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Using Video Games in Science Instruction: Pedagogical, Social, and Concept-Related Aspects

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Abstract: The potential of using video games to promote learning in classrooms is gaining recognition, but few studies have explored how video games impact teaching and learning in science classrooms. This manuscript reports on the implementation of the video game *Nano Legends* in four grade 8 science classes in Ontario. Data sources included interviews with teachers and students, classroom observations, online and written student artifacts, and pre and posttests. The findings indicate that the game was effective at communicating factual content and promoting social interactions in the classroom and virtual world; however, teacher intervention was necessary to supplement learning and provide differentiated instruction.

Résumé: On commence à reconnaître les mérites potentiels des jeux vidéos pour promouvoir l'apprentissage en classe, mais peu d'études ont analysé l'impact de ces jeux sur l'enseignement et l'apprentissage des sciences à l'école. Cet article rend compte de l'utilisation du jeu vidéo *Nano Legends* dans les cours de sciences de quatre groupes d'élèves de huitième année en Ontario. Les sources de données comprennent entre autres des entrevues avec les enseignants et les étudiants, des observations de classe, des artefacts écrits et en ligne de la part des étudiants, ainsi que des test réalisés au début et à la fin du projet. Les résultats indiquent que ce jeu est efficace pour ce qui est de communiquer les contenus factuels et de promouvoir les interactions sociales aussi bien dans la salle classe que dans le monde virtuel. Toutefois, l'intervention de l'enseignant reste nécessaire pour compléter l'apprentissage, fournir un enseignement différencié et évaluer les progrès des étudiants.

INTRODUCTION

Video games are an integral feature of life in this *net generation* (Tapscott, 1998), and commercial video games are motivating as evidenced by the willingness of students to make an extended commitment to play them (Prensky, 2003). Educators have begun to explore the possibilities of tapping in to the inherent motivational aspect of video games to support learning of content in formal learning environments. In recent years, studies have investigated how some commercial and educational video games are implemented in junior, middle, and secondary schools (Becta, 2006; Levy, Wideman, Owston, & Orich, 2007; Sandford, Ulicsak, Facer, & Rudd, 2006; Kiili, 2005; Squire, 2004). These studies report both positive impacts (such as increased motivation)

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and negative impacts (such as failure and frustrations) among students. For example, Levy et al. (2007) found that a role-playing game developed to enhance student acquisition of English language and literacy skills motivated students in grades 4 and 5. Squire (2005) conducted a study of secondary school students using a video game in Social Studies and reported that students who do well in the classroom are more reluctant to view gaming as a legitimate learning tool and experience much more frustration when playing the game. While the preceding studies provide insights into video game use in classrooms, these studies do not address the implementation of video games in science classrooms. All disciplines have a unique structure related to organization of subject matter, modes of inquiry, and knowledge outcomes (Schwab, 1964); therefore there is need to explore how teachers and students experience using video games for science learning.

Investigating digital technology in science education is not new. The literature on science education documents the use of implementing technologies such as simulations, modelling software, and data-logging into the curriculum. These studies indicate enhanced learning and engagement in science (Hug, Krajcik, & Marx, 2005; Jimoyiannis & Komis, 2001; Pedretti, Mayer-Smith, & Woodrow, 1998; Webb, 2005). Few studies have focused on how video games impact science learning. For example, Magnussen (2005) documented how an IT-supported, non-competitive, role-playing game, *Homicide*, promoted scientific inquiry among grade 8 students. Annetta, Cook, and Shultz (2007) documented how MEd graduate students created video games situated in problem-based learning scenarios in biology. The Federation of American Scientists (2006) also reported that the use of video games in classrooms is still not widespread and there is little research that investigates the impact of video games in relation to classroom learning.

Video game implementation in classrooms is dependent on teachers' willingness to adopt the technology. Rice (2006), in a review of 12 scholarly papers identified teacher barriers to video game implementation. The lack of pedagogically-appropriate games and the lack of understanding of cognitive learning supported by more complex role-playing modern games were stated as reasons that teachers did not implement games in instruction. Additional factors identified were: teacher resistance to relinquishing control of the classroom, inability to find teaching role during game-playing instruction, and the notion that video games, though fun, are not serious learning experiences (Dede & Ketelhut, 2003; Rice, 2006).

As well, teachers' decisions to use video games in instruction are influenced by individual attitudes related to general technology adoption, including beliefs that: 1) the technology must be more effective than traditional methods of instruction, and 2) the teacher has the resources and technical ability to support instruction (Sugar, Crawley, & Fine, 2004; Zhao & Cziko, 2001).

The current study contributes to the emergent literature on how video games impact learning in science classrooms and also presents perspectives of teachers regarding appropriate implementation and perspectives of learners concerning the effectiveness of video games at meeting their learning needs. The research questions guiding the study were:

- How do four grade 8 science teachers in Ontario schools integrate the *Nano Legends* video game as an instructional strategy in a science curriculum unit?
- How do grade 8 students experience using the *Nano Legends* video game to learn science?

Nano Legends is an educational video game featuring action and content about the science of cells and cancer and has been recommended as an educational resource for middle and secondary biology curricula by the National Science Teachers Association (NSTA). The game story occurs

TABLE 1
Description of Science Concepts Introduced by Game Level

Game level	*Science concepts*
1	Definition of cells,white blood cells, and cancerous cells
2	Transport of materials across cells including active and passive transport
3	Mitochondrion and cellular respiration
4	mRNA, cytoplasm, lysosomes
5	Organelles involved in protein synthesis
6	Forms of carcinogens and their effects
7	Nucleus

in the future where advances in nano-medical technology have created nanobots to patrol the human body and protect it from disease. The video game enables the student to take on the persona of a female nanobot avatar, Aerin. Aerin's mission is to enter a lung cell and destroy the cancer attacking the cell. As she proceeds on the mission through the game levels, she must learn how the cell works and accomplish tasks, such as creating a glucose molecule which she uses as a disguise to pass through the cell membrane. Assisted by an artificial intelligence device known as LOR, Aerin runs, jumps, drives dune buggies, and shoots proteins as she navigates the organelles of the cell. Students are introduced to terms and images related to cells at each level of the game via narration from LOR (see Table 1). At the end of each level, students complete an in-game quiz. (Previews of the levels are available at http://www.kendallhunt.com/nanolegends.)

THEORETICAL BACKGROUND

This study is grounded in socio-constructivist theories of learning in which learning involves the social and personal construction of meaning (Dewey, 1938; Vygotsky, 1978). Wertsch (1998) argues that all human action, whether it involves an individual acting alone or engaging in social interactions, is mediated action. Vygotsky (1978) emphasized two kinds of mediational means: signs and sign systems (especially the use of language) and interpersonal relations. In the science classroom, interpersonal mediation often translates into the teacher engaging students in activities and discourse that support students in constructing science-related conceptual knowledge (Driver, Asoko, Leach, Mortimer, & Scott, 1994). Additionally, the act of learning concepts is also mediated by the prior knowledge and experiences of the learner—that is, what is learned in one situation provides the starting point for further learning (Dewey, 1938; Vygotsky, 1978). Therefore, signs and sign systems, interpersonal relations, and prior knowledge of the learner serve as mediating tools during science learning. Video games must also incorporate these mediational tools to encourage conceptual learning.

Video games promote learning by engaging students in direct experiences that are guided by the storyline/mission and supported by the knowledge built into the game (Shaffer, Squire, Halverson, & Gee, 2004). Gee (2007) and Shaffer (2006) elaborate that, for a video game to be effective for learning, the game should enable students to learn facts, information, and theories as they play—preferably by solving some real-world problem. Signs and sign systems, such as the language and graphics used in video games, should provide students with possibilities for reflectively exploring phenomena, testing hypotheses, and constructing objects rather than being used primarily as tools for learning factual information (Squire, 2003). The latter is particularly relevant in science learning as the nature of science involves building process skills, such as developing hypotheses and designing experiments.

Squire (2003) further asserts that:

> Video game playing occurs in social contexts; video game playing is not only a child (or group) of children in front of a console, it is also children talking about a game on the school bus, acting out scenes from a game on the playground, or discussing games on online bulletin boards (p. 10).

Students interact socially with video games at two levels: 1) interacting with other students as they play the game or after the game and 2) interacting with virtual characters within the game. Rather than serving as the social mediator for learning and managing the social interactions typically found in science classes, the role of the teacher as the facilitator becomes essential for successful game playing (Kirriemuir & McFarlane, 2003). For example, the teacher takes into account students' prior knowledge of both science concepts and game skills, and provides scaffolding in these areas as needed.

Prensky (2003) sees enormous potential for learning in gaming—the tricky part being to combine the design elements of video games with curricular content in ways that retain, rather than lose, the learner's interest and attention. Effective games give information "on demand" and "just in time" in a context of actual use (Gee, 2007, p. 218). They "find ways to put information inside the worlds the players move through and make clear the meaning of such information and how it applies to the world" (Gee, 2003, p.2). Effective games are also characterized by immediate feedback, clear goals, and challenges that are matched to player's skill levels (Kiili, 2005). Characteristics, such as problem-solving real issues, testing hypothesis, constructing and designing, providing information on demand, immediate feedback, and challenging skills levels, contribute to the effectiveness of video games to act as mediational means in learning. These characteristics incorporate signs and sign systems, interpersonal relations, and prior knowledge to mediate student learning in science. This paper explores the perceptions of teachers and students as they experienced the video game as a mediational means for science learning in science classrooms.

RESEARCH METHODS

Context of the Study

The video game and its accompanying teacher guide with lesson plans (developed by educators in British Columbia) were reviewed by the science and information and communications technology (ICT) curriculum consultants of the local school board as a possible instructional strategy for teaching about cells, organelles, and its functions. They identified the grade 8 unit on life systems called *Cells, Tissues*, *Organs, and Systems*, from the 1998 version of the Ontario Science and Technology Curriculum as an appropriate match to most of the game content and decided to pilot the video game at this grade level. The authors were asked to research the video game implementation with a focus on the effectiveness of the video game and its accompanying teaching guide as a primary instructional strategy in the grade 8 science classroom.

Participants

A convenience sample of four teachers who teach grade 8 science in four Ontario elementary schools volunteered to implement the video game as suggested in the accompanying teacher's guide in their teaching of the life systems unit during the fall of 2007. Three teachers were male and one teacher was female. Teachers self-identified as gamers and non-gamers; two of the male teachers were gamers and the other two teachers were non-gamers. Seven grade 8 classes used the video game (196 students). Six classes used the video game as the primary instructional strategy to learn concepts (164 students) and a total of 25 students from these six classes were selected to participate in interviews. A purposive sample of students were selected by teachers to represent diversity in relation to gender, abilities, English language proficiency, and ethnicity. At least four students in each of the six classes were identified as special needs, including two students with autism.

Procedure and Data Sources

This study employed a mixed methodology. Qualitative methods were used to investigate the teachers' integration of the video game in instruction; qualitative and quantitative research methods were used to study the impact of the video game on student learning of the science concepts (Creswell, 2003, 2007; Muijs, 2004; Patton, 2002). Qualitative data sources from teachers included a general background information questionnaire requesting demographics, education, and teaching experience, pre and post-individual interviews (audio-taped) (see Appendix), two to three lesson observations (video-taped and field notes), post-lesson debriefings (audio-taped), a final group debriefing (audio-taped), and a final open-ended questionnaire.

During September, 2007, three teachers participated in a one-day workshop in which they previewed the video game and the teacher's guide (available at http://www.kendallhunt.com/nanolegends/) and played the video game. Teacher C received the same training at her school. As illustrated in Table 2, three of the teachers taught two grade 8 classes each; one teacher taught one grade 8 class. Teachers A, C, and D used the video game in all their science classes and Teacher

TABLE 2
Number of Grade 8 Classes Using the Video Game

	Number of grade 8 classes	*Number of classes using video game as primary instructional strategy*
Teacher A (gamer)	2	2
Teacher B (gamer)	2	1
Teacher C (non-gamer)	2	2
Teacher D (non-gamer)	1	1

B used the video game in one class and taught the other class without the video game during the duration of the study. Students in the latter class (combined grade 7/8) used the video game at the end of the life systems unit for review purposes.

All four teachers integrated the game into the life systems unit after introducing characteristics of living things, microscopes, and a brief overview of cell parts. At that point, teachers had students play the video game to introduce cell parts, organelles, and their functions. Students in all classes were provided with time to complete all seven levels of the video game. Game playing times varied from 35 to 45 minutes per lesson. The time taken by each teacher to complete the video game sequence of lessons varied depending on availability of the computer lab and student progress through the levels. Most of the students in Teacher A, B, and C's classes worked individually on computers except for instances during which computers were not working; then they paired up. Teacher D had his 35 students work in pairs at the computers and strategically paired students who were gamers with non-gamers. Some students in Teacher C and D's class did not complete all levels. Overall, student participants spent an average of five hours playing the game.

Of the 25 student participants, 17 students participated in two to three individual interviews during the study and a focus group interview; eight students participated in a final focus group interview only. Pre and posttests (provided with the Teacher's Manual of *Nano Legends*) were administered in all classes. The pretest was administered unannounced; the posttest was administered as a final assessment after completion of in-game quizzes and comprehension questions for each level. Student artifacts used as data sources included messages and comments posted to an online discussion board and stories written about the content of the game.

Analysis

All transcribed interviews with teachers and students plus transcripts of online postings were coded manually for common patterns and themes by two researchers independently (Patton, 2002). Initial codes such as *learning* and *instructional strategy* were derived from the research question and interview questions, and further codes such as *scope of curriculum* and *graphics* emerged from the data. The pre and posttest scores were analyzed through a paired samples *t*-test using Statistical Package for the Social Sciences (SPSS) (Muijs, 2004).

In this manuscript, the findings are presented as thematic vignettes, and assertions are supported with excerpts from the qualitative data; quantitative data will be included when applicable. The findings are organized in relation to two categories: 1) pedagogical aspects impacting implementation of the game and 2) social and concept-related aspects impacting student learning. The qualitative data supporting derived categories are selected representative samples to enable inclusion of all findings in one integrated paper.

STUDY RESULTS

The findings of this study are situated within a context of using a video game, *Nano Legends*, as a primary instructional strategy to learn about animal cells and their functions.

Category 1: Pedagogical Aspects Impacting Teachers' Implementation of the Video Game

1. The scope of appropriate curriculum expectations covered by the video game was limited. All teachers commented that the video game focused on a limited number of concepts related to cells and organelles. They explained that the game did not cover many of the learning expectations in the life systems unit related to cells. *Nano Legends* focused on the animal cell with a particular focus on the role of carcinogens on cancerous cells and body defenses. Teachers felt that:

> The game was very narrow, very focused on the mission at hand which was basically the cancerous cell. [Teacher D]

> The game talked about the lungs but it didn't go into what the lungs do. [Teacher A]

In addition, some concepts covered in the game were not required for grade 8 students (e.g., active and passive transport).

> There are a lot of expectations that the game covers that don't even fall within the unit. They get into active and passive transport, but they don't talk about diffusion and osmosis which is the basis of movement within cells and organisms. [Teacher D]

> Some things such as osmosis and diffusion aren't really well covered in the game. [Teacher B]

The need for additional content resulted in teachers having to spend extra time reinforcing and reviewing concepts that were not in the grade 8 curriculum. Students, however, did not comment on the additional information as being difficult to understand.

2. Teaching modifications were made for differentiated instruction. While the video game addressed differences in gaming skills (e.g., executing jumps, manipulating controls to execute jumps, shooting grenades, or acquiring materials) by providing different levels of skill difficulty for each chapter of the game, there were no mechanisms built into the game to modify content and quizzes to differentiate instruction. Teachers had to supplement the quizzes and questions accompanying the video game by modifying the assessment and evaluation tools (e.g., creating two sets of assessment tools to cater for higher and lower ability students) or they created their own assessment tools for the different game chapters [Field notes]. Teacher D spoke about the in-game and teacher guide assessments:

> I just found the assessment far too easy. True or false or multiple choice questions didn't provide for those opportunities for higher-order questioning skills. [Final interview]

Teacher C also commented on the limitations of the video-game to incorporate different kinds of instructional strategies used for differentiation.

> I try to have a balanced program. . .a combination of modeling and guided and independent reading. . . .*Nano Legends* doesn't provide that opportunity because it's very independent, at least the way I ran it. [Final Interview]

A continuous focus by teachers on using the video game to learn concepts over a series of lessons prompted some students to verbalize the need for a variety of activities.

> I like doing things under a microscope so I can see how they actually look. But the game was fun, too. [Focus group interview]

> Maybe we could do more of a group open discussion where people guide the groups, and we could talk about what we learn, then write it down and present it [to the whole group.] [Focus group interview]

Teachers in the study did at times incorporate additional activities to cater for different learning styles and augment learning [Field notes].

3. Science content needed to be augmented with additional lessons and strategies. The limited scope of the science content in the video game had implications for teachers' planning of this section on cells. Teachers found the analogies used in the game (such as the *endoplasmic reticulum is the superhighway to the cell),* useful as it was the same analogy used in many science textbooks. Teachers, however, felt that the video game did not elaborate on all parts of the cell and on processes occurring in all organelles. They had to augment missing content by sequencing a number of additional lessons into the series of lessons provided by the teacher's manual.

> Basic cell structures—I don't think the game goes into it in enough detail really. I had kids build cell models halfway through *Nano* and I relied heavily on their knowledge of *Nano* to complete the assignment. . . .and I had to go back to it because it wasn't completely covered in the game. [Teacher C, Final Interview]

> I'm trying to draw connections that are textbook-based with what material we are learning . . . our next step right now is to take a look at the cell membrane and the nucleus through a microscope. So now we are taking what we've seen in the game to an actual new level, and seeing how iodine reacts with protein—that is one of the ways I am trying to draw connections. [Teacher B, Interview 3]

The four teachers also used other resources to address gaps that would occur in student learning. For example, video game images of cell structures had to be supplemented with images from the textbook or the microscope.

> Because the organelles don't look like they do in the game,. . . when we talk about the Golgi apparatus, they [students] aren't expecting this huge cavernous thing that people can walk through—[so the textbook shows] what the actual structure and function are.[Teacher B, Second Interview]

The use of the microscope to observe actual cell parts was integrated before, during, or after the video game depending on individual teachers' preferences. Additionally, Teacher A suggested that if the video game was to be used as a primary teaching resource, then it should include "add-ons such as short clips showing cell division or fluid transport in a cell in a microscope view."

4. Accommodations for non-gamers were related to teachers' gaming abilities. The variation in student abilities to play video games was a pedagogical factor that teachers had to take into account during implementation. For example, executing jumps or driving the dune buggy were technical skills that frustrated many students in all classes, echoed in this student sentiment: "Sometimes I felt like ripping out my hair because I couldn't make a jump and I fell all the way to the bottom!"

Teachers in this study used different strategies to address this factor. Teacher D, a non-gamer, did a pre-unit assessment quiz on his students' gaming abilities. As a result, he paired experienced gamers with inexperienced gamers at the computers. During implementation, he did not offer personal assistance to his students; peers assisted each other. Teacher A, a gamer, personally assisted non-gamers with their technical jumps. He also encouraged students who were skilled gamers and finished playing early to act as peer assistants and help those needing gaming assistance. Different gaming abilities among students also raised a concern among all teacher participants that students with poor gaming abilities would be at a disadvantage in accessing conceptual knowledge required to pass level quizzes. The concern was that a focus on trying to master technical skills to win levels of the game would distract students from learning the science information. As one student commented, “The only thing I don’t like is when I spend too much time trying to make a jump or get through a crowd of carcinogens, because it’s not teaching me anything.”

To help all students learn from the video game, the teachers who were gamers adopted similar strategies of giving students a summary overview of the game in the forthcoming level before taking students to the lab. While this strategy was helpful to most students, a few students expressed their dissatisfaction; they did not like the fact that the element of surprise was not there when they went in to play the game. The two non-gamer teachers had students work though the worksheets from the teachers’ manual after the levels or had students fill in the worksheet as they progressed through the levels.

5. Scheduling computer time was a barrier to continuity of video game. Continuous access to the video game was not possible for all classes because of scheduling issues. All schools worked on a ten-day timetabling cycle, and science classes were not scheduled on consecutive days, making it difficult to maintain continuity of the game for individual classes. As well, teachers found it difficult to cover the game for their two classes at the same pace. Some teachers resorted to making special arrangements. For example, Teacher A taught two classes—his homeroom class and one additional science class (on rotary). He modified his timetable and scheduled computer lab time for his homeroom class to maintain continuity of the video game. He found it a challenge to schedule additional classes for his rotary class:

> I had to talk to other teachers and try to barter to get computer lab time to keep them on the same page. I worked it out pretty well between the two classes. We did tend to lose track of where one class was in relation to the other. However, [both classes] finished about the same day and wrote the test the same day.

Teacher C divided students into two groups and had her student teacher supervise game playing while she taught the rest of the students from the teacher’s guide. These types of arrangements would not be possible for all teachers and maintaining continuity of the game was problematic throughout the study.

6. Technical infra-structure impeded game completion. All schools in this study had one computer room that was shared by all grades. Computer labs did have sufficient computers for students to work individually or in pairs, but teachers often encountered technical problems such as computers that were old or did not have the capacity to run the video game. For example, on some computers, jumps were almost impossible.

> Some of the computers just don’t run the games very well .. and you’ve got students who are impeded by a technical limitation versus their actual ability to learn [Teacher B, Interview 2]

This resulted in students taking a longer time to complete levels as they would have to share computers. In Teacher D's case, he had no option but to have students work in pairs.

> The infrastructure here wasn't necessarily conducive to a one-to-one ratio between the students and the computer. So students had to double up. So in essence that sort of doubled the time that was needed in order to get through the activities [Teacher D, Final Interview]

Category 2: Social and Concept-Related Aspects Impacting Student Learning

1. The video game was motivating and engaging. All student participants indicated that using the video game was fun, motivating, and engaging. It also gave them opportunities to interact with characters and be part of the lesson.

> It was definitely better than sitting in a chair all day and listening to a teacher talk because that is really boring. So, I liked it because you get to interact and actually be a part of the lesson. You got to learn and have fun at the same time.

> I loved using the video game. . .Most of the kids in my class don't like reading out of textbooks, so the video game made it a lot more interesting and easier to learn.

> I liked the interaction; that you could interact with what was in the cell. It's not the real thing, but it's close to it.

> I would definitely recommend this game because it's lots of fun and I know that kids these days don't like sitting reading a board or reading a textbook. And lots of kids play video games and everyone was really happy about that.

> It's a good teaching method I think. You learn a lot. [student with autism]

> It's a great way to learn and have fun at the same time. Lots of people don't like learning in class, especially boys. But even for a girl, I think they enjoy it a lot too, sitting in the computer lab playing a game rather than writing.

Five students were not so positive about using a video game for learning. These students' attitudes appeared to be related to their learning styles and their perceptions of using video games for winning and having fun rather than learning.

> I'd rather read through a book. It was easier doing it through a book . . . and maybe draw the cells, because if I draw it, then I know what it looks like. [Student 1]

> I'm not sure [that I would recommend the game] because I like doing lab stuff. I think doing hands-on stuff is a better way to learn. Like actually seeing how the structures are and everything. [Student 2]

> [I did not find it very helpful] because it's like a video game, you don't really look at your surroundings, you just really shoot things. [Student 3]

2. Fair play and cooperative/leadership skills were fostered. Teachers commented on the higher level of fair play and cooperation among students as a result of the game-playing.

> With their partner, they had to work together. . . so there was a higher level of cooperation among the students —that is something you don't normally see in class. [Teacher D, Final interview]

TABLE 3
Mean Student Scores on Pre-test and Post-test

	Mean	*N*	*Std. Deviation*	*Std. Error Mean*
Post-score	20.466	164	5.9736	.4665
Pre-score	10.402	164	4.3690	.3412

When students couldn't get through a certain aspect of a level, there was always someone in the class from the game-playing standpoint to steer them through. [Teacher A, Final interview]

Researchers also observed collaborative interactions during classroom observations:

When students needed advice, they turned to one another to solve the problem. [Field notes of lab observation]

Leadership was exemplified by students taking the initiative to act as peer technical assistants. A student commented:

Everybody was working by themselves. So I tried to help out. . .I would say, "It's not always easy to do stuff. You just have to take your time. Sometimes it takes you a while to learn how to jump. So, okay, I will help you get through this once and then you can play it after.

3. The video-game was effective at teaching the science content it was designed to teach. Statistical analysis of pre and posttest scores for the aggregated scores of 164 students from the six classes that used the video game revealed mean scores showing that students scored 10.5 out of 31 on the pretest and 20.5 out of 32 on the posttest (see Table 3). As well, there was a statistically significant difference between pretest scores and posttest scores; a paired samples t-test ($n = 164$) revealed a p value less than 0.05 (see Table 4). Effect sizes were strong ($d > 1$) suggesting that a strong statistically significant relationship exists. The results suggest that the video game was effective at teaching students concepts related to the structure and function of animal cell—specifically, the names and functions of parts of the animal cell, the processes of active and passive transport in cells, and the different types of cancer-causing carcinogens.

Another indicator of the effectiveness of the video game for student learning was the accuracy of students' use of science vocabulary during interviews, with each other, in written stories, and in

TABLE 4
T-test Results From SPSS

	Paired Differences							
				95% Confidence Interval of the Difference				
	Mean	*Std. Deviation*	*Std. Error Mean*	*Lower*	*Upper*	*t*	*df*	*Sig. (2-tailed)*
Post-score-Pre-score	10.0640	5.9495	.4646	9.1467	10.9814	21.663	163	.000

online discussion postings. Evidence from written artifacts and interviews suggests that students did gain an understanding of science concepts illustrated in the game.

> When Aerin gets into the cell, she goes to the mitochondria. The mitochondria creates energy for the cell. [Written story]

> LOR says, 'What's glucose made of? Glucose is made up of three components: hydrogen, carbon, and oxygen. You must collect these atoms to create a glucose molecule. But to pass this level, you will need to shoot some worker proteins.' [Written story]

> The mitochondria is the powerhouse and the nucleus is the brain of the cell. [Student interview]

Teachers also described the game as effective in teaching basic science concepts:

> There was definitely some understanding by every student, even the lower-ability students or the ISP (special needs students on individual student plans) students who didn't get assistance. [Teacher A]

> They definitely learned the basic science concepts that were introduced in each chapter. They were using the language. I think their knowledge as far as how cells divide has increased and their knowledge about how cancer forms and develops has increased. [Teacher B]

> A video game for instruction is something that is useful. And I say that because of the assessment results that I got. I'm seeing kids who would normally struggle scoring grade standard marks in their achievement level. [Teacher D]

A student commented:

> I would say it helped us understand it in an easier way. Because when you use a textbook there are words you don't understand, but in *Nano Legends*, they give you examples, better than the textbook.

4. Graphic representation of scientific objects led to some misconceptions. The two gamer teachers reported that the use of fantasy images to represent some scientific objects such as the organelles and the carcinogens in the game led to misconceptions and alternative perspectives of scientific concepts. Fantasy depictions of real objects, such as the radon carcinogen, communicated an unrealistic representation of what a real carcinogen looked like.

> The problem I found was that students did not always link the [game representation] of the radon carcinogen with the actual radon gas or chemical that we take in everyday. Tobacco carcinogen was a big monstery thing . . . The students asked, "Is that really what it looks like?" I don't know whether the real world and the dream world were blending together, or not. As the game went on, they got better and understood—they saw more links between what was in the game and what was in real life. [Teacher A]

> I think a lot them had a vision in their mind of how the graphic designers illustrated the concept. When I start describing and showing diagrams or illustrations or even getting under the microscope with them looking at the actual organelles and cells, it's almost like a fantasy world. . . like understanding the endoplasmic reticulum, what does it look like for real inside a cell as opposed to what the game chooses to represent it as. [Teacher B]

Five students made references to the nature of graphics used in the game. For example, one student described the graphics as impeding learning science through a video game: "The most difficult part is probably that everything in the game—it's all cartoons." Another student added, "It confused me—the body looked like a city or something. It was like a TV show."

There was also a contradiction between how the objects (i.e., cell parts, worker proteins) were depicted in the game and students' perceptions of what the functions of the objects were from the scientific perspective. For example, the function of worker proteins is to kill foreign bodies entering the cell. In the game, the main character disabled the worker proteins by shooting them. Teacher A recalled a student asking him, "Why are we shooting proteins when they are supposed to be good? Shouldn't we just stun them?"

The ease with which cancer characters were killed in the video game also communicated cultural messages that conflicted with students' knowledge of cancer as a life-threatening and debilitating disease. Another student questioned:

> What I don't get is. . . is it that easy to destroy cancer? How many people are dying from it? Because in the game it was actually kind of easy to get rid of it—you get them with one shot.

5. There was limited promotion of scientific higher order thinking and process skills. All teachers felt that there was an "emphasis on vocabulary and idea recall." The context of the game, cells being attacked by carcinogens, did reflect science, technology, society, and environment (STSE) issues, but "what was missing were higher level thinking skills." The video game encouraged problem solving and decision making in the context of making decisions about strategies to successfully complete the levels of the game. However, the video game provided few science-related scenarios in which problem solving and decision making strategies were required.

> It seemed as though the information was just given. It was very much drilling instructed and the information was just told to the students. [Teacher C]

Teacher D felt that the video game did not include many science process skills required by the Ontario curriculum.

> The hands-on activities, the questioning skills and hypothesis, the big core values of science were lost in the game.

Teacher B felt that the game was not very successful at promoting transfer of knowledge from the game to apply in other science contexts.

> Students are having a difficult time transferring knowledge from the game. . .If I ask them an extension question that requires a little bit of application of knowledge, they don't have it.

6. There were limited, built-in mechanisms for review and reinforcement. An analysis of interview data with student participants revealed the following issues. Eleven students stated that a lot of the factual information presented in pop-ups disappeared too quickly; hence there was not enough time to review or write down definitions. During game play, the only way to review was to die and replay the entire level. Students wanted mechanisms, such as pop-ups or pause features, to be built into the video game to review and reinforce knowledge as the game was played. Some student comments were:

> The information did go pretty fast, and it's kind of hard to write down everything. . . If they had a little button where you could press on it, you could review it again.

> If you could press pause, it would still say stuff in the corner and not go to that other screen. You could write that down in your books so you could study off of it.

DISCUSSION AND RECOMMENDATIONS

The four teachers in this study volunteered to integrate the video game into the grade 8 life systems unit as a primary resource to mediate students' learning about animal cell organelles and their functions. In using the video game as a primary teaching resource, the findings show that there were *pedagogical, social,* and *concept-related aspects* that influenced teacher implementation and student learning. These aspects will be analyzed in relation to the three types of mediational tools (*signs and sign systems, interpersonal relations,* and *prior knowledge*) and *characteristics of video games* introduced in the theoretical framework.

The findings indicate that the *Nano Legends* video game was effective at teaching the content it was designed to teach. Students' mean scores increased from 10.5 to 20.5 out of 31. *Signs and sign systems,* specifically the language used to give instructions and communicate the storyline and definitions of the organelles and their functions, served as an effective mediational tool for teaching science vocabulary. Additionally, several skill levels within a game chapter differentiated for novice and skilled gamers, and built-in quizzes at every level provided "just in time" feedback in relation to the learning of science concepts. These characteristics are consistent with recommendations for effective video-games (Gee, 2007, p. 218; Shaffer, 2006).

However, from a *pedagogical perspective*, the content and quiz assessments built in the video game were static and did not provide differentiated instruction for learners of different abilities and learning styles. Teacher participants had to devise ways to augment missing content and differentiate learning for students. They created supplemental resources, differentiated assessments and worksheets, and provided previews or reviews of each game chapter to draw all students' attention to the salient science concepts. The latter strategy was in response to the concern that some students would focus on the thrill and excitement of navigating through the levels to accomplish the game task and lose track of the concepts to be learned.

Since this was the first time that all teacher participants in the study were integrating a video game into their instruction, they made decisions about how and where to integrate the video game in the life systems unit. The teacher's guide was useful in providing teachers with guidance on the content covered in the game and what prior knowledge students would need to understand concepts in the game. Supplementing instruction was necessary for student success in learning and the crucial role of the teacher has also been described by Levy et al. (2007) in their study of how grade 4 teachers implemented a role-playing game promoting literacy. Pretest and posttest scores in our study suggest that teacher-scaffolded instruction was effective at supporting students in learning the scientific concepts. The finding that non-gaming teachers in this study were also successful at devising strategies to integrate the video game into their classes can help demystify the experience for teachers who are non-gamers.

When reflecting on their experiences at the end of the study, all four teachers felt that the time taken for students to progress through the seven chapters of the game was too long compared to the amount of curriculum covered in that time. All teachers stated that they saw improved engagement and learning among their students as a result of the video game, but from a logistical viewpoint, they preferred to use the video game as a supplementary resource or a review and reinforcement strategy at the end of the unit. They also suggested that student access to the game levels at home or online would be a better way of integrating the game in the classroom. The lack of alignment to standards and the time needed by teachers to adapt materials has been previously noted as barriers leading to teacher resistance to implementing games in instruction (Rice, 2006; Deubel, 2002; Dede & Ketelhut, 2003).

Of specific interest in the current study were the different types of *social interactions* and power relations that were evidenced when the video game was incorporated as an instructional strategy. All teachers addressed students' prior gaming skills and provided scaffolds to enable all students to have access to learning from the game. Non-gamer teachers did not intervene to assist students during game play; peers assisted each other. This latter situation indicates that teachers were no longer the primary experts in the classroom; peers took on mediational roles in relation to game-playing skills. Skilled student gamers took on leadership roles, mentored novice gamers, and encouraged them to continue playing, thereby promoting student learning. Peers also assisted each other in filling out the worksheets during game play. Peer assistance fostered collaboration among students and developed leadership skills. *Interpersonal relations* between peers therefore acted as a significant mediational tool for student learning during game playing. Dede & Ketelhut (2003) noted that teachers, even those professing a constructivist approach to teaching, need more support in finding their role so they also experience satisfaction during game-based instruction and feel confident in allowing students to assume these roles.

V*irtual interpersonal relations* played a key mediational role in learning concepts. When students took on the role of the avatar and engaged with characters in the virtual environment, this virtual social relationship motivated and mediated learning. Teachers noted that students, including students with learning disabilities such as autism, were engrossed in the game and learned science concepts as evidenced by pre and posttest scores. However, it should be noted that three student participants indicated a preference for learning from their textbooks and felt that the video game was not effective at explaining content as extensively as a textbook. This finding is similar to that reported by Squire (2005) and raises questions about how teachers should address the concerns expressed by students who do not view video games as legitimate instructional and learning strategies in the classroom. We believe that as teachers become more adept at playing video games and more comfortable and skilled at incorporating video games in a seamless fashion into a unit, students and teachers will accept video games as part of regular instructional practices and perceive video games as legitimate for learning science concepts rather than as a strategy for review and reinforcement.

In relation to *concept-related aspects*, a key finding of this study was the effect of graphic images used in the game on students' understanding of scientific concepts and theories. The use of fantasy images to represent carcinogens led to some students interpreting the fantasy images as the scientific representation of the object. Such conceptions communicated by video games contribute to students having alternative conceptions in science. Although teachers in this study had previewed the game, they had not anticipated such responses from students and they made modifications in their teaching as they became aware of these issues. The implicit and explicit messages that graphics could communicate about scientific representations of objects suggests that teachers need to preview science video games critically to assess how scientific objects are represented in video games, and build in necessary scaffolds as they plan the unit. Although fantasy images are necessary to create the virtual world that motivates students, mechanisms could also be built into the video game to minimize misrepresentation of scientific concepts. As suggested by one teacher participant, pop-ups within the game could provide students with the scientific representation of fantasy images.

The video game did exhibit some *characteristics of effective video games* as outlined by Gee (2007); it was situated in a real world context of carcinogens attacking cells in a human body and engaged students in the exciting challenge of getting rid of these carcinogens. However, the game did not incorporate many science process skills, such as investigation and inquiry, and did not provide for reflectively exploring phenomena, testing hypotheses, and constructing objects as recommended by Squire (2003). *Nano Legends* primarily communicated factual information. For video games to be effective as mediational tools in science, they should engage students in interactions that promote higher order thinking (e.g., problem-solving) and support the development of science process skills such as developing hypotheses (Ontario Ministry of Education, 2007). As well, many students felt that the game did not provide adequate mechanisms for review and reinforcement of chapter expectations.

In summary, the preceding discussion shows that as a mediating tool, the *Nano Legends* video game was effective at communicating factual science content and promoting social interactions in the classroom and virtual world; however, teacher intervention was necessary to scaffold students' prior knowledge and provide differentiated instruction and assessment.

CONCLUSION

This classroom study provides unique insights gained from science teachers and students as they experienced teaching and learning science from a video game, respectively. Findings, grounded in practice, provide practical pedagogical considerations that science educators should consider to maximize the potential of video games for students' learning of science concepts, process skills, and higher-order thinking. These findings reveal that the process of integrating video games as an instructional strategy in science classrooms is not a simple matter of having students play the game. Instead, the results of this study point to the need for pre-service and in-service teachers, through teacher education programs and in-service professional development, to gain awareness of the pedagogical, social, and concept-related aspects involved during classroom instruction with video games.

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APPENDIX

Sample Interview Questions for Teachers

Short 10 minute interviews:

Can you describe what the goal of the lesson was?
How do you think students participated in the video game activities?
What do you think went very well in this lesson?
What do you think you might have changed during the lesson?

Final interview:

Can you describe how you planned to integrate this game into your unit?
Did your implementation proceed as you had planned?
Did you find it easy to integrate the game into the unit? If yes, why? If no, why do you think that?
Do you think participation in the video game gave students a better understanding of the science concepts?
How did this understanding reflect in the pre- and post assessments?
How effective do you think this video game was at teaching the science concepts in this unit to your students? Explain.
Would you recommend this game as a resource for all teachers? Why?
What kinds of additional supports might be helpful to implement the video game in your class?
Did you think the game promoted problem-solving and decision making?
Is there anything about the game that you would like to see changed or be designed differently?

Sample Interview Questions for Students

What aspects of the game did you really enjoy? Why?
What aspects of the game did you not enjoy? Why?
Did you find that the game progressed from a lower level of skills difficulty to a higher level of difficulty?
Can you give some examples from the game?
Did you take on a role while playing the game? Please describe. . . .
Were you involved in any decision-making where you had to make a choice in the game or problem-solve?
Can you give me an example of where and what you did?
What were the most important things that you learned about cells while playing the game?
Is there anything about the game that you would like to see changed or be designed differently?
Are there any other ways that the teacher could have used the video game in class that would have been more helpful to you?
How do you now prefer to learn about animal cells, their structures and functions?
Would you recommend this game be used for other students in future years? Why?