Metrics for Evaluation of Educational Experiences: Will Virtual Reality Have Impact?

Rachel Ralph, Derek Jacoby, Yvonne Coady
Department of Computer Science
University of Victoria,
Victoria, BC, Canada

Deepak Balachandar, Emily Burt, Nathan Hnguyen,
Jongjik Kim, Krisha Maclang, Steven Wong, Larry Bafia
Centre for Digital Media
Vancouver, BC, Canada

***Abstract*—Virtual Reality (VR) is poised to revolutionize education by immersing students in learning experiences in a way no other technology has before. In these early days of educational VR applications, it is critical to establish meaningful metrics to determine the potential benefits—and risks—of exposing elementary school students to interactive media using head mounted displays and hand held controllers.**

Previous work has determined that today's VR hardware is safe for children, but relatively little work has explored metrics educators could use to determine if the experience promoted learning. Based on established educational theoretical foundations, our work proposes metrics that directly align with 21st Century Learning. We propose combining questionnaires for Presence, Immersive Tendencies, and Flow, along with Rubric assessments for problem solving. The case study for our work is a VR exhibit on the *gold rush* we are developing for the Royal British Columbia Museum.

***Index Terms*—Virtual, Augmented, Mixed Reality, education, metrics.**

I. Introduction

A Virtual Reality (VR) experience can provide a profound means of knowledge transfer. Essentially, VR allows a user to control their progress through a contextualized knowledge-base in a realistic, natural, interactive way. Additionally, the virtual surroundings evoke psychological and physical reactions, that potentially have a deeper impact than other forms of media. But will VR transform education?

We are building an exhibit for the Royal British Columbia Museum for children and young adults to experience British Columbia's *gold rush* in the early 1800s. The story board for the experience shows the incorporation of a panoramic view, and mechanics for panning for gold (Fig. 1). Though it is our hope that this will be a learning experience, we discovered that there was very little research on metrics for determining impact of VR experiences in education. Do we elide content for overall feel? How do we measure efficacy of different design elements? When does engagement promote learning?

The key contributions of our work in this paper can be summarized as follows:

1) A survey of approaches used to measure learning currently used in education.
2) A proposal to combine metrics for presence, immersion, flow with rubrics to establish efficacy of a VR learning experience.

The remainder of this paper is organized as follows. Related work is reviewed in Section II. Section III surveys both quantitative and qualitative metrics, along with goals for 21st Century learning. Section IV provides the landscape for education and VR, while Section VI establishes the *why* and the *how* of VR in education today. Concrete examples of metrics we propose to combine in our evaluation strategy are presented in Section VI. Finally, Section VII discusses future work with conclusions.

II. Related Work: Educational Theoretical Foundations

Constructivism arose from major traditions of psychology, philosophy and sociology (i.e., cognitive and developmental perspectives of Piaget and Gagne, cultural perspectives from Bruner and Vygotsky, and environmental factors of Dewey) [1, 2, 3]. Constructivist values are built upon the behaviourism and cognitivism of other learning theories like Gagne's conditions of learning. Kolb expands upon traditional constructivist values of Dewey and identifies experiential learning experiences [4].

Constructivism posits that learning can be constructed by one's own knowledge with connections through prior knowledge, and that knowledge construction is influenced by experiences and ideas through interactions with peers [5, 6, 7, 8]. Knowledge construction, for many students, is strongly impacted by social interactions with teachers, parents, and peers. Social learning, while not described in detail in this paper, has some influence on learning and collaborative processes[9, 3].

Constructivism has pedagogically influenced many teaching methods and constructivist methods are widely advocated in educational practices. In general, constructivism is how people learn using prior knowledge and experiences to construct understanding through active collaborative experiences. Teachers who use constructivist methods encourage learners to relate, experience, apply, cooperate, and transfer knowledge and understandings [5]. Knowledge construction involves higher level thinking skills and a VR environment can provide

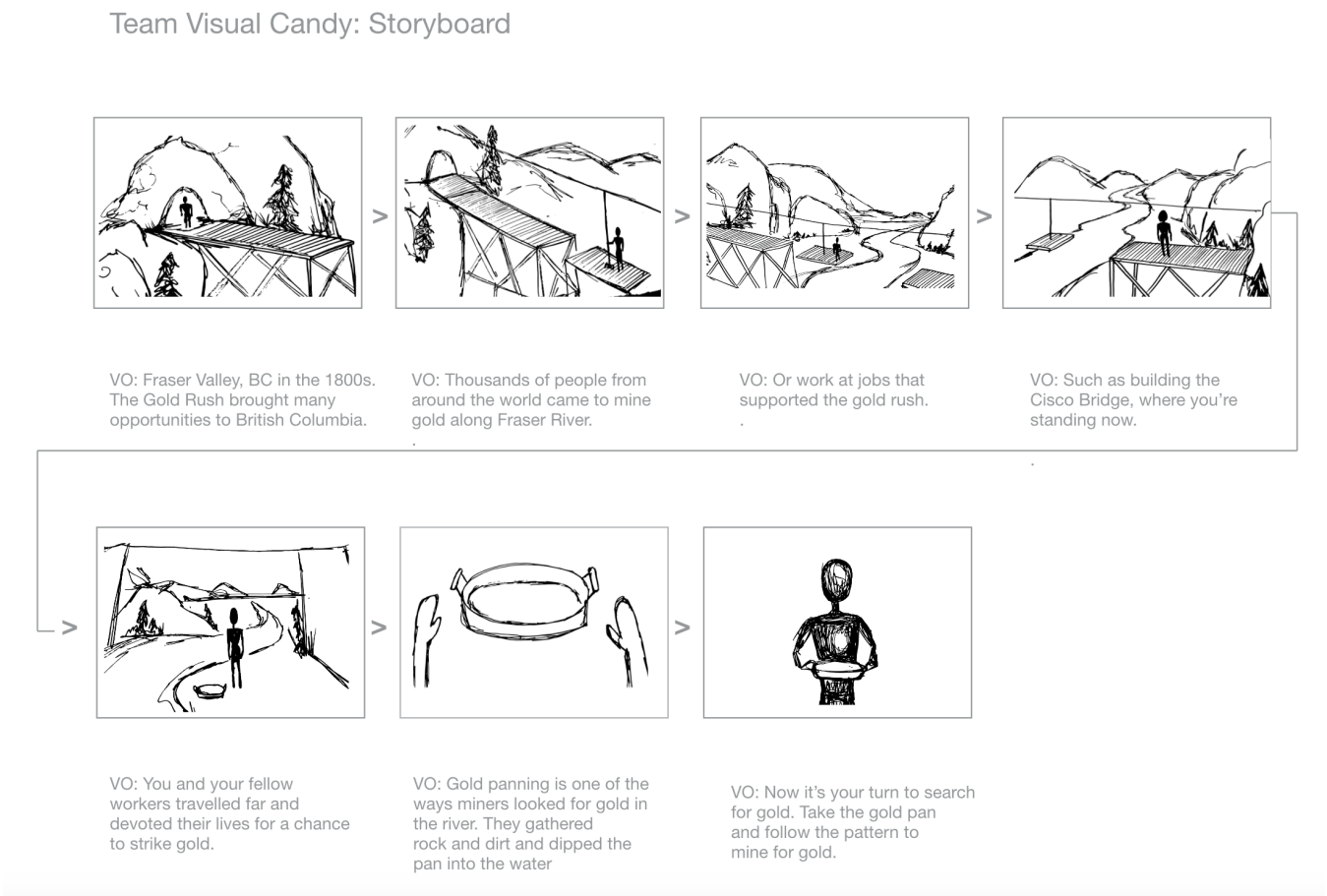

Fig. 1: Story board developed by team *Visual Candy* for testing showing Voice Overs (VO) to guide the user experience.

opportunities to assess these skills. Through social learning, experiential learning, and instructional events and cognitive process and constructivist theories VR can have a significant impact in educational settings.

Teachers and designers of VR experiences have the ability to establish ideal conditions for learning by providing opportunities for students' exposure to complex problems that are addressed in a collaborative environment and require active engagement. Even if students do not have explicit experiences within VR, they can still bring prior knowledge and be actively involved in the activity. In particular, students can bring prior knowledge of the historical setting or scientific understandings to navigate the path in a VR experience. Or students can bring prior knowledge of playing with video games or in other simulations and understand how to navigate the VR experience in this way. Learning theories ground the measurement of content knowledge and 21st century learning in VR settings.

III. Quantitative and Qualitative Metrics

When exploring the role of VR in education, we can look at two types of skills: hard and soft. Hard skills typically rely on quantitative metrics, such as content knowledge; whereas soft skills are much more qualitative and interpersonal, such as 21st century learning. Content knowledge is the understanding of a specific subject matter [10]. For example, in science education, students' content knowledge is focused on plate tectonic movement, (i.e., what plates are and what they do). Twenty-first century skills, not unique to the 21st century, have been defined as problem solving, critical thinking, self-directed learning, and collaboration by solving real-world scenarios [11]. For example, students would investigate a driving question of exploring the impacts of an earthquake in Vancouver (i.e., focus on collaboration, creativity, and problem-solving). Content knowledge and 21st century learning will be defined in more detail along with some of the current research of VR in these contexts in the next sections.

A. Content Knowledge

Content knowledge is the specific subject matter students attain in learning environments [10]. The content knowledge is generally based on Bloom's Taxonomy of cognitive understanding, including: knowledge, comprehension, and application [12]. In VR research, several studies have identified that learners that we exposed to VR significantly outperformed learners not exposed to VR in terms of content [13, 14, 15, 16]. Many of these studies were measured using pre- and post- knowledge tests for the students. Several quasi-

experimental studies found that the students in the experimental group who were exposed to VR performed better in course performance compared to the control group [14, 16]. Bricken and Byrne [13] found that there was a rapid comprehension of complex concepts when students were using VR. Gazit et al. [15] also found that students were able to develop scientific understanding, and in this case, the cause of the day-night phenomena. However, they also found that some dynamic misconceptions emerged and that learning needs to be scaffolded and guided by the teacher. As much research regarding technology and education suggests, just using the technology does not guarantee knowledge and the ability to navigate through successfully without misconceptions. The role of the teacher does not disappear; rather the teacher becomes the facilitator of knowledge through the assistance of VR technologies. The teacher can also play a significant role in the development of 21st century learning skills in a VR experience that will be defined in the following section.

B. 21st Century Learning: A Synthesized Definition

Twenty-first century learning has been described as learning that encourages high-level thinking skills and the development of technological literacies. It also includes: problem solving, critical thinking, self-directed learning, and collaboration by solving real-world scenarios and involves the use of technology; and moreover these skills are transferable among subjects, grade levels, and life [17, 18]. See Fig. 2 for a synthesized definition from Canada, the United States, and the European Union. The 21st century extends Bloom's taxonomy to the higher-order thinking levels of analysis, synthesis, and evaluation [12].

These skills are not especially unique to the 21st century, as critical thinking and problem-solving have been inherent in educational curriculum since the 1960s [17, 18, 19]. In particular, the concept of student-centered education using real-world authentic situations came out 1960s with problem-based, project-based, and inquiry-based learning. However, 21st century learning skills are being integrated or implemented in different and new ways. In particular, there are higher expectations towards students having multiple STEM (science, technology, engineering, and math) skills as well as other interdisciplinary abilities [20]. Current emphases, such as globalization, low civic engagement, and the prowess of the economy have been a catalyst for students to learn a variety of skills that have been not as effectively displayed in traditional ways of learning about the government [18]. Twenty-first century learning shifts towards higher-order thinking skills as well interpersonal and self-directed skills, or the ability to work in a team or individually and become a leader while being accountable and adaptable; in other words, a form of social responsibility.

IV. Education and VR

Several researchers have studied the impact of VR on 21st century skills [21, 22, 23, 24]. For example, Barab et al. [21] and Thorsteinsson and Page [24] explored student collaboration in a VR learning environment. Barab et al. [21] described student understandings within a collaborative participatory learning environment and they found that participation and collaboration in a technology-rich VR setting contextualized knowledge. Also, Thorsteinsson and Page [24] found that collaboration was important for idea generation.

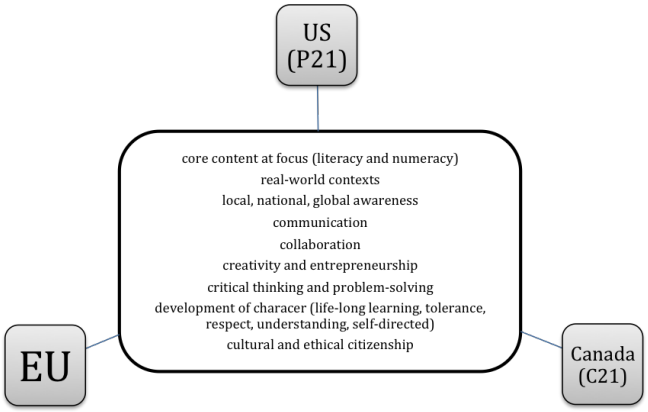

Fig. 2: Canada, United States, and European Union 21st century ideas synthesized.

Hauptman [23] explored the role of virtual spaces and how it can impact self-regulation. Self-regulating questions are used to determine how students activate, alter, and sustain their learning [25]. They found that self-regulating questions make use of VR more efficiently and can have influences on self-regulation and encourage higher order thinking skills. Poland et al. [22] found that the use of a VR environment in ecological fieldwork transformed more constructivist problem solving skills. Some studies looking at 21st century learning skills while using VR suggest possible measurements using qualitative techniques, such as observations and interviews. Even though evaluation and creation using logical reasoning, judgment, and critical thinking began much earlier than the 21st century [12], the amount of technologies available to support this learning has grown exponentially in the 21st century.

More research is needed regarding these skills with VR. But some may ask why we should use VR? And how can we use and measure VR experiences in supporting the learning of content knowledge and 21st century skills?

V. Why and How VR?

VR does not just mean playing games and watching videos with a funky head mounted display. This misconception has lead to a degradation of VR or use without pedagogical support, which in turn has led many to not use VR at all. The use of VR and digital media seem to have created a "new realm of interaction" [17](p.132). There are a variety of concerns from too much screen time to logistical lack of devices or non-functioning issues [26, 27]. A deeper understanding of why and how to integrate VR into pedagogical practices is needed.

A. Why?

A growing number of educators are interested in the "interaction age" in which students and teachers shift their expectations to adapt to the changing job market [18]. Being technologically literate can be quite difficult as many presume that students know technology just because they are "digital natives". They know how to text or Instagram or take a selfie, but many nuances of technology are not known to them. Teachers increasingly encourage the exploration of different technologies through critical thought. Part of the issue lies not in how to use technology to support traditional models of education, but rather to shift thinking with pedagogical integration.

With the rapid evolution of technology and the increasing pressures to use VR, society has different expectations. It is not just the use of computers, or iPads or VR headsets or other applications associated with this media, rather it is how we use these devices pedagogically to encourage thinking and learning of hard and soft skills. Perhaps most importantly, as researchers, the question is: how will we measure learning to establish if VR enhances pedagogical practices?

B. How?

Today, many digital technologies are more closely linked to this experience of creation and interaction. Technology and in particular some VR developments allow, encourage, and force interdisciplinary applications [17]. VR allows 21st century learners to dream, explore, collaborate and create. Rather than watching television and increasing the amount of screen time for students, a warning from the American Academy of Paediatrics (AAP), we need to reshape the thought of creating digitally literate learners who use technology to create and find information. Prior research in VR describes how we can use VR to promote skills and knowledge through its immersive and interactive qualities [13]. Additionally, VR allows the opportunity to develop real-world authentic situations, which is reflective of constructivist practices [7]. Research needs to reflect the constructivist values of meaning making within a VR experience.

VI. Proposed Approach: Combining Metrics

Some researchers have begun to explore quasi-experimental ways of measuring successful VR experiences through various knowledge pre- and post-tests, focusing on measuring content knowledge [14, 23]. Other researchers have used surveys or questionnaires to measure the VR experience in general [28]. Still other researchers have measured presence, immersion, and flow as a way of understanding immersion and interaction, which can lead to learning [29, 30]. However, finding the right measurement is challenging due to the intangible impact of immersion in terms of educational outcomes. Here we provide some examples of effective and validated measurement tools, and propose to use the combination of these methods in the evaluation of of gold rush exhibit.

There are several survey questionnaires that have been developed and validated that would be appropriate for measuring

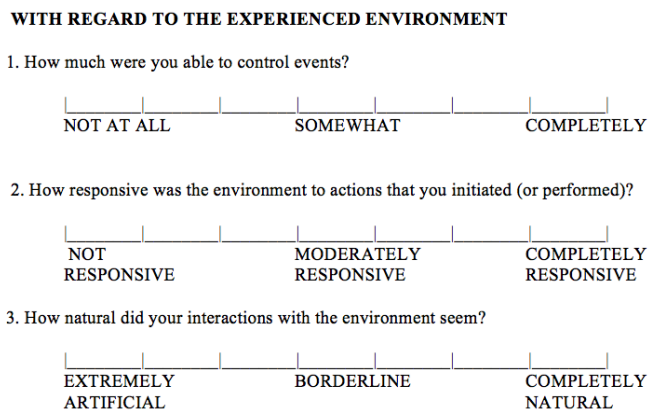

Fig. 3: Example of the Presence Questionnaire

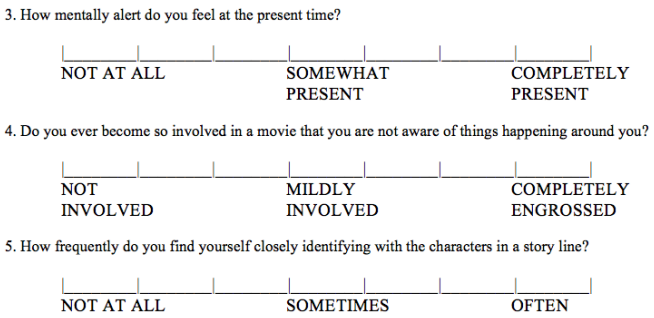

Fig. 4: Example of the Immersion Tendency Questionnaire

learning. The first is the Presence Questionnaire (Fig. 3) and the Immersion Tendency Questionnaire (Fig. 4) [30, 31]. Presence is described as a "psychological state of being there mediated by an environment that engages our senses, captures our attention, and fosters our active involvement" [30] (p.298). Immersion is also a psychological state and can be characterized as "perceiving oneself to enveloped by, included in, and interacting with an environment that provides a continuous stream of stimuli and experiences" [30] (p.299).

Given that education requires learners to be attentive and active, measurements of presence and immersion have significant potential to capture the impact of VR on learning. We believe that these two surveys, combined with a knowledge test, would provide detailed data on how students learn.

Another questionnaire that has potential to capture the subtle consequences of VR focuses on *flow*. Flow is a state where "people feel involved in meaningful actions, maintain a sense of control and stay focused on a goal" [29] (p.506). The flow experience "seems to occur only when a person is actively engaged in some form of clearly specified interaction with the environment [32] (p.43). Similar to presence and immersion, flow is focuses on active engagement within an environment. For example, Bressler and Bodzin [29] used a short flow state scale to measure flow in a post-survey with

Statement	I strongly agree	I agree	I don't know	I disagree	I strongly disagree
1. I was challenged and I felt I could meet the challenge.					
2. I did things naturally without thinking too much.					
3. I had a strong sense of what I wanted to do.					
4. I felt I was on track towards my goals.					
5. I was totally focused on what I was doing.					
6. I felt I was in control of what I was doing.					
7. It felt like nothing else mattered.					
8. I lost my normal sense of time.					
9. I really enjoyed what I was doing.					
10. I was in the zone.					

Fig. 5: Example of flow questionnaire

Process	• Unsure/loses sight of problem and does not recognize what to do • Uncertain of strategies • Resistant to alternatives • Does not monitor progress	• Uncertain of approach • Applies strategies, but cannot explain why • Seeks suggestions for alternatives but gets frustrated • Seeks help for progress	• Capable and makes changes when necessary • Applies strategies and clarifies ideas • Explore unique procedures • Functions independently
Representation	• Restates the problem with difficulty • Communicates about the process with difficulty • Partial organized/disorganized / incorrect	• Restates some features of the problem • Reflects on some processes • Organizes solution complete, but not thorough	• Communicates details of the problem • Describes thinking processes • Organizes solution thoroughly and organize

Fig. 6: Rubric assessment for problem-solving

students (Fig. 5). These survey questionnaires could be the grounding for measuring some 21st century experiences and could be combined with knowledge tests to measure content knowledge acquisition and understanding.

For further measurements of 21st century skills, including collaboration and problem-solving, the focus has been on more qualitative observations and interviews [21, 24]. One example of how to code the data would be to use a problem-solving rubric. For example, using the British Columbia Ministry of Education's evaluation for problem-solving, adapted from Petrina [33], rubric to observe problem-solving skills (Fig. 6).

More research is needed to directly explore if presence, immersion, and flow can lead to learning or what role learning and education can play in a VR experience. Also more research needs to be conducted to include quantitative and qualitative data to measure both content knowledge and 21st century skills. The future of technology is not predictable, and with the ever-changing landscape it can be overwhelming for teachers and researchers to imagine how to integrate current technology and VR, without even thinking about the future. Technology will play an important role in many students' futures and needs to be measured appropriately and integrated with pedagogical thinking in order to help facilitate the potential for greater educational success.

VII. Conclusions and Future Work

The growing interest, access, and development of VR experiences is continuously shifting, and the role of VR in education has yet to be defined. Content knowledge and 21st century learning skills are the hard and soft skills at the forefront of education. Students need to be exposed to many sources of digital media and technology tools like VR with a grounded pedagogical approach.

Several validated survey questionnaires have been established that can provide some insights to learning, such as measures of presence, immersion, and flow—or engagement, interests, and motivations. Furthermore, these have been combined with knowledge tests for students to measure their content knowledge gains in VR settings. These quantitative results combined with qualitative observations and other measures, such as a problem-solving rubric, and interviews, can provide some insightful information on learning in VR settings.

We are nearing the third decade of the 21st century and the popularity of VR continues to grow. Students today will grow up in a world vastly different than our own. We need to understand that "the child starting kindergarten this Fall will graduate in the third decade of the 21st century" [34] (p.2-3). Our goal is to use our proposed metrics to measure the impact of VR in the *gold rush* experience, and to establish efficacy according to 21st Century Learning skills.

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