The *History of Biology*™: Examining a Digital Game for Improving Students' Nature of Science Conceptions and Promoting Student Engagement in Biology

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1. Introduction

In the context of an increasingly science and technology-based society, school systems around the world have acknowledged the need to improve students' scientific and technological literacy; develop students' 21st century skills; and engage students in curricular activities that promote life-long learning [1] [2]. Dede [3] reports that emerging learning styles signal that teachers adapt their teaching styles accordingly. The nature of science (NOS), an essential element in the development of science and technology literacy [4], incorporates the history, philosophy, and sociology of science, including understanding how scientific knowledge is developed, validated, and accepted as legitimate. Recently, researchers have found that computer-based games have significant educational value [5] and may help students learn the principles, laws, and theories of science, problem-solving in science, and elements of the nature of science [6]. The *History of Biology,* an online digital game designed to guide students through concepts about the history of biology is the basis for this research study, which explored teacher candidates' (TCs') views of the game and its potential for teaching NOS in grades 7-12 science classrooms in the Province of Ontario, Canada. Specifically, the portion of the study examined TCs' a) demonstration of learning about NOS as a result of playing the *History of Biology* game; and b) views on the role of the *History of Biology* game in teaching and learning NOS.

2. Frameworks

2.1 Digital Games in Education

A primary challenge for education today is to transform students' learning processes in and out of school and to engage student interest in gaining 21st century skills. Lemke [7] reports a link between the acquisition of 21st century skills and academic achievement, making the case for incorporating teaching activities that promote 21st century skills. Additionally, the Federation of American Scientists (2005) [8] argues that digital games can help students learn 21st century skills, including critical thinking, collaboration, and innovativeness [9]. Many studies have evaluated the effectiveness of digital games for learning in science education [10] [11]. Results include enhanced learner experiences and development of positive experiences toward subject area; increased student motivation; improved cognitive outcomes (recall and higher order thinking); and improved problem solving skills [3].

2.2 Nature of Science (NOS)

Teaching NOS has long been a goal of science educators because it helps students avoid misconceptions, learn science content, develop problem-solving skills, and become more interested in science. NOS research shows that K-12 students and teachers possess inadequate NOS conceptions; NOS concepts are best acquired through explicit, reflective instruction; and teachers' NOS conceptions are not automatically translated into classroom practice [12]. Mixed results were noted in attempts to improve student conceptions of NOS through resources addressing NOS implicitly. These findings signalled that explicit NOS instruction is critical. Literature on the utilization of digital games in science education is increasing [10]; however, literature on the use of digital games to teach NOS in pre-service secondary science education is nonexistent.

2.3 Engagement in Science Education

Recent international research on science education shows that by age 14 or 15 students have decided whether or not they are going to pursue science studies, and in increasing numbers, the answer is no. Student interest and engagement in science learning are two strongly influencing factors in making these decisions [13]. According to Dunleavy and Milton [14], higher levels of intellectual engagement in learning may be produced by "Bridg[ing] students' experience of learning in and outside of school by exposing them to digital technologies in knowledge building environments" (p. 2). Digital games in science education provide an opportunity for helping to improve students' enjoyment and interest in learning science and the nature of science.

3. Methodology

3.1 The Game

The *History of Biology* game is an online digital game designed to guide grades 7-12 students through concepts about the history of biology, scientists and their discoveries, and the impact of scientific discoveries on society. Users progress through 14 stages of a story-driven game paralleling a timeline of discovery. Missions are designed to expand players' knowledge of science and NOS, and to foster critical thinking, communication, problem solving, and collaboration.

3.2 The Study

This study involved TCs in an Intermediate/Senior Biology methods course in a Faculty of Education at a Canadian university. In this mixed-methods study, 9 TCs (3 males; 6 females) volunteered to play the *History of Biology* game over 4 months. Data included pre-post (Likert scale) NOS questionnaires [15] and semi-structured interviews conducted after completing the game. Interviews explored changes in TCs' NOS views, their experiences with educational digital games, and their experiences with the *History of Biology* game. Table 1 lists NOS aspects included in the questionnaire [16].

3.3 Data Analysis

NOS questionnaires and interview transcripts were analyzed to generate pre- and post-instruction profiles of participants' NOS views. Data from each questionnaire were used to generate summaries of TCs' NOS views. NOS questionnaires and interviews were analyzed through an interpretational analysis framework involving thematic coding and constant comparison [17]. By comparing and contrasting the data, common patterns and themes emerged pertaining to the effectiveness of the *History of Biology* game in influencing TCs' learning about NOS, and the impact TCs' views have on the role of the *History of Biology* game in teaching and learning NOS.

Table 1. *NOS Aspects and Descriptions that Served as a Basis for Comparison*

Aspect	Description
Tentativeness	Scientific knowledge is subject to change with new observations and with re-interpretations of existing observations.
Empirical basis	Scientific knowledge is based on and/or derived from observations of the natural world.
Subjectivity	Personal values, agendas, and prior experiences dictate what and how scientists conduct their work.
Sociocultural Embeddedness	Science is a human endeavor and is influenced by the society and culture in which it is practiced.
Human Inference, Imagination, and Creativity	Scientific knowledge is created from human imagination and logical reasoning.
Laws and theories	Theories and laws are different kinds of scientific knowledge – laws describe relationships; theories are inferred explanations.

**Note: None of the aspects in Table 1 can be considered apart from the others*

4. Results and Discussion

4.1 TCs' Views of Digital Games in Science Education

Aside from participating in playing the *History of Biology* game, one of the participants had used digital games previously in a teaching and learning context. The TCs unanimously agreed that science teachers should use online digital games in their science teaching as this is one form of engagement for students because *"[they] make learning more interesting as gaming is exciting for students*" [13] [14]. Relevance was also cited for including digital games: *"the youth culture right now, gaming is very popular, so if we want to connect to the kids where they are, then we definitely need to get into their culture and use it to our advantage"*. Promoting 21st century skills [7] was evident in TCs' accounts of the importance of digital games for keeping abreast of 21st century trends: *"this is the way the world is going; we are online; we are digital and need to teach those skills … it is another medium which would be a step out of conventional teaching.*"

4.2 TCs' NOS Conceptions

Despite explicit-reflective NOS instruction during the course, a suitable description of NOS was elusive during the TCs' interviews. Nevertheless, there was agreement amongst the TCs that teaching NOS in science class is important:

I think it's important to introduce students to the nature of science, to the history of how things are discovered, to the misconceptions people have had over the years … to see how science is done and how scientists come up with theories.

The results of the pre/post questionnaires indicated that participants' views included several naïve conceptions about NOS; none the TCs held well informed views of all NOS elements (Table 1), though several did hold

adequate views of certain elements [12]. Changes in TCs' views were particularly evident with regard to the distinction between observation and inference, human imagination and creativity, social and cultural NOS, and subjectivity in science. TCs' NOS views changed from *neutral/disagree to agree* on statements claiming that science involves creativity; observations are theory laden; intuition plays an important role in science; science is social and cultural; and scientific studies are valid even if they are not experimental. TCs' NOS views changed from *agree/disagree to neutral* on statements claiming that scientists should divorce themselves from personal and emotional involvement with their inquiries. Finally, TC views changed from *agree to disagree* on statements claiming that students should be discouraged from generating creative ideas and encouraged to think logically and carefully. These findings parallel similar studies on teachers' and students' conceptions of NOS [12] [16].

TCs ascribed the changes in NOS views to explicit instruction and the *History of Biology* game. Explicit instruction (video case study on misconceptions, lectures, NOS literature, and a biology timeline assignment) was cited as a key factor for influencing TCs' NOS views. This finding is comparable to those of similar studies on the development of NOS conceptions [12]. The *History of Biology* game was credited with contributing to learning in science as it provided a context for teaching science content and NOS:

… the humanness of scientists is definitely there; not in every case, because the information comes from online sources too, but in a lot of cases. You learn things you wouldn't have thought about these people, and you find out that they are just people … in that sense the nature of the enterprise, it's not this rigid objective thing.

TCs' motives for participating in the game included seeking ways to incorporate new technologies in the classroom, exploring various strategies to engage students, evaluating the game as a teaching and learning tool, and assessing the game's potential for teaching and learning about science and NOS.

5. Implications

By providing opportunities for exploring NOS via a digital online game, TCs enhanced their own scientific and technological literacy, and also developed positive attitudes toward teaching NOS through digital technologies in the classroom. By the end of this study, participants made substantial gains in their understandings of various aspects of NOS. As indicated in the findings, these gains can be attributed to explicit-reflective NOS instruction and the *History of Biology* game. The results of this study raise many issues and questions. Future studies on online digital games in science education, such as the *History of Biology*, could explore a specific topic in science, a cognitive skill, or an age group, and explore how these factors interact with, and contribute to, learning science and NOS. These issues warrant further research in terms of how we envision teaching and learning science and NOS, implications for enhancing scientific and technological literacy, and equipping students with 21st century skills.

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