. For example, players choose between “continuous” and “discontinuous” holographic images of themselves to help them fool the zombies as they walk through the street. The discontinuous image jumps around and appears and disappears randomly, while the continuous image is projected a set distance away and mimics the player’s actions. These concepts are normally presented in abstract ways, making it difficult for students to transfer to real-world examples later. This aspect of situated learning allows players to develop conceptual understanding of abstract principles as things they can connect to the real world, which in turn provides context for the abstract problems they also must be able to solve. The key to ensuring this transfer (both from abstract to concrete, and then back again to abstract) lies in debriefing and making that connection explicit. In other words, it is not enough to watch students complete the problems; we have to also talk to them about *how* and *why* they were able to solve those problems.

Integrating Commercial Games

Another way to use digital games for mathematics education is to use existing commercial games. Commercial, off-the-shelf (COTS) digital games are far more prevalent than serious games and have the advantage of being valued problems by virtue of the marketplace. So what about the use of COTS games that have not been designed for these purposes as part of our DGBL? Can they also promote problem solving and transfer? The answer is that they can, if we understand how they are both similar and different than these other approaches and if we embed them in larger lessons that make use of good instructional design (DGBL).

As you might expect, using COTS DGBL involves the same theoretical and practical approaches we have already discussed, but the ways in which situated learning and authentic problems are manifested in COTS games differ from the first approach. With COTS games, you do not have as much control over the content of the game itself and instead must work around the limitations of the game. But this is not the no-man's land it might first appear to be.

Just as you must analyze serious games for their autoexpressivity, the value of their problems to your learners, and the content coverage you require, with COTS games you will also need to identify where there are gaps and inaccuracies in the game content or where the strategies employed by the game for solving the challenges is insufficient (e.g., trial-and-error vs. reasoned thinking). In other cases, the game may lead to misconceptions or an incomplete picture of the content and skills. And since you cannot change the game itself (in most cases), these are the places where you will need to design extension activities to extend the learning. And because the commercial game is not explicitly about the content itself, you must also develop instruction that helps learners see the connection to the content under study.

But while this sounds like more work than a serious game would require (and in some ways, it is), it is not so different from any DGBL. No game perfectly replaces an entire unit of instruction. Just as with any other medium, integrating any game into your curriculum will involve the design of a curriculum within which to embed the game as one modality. This might be more familiar if we switch the medium—nobody expects that showing a movie (e.g., *Old Yeller*, or *To Kill a Mockingbird*) will serve as a stand-alone unit of instruction—we design pre-instructional activities, homework, application exercises, worksheets, classroom activities, and assessment methods. And these are then deployed according to a plan, with the instructor serving as coach, facilitator, guide, assessor, etc. The same is true for digital games and DGBL.

Your goal in specifying these activities to address the strengths and weaknesses in a given COTS game is not to provide "the answers," but to support learners as they generate the knowledge necessary. As you do so, you should think in terms of designing problems, roles, and projects that are *authentic* to the game environment and which serve your learning outcomes as described earlier. So while it is possible to generate a problem that addresses the gaps in the learning outcomes supported by a given game, we must (1) tie the problem to the problems in the game, (2) tie the roles of the learners to the roles in the game AND to the people who would be involved in solving such problems, and (3) tie those roles to the kind of project that such people would work on in order to solve those problems. In short, we have to ensure that the principles of authenticity and situated learning permeate the full scope of our instructional solution (our DGBL).

So how do you identify a good COTS game? Titles are your first clue about whether a game might be applicable to your curriculum. Game titles like Civilization, 1701 A.D., and Zoo Tycoon all convey enough information about their content to make them candidates for further evaluation to teach history or biology, for example.

But the relevance of a game to your content is not always apparent from the title. Understanding what the game actually *requires* of the learners and how autoexpressive the game mechanics are in terms of authentic (not realistic) content opens up a whole range of COTS games for DGBL that might at first glance appear to be of little value. While it seems obvious that Zoo Tycoon might have application for biology, playing the game and analyzing it reveals that some of the other primary content areas for this game are economics, business, marketing, and mathematics. Zoo Tycoon requires that one manage the business of the park, attending to outputs from a fairly sophisticated simulation of the zoo's financial health. Factors like costs, customer satisfaction, and animal health are influenced by (and require adjustments from the player to) the number of animals, cost of their appropriate habitats and food, the number of food stands, money spent on maintenance and sanitation, and the prices of admission and services. Roller Coaster Tycoon (Atari 2003) is another COTS game that, in addition to the business and mathematics applications of Zoo Tycoon (Microsoft Studios 2001) can be related easily as well to mathematics (calculus) and physics. Roller coasters, in the real world, are built by engineers who must know physics and mathematics. While the game itself does not *require* this knowledge, it is reasonable (and authentic!) to expect that building roller coasters in the game world would normally be done by engineers using these skills, and thus be subjected to the same constraints as in the real world (e.g., safety inspections, design document and blueprints, computer simulations). It is reasonable to posit that engineers built the roller coasters, even if the game does not employ them. Thus, the activities we design around the game can leverage authentic problems while remaining situated within the game fantasy and still address our content areas and outcomes.

Further, the same game can be used to teach these areas at different grade levels by varying the complexity of the supporting activities. Middle school and high school students might write simple reports and design documents about one part of a specific roller coaster using Newton's laws and basic computations of energy, mass, and acceleration as project outcomes, while undergraduate and graduate students could generate detailed design specifications and reports that focus on higher-level calculus, vectors, conceptual physics, and stress tolerances for an entire roller coaster, or even build simulations to test existing designs. Middle schoolers might write reports (as zoo managers) about the financial health of the zoo or (as exhibit designers) proposals about a new animal acquisition and habitat, while graduate business majors write detailed analyses of the underlying economic model of the zoo simulation and predict its behavior if it were based on a different economic model. By focusing on the strategies required during gameplay (the autoexpressivity) rather than just the surface content of the game, one finds that there are many games out there with potential to teach a wide variety of topics at several grade levels. This is a complex process presented in more detail elsewhere (Van Eck 2008).

Having Students Build Games

The third and final way to use games to teach mathematics is to put the design process in the hands of students. In this approach, students use a variety of tools to build their own games. A variety of tools exist for this purpose (e.g., Scratch, GameMaker, RPG Maker), many of which are inexpensive or free. Whereas in the past building games was only appropriate for teaching computer programming, with the addition of instructional design elements, one can use this strategy to teach any content. For our purposes, mathematics, the key lies in finding elements of the game design that embody mathematical concepts (the game design itself is problem solving).

When creating virtual worlds, one has to define the space (area) and decide how many things can be in that space (density) and how far apart they are in relation to their size (scale). When populating that space with people, one has to consider travel time (speed × distance), how much weight can be carried, how much damage each person can do in combat, etc. When populating the world with artifacts such as weapons and loot that can be acquired, one must determine how much each costs and how much it weighs, so that when a character attempts to carry it, he or she will only carry items for which there is room, and when he or she attempts to sell it, we know how much it is worth. We have to determine how much protection each type of clothing and armor should provide versus how much its mass will slow the user down. All of these things require the generation of algorithms (e.g., weight of items slows down travel speed; selling items leads to transfer of money from one place to another; weapon damage vs. armor class × strength of attacker).

Because all such real-world projects (building a game) require planning, it is a normal (authentic) practice to generate these specifications ahead of time and test them on paper (mathematically) before taking time to develop them. It is true that many game tools will generate a lot of these decisions for the player, and it is possible to populate that world *without* a plan. As teachers, though, we can (and must) place constraints on the experience so that it is embedded in a full lesson plan rather than allowing the game activity to stand on its own. Remember that transfer cannot occur without additional instruction to support it as an outcome. We create the requirements to plan and work authentically with the mathematics in the context of game design so that students see the relevance and so we can ensure all the instructional events are present to ensure learning. This includes specific instruction on the connection between the mathematics and the environment/activity.

In addition to game design tools, there are some games that allow players to design new levels or maps to extend play within the game. These tools are invariably free and can be a great resource for this kind of DGBL. One example is the game Portal (Valve 2007). In this game, you control a robot that has to find a way through a series of challenge rooms by following marked paths blocked in various ways by the testing facility the player finds him or herself in to start the game. To solve for the unknown, the player must solve puzzles by manipulating levers, springs, acceleration technology, and portals that warp dimensional space to avoid things that will harm the player's character. For example, to get across one room, I may have to push a cube onto a button that triggers a door to get into a room that will let me use my portal gun to open a pathway to another part of the room that has a spring-loaded launcher that will fling me over an acid bath obstacle but only if I shoot a portal in the wall while in mid-air so I come out in a different room. Obstacles and devices can be combined in thousands of ways to make an infinite number of challenges, and Valve has released Puzzle Maker software that allows players to make their own test chambers using these tools. Note that in addition to the mathematical elements described previously, this game offers additional options relating the mass of cubes and the player character (a robot) versus the force needed to trigger a switch and the stored kinetic energy of spring launchers, all calculated against gravitational forces and navigation of 3D space. Planning such puzzles would, authentically, involve making mathematical calculations as part of the design document, thus providing a context for mathematics study.

Final Thoughts

It might seem from this chapter that the issue of transfer and games is both well-researched and settled. The truth is that most of what we think we know about games and transfer is based on thought experiments that extend prior empirical research. There is no question that more empirical research must be done, both on games and transfer, and on how they do and do not work together. We have little reason to believe, however, that situated learning principles, which have received significant support in past modalities, would suddenly become less effective when used to design games, for example. To be sure, each new medium influences the message; we may know something about the instructional strategies (scaffolding) needed to help promote transfer and still not know the best way to deliver them in different kinds of gaming environments. But the tools exist and the theories are sound, so the only thing stopping us from answering these questions is the will to do the research that is needed.

And in that regard, this chapter serves as much as a guide for the work that must yet be done as a definitive treatise on how games promote transfer. The procedures and examples I have presented here are about how DGBL and COTS DGBL can be designed to promote problem solving and transfer while meeting our curriculum goals. There is, of course, a lot more involved in putting it into practice. And it is important to remember too that digital games are by no means the only way to achieve these goals. In fact, the only reason games are effective in this regard is that they employ theories that have stood the test of time, decades before the arrival of the digital game. Digital games are, however, a very good model for how to build situated, authentic problem-solving environments, which we know is a goal that eludes most educators. So I leave you here with some parting thoughts to keep in mind as you seek to integrate digital games into mathematics instruction.

Remember That It Is About the Theory, Not the Medium

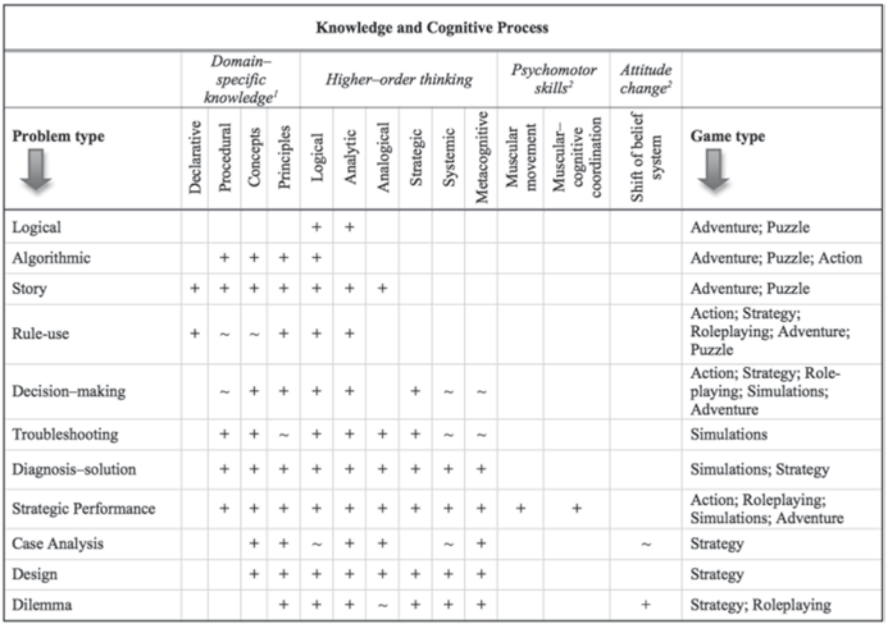
Transfer is promoted through repeated exposure to a wide variety of problems in different contexts. The more similar the learning and performance contexts are, the more likely transfer will occur, although there is no guarantee. The more problems we are exposed to, and the more varied the contexts of those problems, the more likely we are to exhibit far transfer. Authenticity is more important than realism—ensuring that the problem requires the authentic application of the skills under study will trump whether that problem is "realistic" or not. Engagement is about cognitive effort and autonomy, not about fun. It emerges from effortful learning that we pursue for the value of solving the problem.

Remember That Not All Instruction Must Be Realistic, Authentic, Situated, or Problem Based

Lots of instructional goals can be achieved without going to this much trouble! Do not fall into the trap of trying to use digital games for all learners, all content, all the time. A jet will get you to the grocery store, but a bike or pair of tennis shoes will do so too, and you won't have the problem of parking! If you can achieve your goals without developing authentic, situated, problem-centered learning, then do so. Use problem solving, situated learning, and DGBL when and where they are needed.

Remember to Use the Right Game for the Right Purposes

Space does not allow for a discussion of the different types of problems that exist any more than it does for the different kinds of games. Logic problems (e.g., the classic dinner party logic puzzle) differ from moral dilemmas, for example, and games like *Jeopardy* (verbal information) (Friedman 2013) differ from games like Bioshock (problem solving). My colleague and I have made some preliminary efforts to address these differences and to align different problem and game types. Figure 3 presents a summary of these findings, for which the full context can be found in the chapter referenced there.



Knowledge and Cognitive Process														
	Domain–specific knowledge[1]				*Higher–order thinking*						*Psychomotor skills*[2]		*Attitude change*[2]	
Problem type	Declarative	Procedural	Concepts	Principles	Logical	Analytic	Analogical	Strategic	Systemic	Metacognitive	Muscular movement	Muscular–cognitive coordination	Shift of belief system	**Game type**
Logical					+	+								Adventure; Puzzle
Algorithmic		+	+	+	+									Adventure; Puzzle; Action
Story	+	+	+	+	+	+	+							Adventure; Puzzle
Rule-use	+	~	~	+	+	+								Action; Strategy; Roleplaying; Adventure; Puzzle
Decision–making		~	+	+	+	+		+	~	~				Action; Strategy; Role-playing; Simulations; Adventure
Troubleshooting		+	+	~	+	+	+	+	~	~				Simulations
Diagnosis–solution		+	+	+	+	+	+	+	+	+				Simulations; Strategy
Strategic Performance		+	+	+	+	+	+	+	+	+	+	+		Action; Roleplaying; Simulations; Adventure
Case Analysis			+	+	~	+	+		~	+			~	Strategy
Design			+	+	+	+	+	+	+	+				Strategy
Dilemma				+	+	+	~	+	+	+			+	Strategy; Roleplaying

Fig. 3 Problem types, their associated cognitive processes, and learned capability outcome, and the gameplay types that might best support them. For the problem types that are more complex and highly contextualized, the acquisition of domain knowledge is assumed to be required, and for purposes of readability, is not marked in this figure (Reprinted with permission from Hung and Van Eck 2010). (Note: [1]For the learning type under Domain Knowledge, application of the knowledge is also assumed in this chart. [2]For Psychomotor Skills and Attitude Change: domain-specific procedural and principle knowledge and metacognitive thinking are assumed. + signifies "always required."; ~ signifies "sometimes required.")

Games Are a Part of, Not a Replacement for, the Curriculum

Games are no shortcut to instructional design—rather, they require more than other forms of instruction in many ways. They also allow us to achieve higher goals than we can otherwise achieve, which makes them worthwhile. So we need to choose where we use them carefully. To justify the significant effort they take to plan and implement, we should use them for problems that can cover significant portions of our curriculum and for which we do not have good instructional solutions.

The stakes for mathematics education have perhaps never been higher, with the growing STEM gap and continued evidence that US students lag behind their international peers. Fortunately, we know what to do, and digital games can be a great way to do it—but only if our practice is based on theory and if we don't fall prey to the hype about games being fun, automatic, or easy ways to do it.

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Richard N. Van Eck is Associate Dean for Teaching and Learning and the founding Dr. David and Lola Rognlie Monson Endowed Professor in Medical Education at the University of North Dakota (UND) School of Medicine and Health Sciences at the University of North Dakota, in the United States of America. He has also served for 11 years as a professor of Instructional Design and Technology at UND and for 5 years at the University of Memphis, Tennessee, where he was also a member of the Institute for Intelligent Systems. He has been studying games and learning since 1995 when he entered the PhD program at the University of South Alabama and worked as an instructional designer or developer on several learning games there, including Adventures in Problem Solving (Texas Interactive Media Award 1999) and Ribbit's Big Splash (Gulf Guardian Award 2002; Environment Education Association of Alabama's 2002 Best Environmental Education Award). Since then he has been a researcher and designer on several other STEM games, including PlatinuMath (mathematics game for pre-service teacher education), Project NEO (science game for pre-service teachers), Project Blackfeather (programming game for middle school students), Contemporary Studies of the Zombie Apocalypse (mathematics game for middle school students) and Far Plane (leadership game for high school students and adults). Dr. Van Eck is a frequent keynote speaker nationally and internationally on the educational potential of videogames, and his scholarship on games, in this area includes dozens of books, chapters and refereed publications, and more than 75 presentations on games and learning including talks at TEDx Manitoba and South By Southwest. In addition to his work on serious games, Richard has also published and presented on intelligent tutoring systems, pedagogical agents, authoring tools, and gender and technology.