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BEYOND THE FRONTIERS OF EDUCATION: HOW IMMERSIVE MEDIA CHANGES THE WAY WE LEARN

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Abstract *–Many studies have demonstrated that by embracing technological developments the quality of education improves, with evidence coming from virtual reality, serious gaming, and intelligent tutoring systems. In addition, by taking advantage of sensing technologies and learning analytics it becomes possible to monitor individual and group learning performance online and intervene when a student struggles, thus providing personalized education. However, immersive media offers an extra advantage, one that can affect many. Whereas in the past, educational technologies were implemented locally, within a school or school district, it has become conceivable to put new technological opportunities into effect worldwide. By taking advantage of cloud computing, 5G networks, and virtual reality headsets (or their proxies), it is now possible to deliver educational content that is developed anywhere in the world, everywhere in the world. The current paper describes what it takes to provide high quality education worldwide, given the existing hardware and software options, and illustrates these opportunities with the SpaceBuzz initiative and the accompanying educational program.*

Keywords – Artificial intelligence, education, intelligent tutoring systems, learning analytics, serious gaming, virtual reality*.*

1. INTRODUCTION

When it comes to our educational systems there is every reason for optimism, but there are likewise reasons for concern. The *Organisation de Coopération et de Développement Économiques* (OECD) Programme for International Student Assessment (PISA) has for almost two decades evaluated education systems worldwide by testing the skills and knowledge of 15-year-old students, representing 28 million students in 72 countries and economies [1]. The PISA findings give reasons for optimism about student performance. Eight percent of students across OECD countries are top performers in science, and science performance of the majority of countries has remained the same since 2006. At the same time, however, 20 percent of students in OECD countries do not attain a baseline level of proficiency in reading. Students report a broad interest in science topics and recognize the importance of science, yet only a minority of students report that they participate in science activities. According to the PISA recommendations, disadvantaged students and those who struggle with science would benefit from additional support, to develop a lifelong interest in the subject.

An additional concern is that education does not adapt to the societal changes facing populations worldwide. For instance, the National Center for Educational Statistics [2] results show a deep divide between student knowledge and procedures, and their understanding of applying that knowledge through reasoning and inquiry, drawing the following conclusion: “Seldom has such a consistent message been sent across K-16+ as to the need for substantial change in what we expect students to know and be able to do in science, how science should be taught, and how it should be assessed” [3].

Another multi-year, multi-country OECD study demonstrates that more emphasis is needed on social and emotional skills [4]. According to this study, skills such as responsibility, teamwork, perseverance and creativity become acutely important in today’s society, even more important than knowledge itself. Currently, these skills are not consistently developed inside the existing educational systems.

Formal education is constrained by national legislation and compliance. Yet it is supported and nourished by a more flexible system of informal education, a learning that does not feel like learning. Informal science education presents opportunities for lifelong learning in fields such as science, technology, engineering, the arts, and math (STEAM) that takes place outside of the formal classroom environment. In fact, learning about science often occurs outside traditional formal education, and as such, can begin before children enter school and continue long after having left school [5, 6, 7]. An average child in the western world spends less than five percent of their life in classrooms, and an ever-growing body of evidence demonstrates that most science is learned outside of school [5]. Past research examined the beneficial effects of informal science education in museums and during free-choice learning [8, 9]. Consequently, there is every reason to encourage informal science education tailored to the needs and interests of individual children. However, informal science education tends to be costly and is generally not accessible to all. For example, science museums tend to be located in (specific neighborhoods of) larger cities and individualized learning activities carry considerable additional costs.

However, already in 1984, Bloom noted that personalized tutoring is highly beneficial in the learning process. He reported the findings of a comparison in student achievement between (a) conventional learning in 30-student classrooms with periodical assessments being taken, (b) mastery learning that was comparable to conventional classrooms, except that assessments were followed up by corrective procedures, and (c) tutoring sessions in which a tutor sat down with up to three students followed by assessments [10]. Bloom found that students in the small tutoring sessions (preferably, one-to-one) performed two standard deviations better than students in the conventional learning condition. Bloom concludes: "The tutoring process demonstrates that *most* of the students do have the potential to reach this high level of learning. I believe an important task of research and instruction is to seek ways of accomplishing this under more practical and realistic conditions than the one-to-one tutoring, which is too costly for most societies to bear on a large scale […] Can researchers and teachers devise teaching-learning conditions that will enable the majority of students under *group instruction* to attain levels of achievement that can at present be reached only under good tutoring conditions?" (p.4).

Since Bloom's question posed 35 years ago, development educational psychology and educational technologies have proposed different solutions for a method of group instruction as effective as one-to-one tutoring. A promising solution could be online education, such as Massive Open Online Courses (MOOCs), which can reach larger groups of students. MOOCs can lead to a changed mindset, from the idea that not everyone can learn, e.g., mathematics, to the idea that everyone can [11]. However, this solution is not yet comparable to a personal tutor, such as that proposed by Bloom [10]. Instead, we pose the answer lies in a combination between virtual reality, serious gaming, intelligent tutoring systems and learning analytics. Recently, we have taken the first steps to bring such interactive technologies and learning behavior together in an innovative educational program, exploring creative avenues for interactive, immersive, personalized education to better educate and prepare students for the future.

2. SPACEBUZZ

The non-profit organization SpaceBuzz developed an innovative educational program aimed at Grade 5 primary school education. An important goal of SpaceBuzz is to introduce 9-11 year olds to the subjects of science and technology in the context of sustainability in a way that is playful and easy to learn, inspiring them to make positive contributions to society as they get older. The program has been developed in line with the career path of a real astronaut. It comprises three elements: (1) A pre-flight astronaut training, involving a variety of activities and lessons in the classroom which prepares children for their journey through space. (2) After children pass the pre-flight astronaut training, a 15-meter long rocket arrives at the school to virtually launch children into space (Fig. 1). When children sit down in the rocket and put virtual reality headsets on, their chairs move hydraulically, and the rocket is launched into space under the guidance of a virtual reality embodiment of an actual astronaut, currently European Space Agency (ESA) astronaut André Kuipers. When children virtually arrive in orbit around the earth they experience what every astronaut has reported: Deep feelings of awe and self-transcendence viewing the earth from outside its atmosphere, describing it as an "explosion of awareness" and an "overwhelming sense of oneness and connectedness… accompanied by an ecstasy … an epiphany", a cognitive shift in awareness also known as the overview effect [12]. (3) Finally, in a post-flight training at the children's school, children give press conferences to friends and family and tell them about their experience in space.

Fig.1 - Images of SpaceBuzz rocket ship, outside (left) and inside (right)

The SpaceBuzz program pays no-cost visits to schools across the Netherlands, with 373 schools in the nation already signed up for this free program (78 from areas with a lower socioeconomic status), totaling over 20,000 children. Hundreds of children have already participated in the first user test experiments. With a visit to NASA's Lyndon B. Johnson Space Center in Houston, as well as a presence at the International Astronautical Congress in Washington, the SpaceBuzz rocket ship has been experienced by some 60 astronauts and some 2,000 international visitors. In the words of Iranian-American astronaut Anousheh Ansari: "I think it should be something that every human being, young and old, gets to see. Of course children will really enjoy it and will take this experience to heart, but I think we should take it to the UN and make all the world leaders do the same thing" [13].

In a recent study with 200 school children we investigated whether we were able to simulate the overview effect in virtual reality, and whether the virtual reality experience yielded learning gains. Findings from questionnaires and head gaze demonstrated that children indeed experienced the overview effect, and that this experience predicted learning gains. These findings show that a novel combination of virtual reality, serious gaming, intelligent tutoring systems and learning analytics may contribute to an immersive experience that yields learning [14].

In the following sections, we describe immersive media components currently being integrated as a part of the SpaceBuzz program that all contribute to effective and personalized learning. These components are serious gaming in combination with virtual reality, intelligent tutoring systems and learning analytics.

3. SERIOUS GAMES

Past experimental studies have shown a variety of beneficial effects of games on cognitive functions ranging from attention, visual imagery, problem solving, visual processing, response speed, cognitive flexibility, and — importantly — learning [15, 16, 17, 18].

Various initiatives have been set up to bring learning games to children. For example, National Geographic (kids.nationalgeographic.com) and World Wildlife Federation (wwf.panda.org) provide online learning games where children can combine interactivity, exploration, curiosity, and knowledge acquisition.

There are clear benefits to incorporating serious gaming in formal and informal education. The first, and most important one, is enjoyment [19, 20]. Despite, or perhaps thanks to, educational games often being viewed as entertainment more than education, they provide a more motivating way to acquire skills and knowledge than traditional methods [21, 22, 23]. Especially when motivation in STEAM subjects is low, this is a valuable benefit [24]. After the SpaceBuzz simulation, children (N = 183) scored high on both happiness (M = 4.37, SD = .75), and excitement (M = 3.85, SD = 1.10), and low on boredom (M = 1.39, SD = .81), on a five-point Likert scale. Results like these indicate how motivation can be increased through simulations.

The second benefit is the possibility to personalize the content of the educational material. Games can be adaptive and thus automatically tailored to specific users with different skill levels, combining educational methods with game mechanics, and hereby making learning more effective [25, 26].

Additionally, serious games cannot only be used to inform players on certain topics, they can be used to persuade the player to adopt a certain behavior [27], where more meaningful narratives increase the game's effectiveness, and, in turn, player engagement [28], especially in virtual reality based environments.

4. VIRTUAL REALITY

New hardware has provided vast opportunities to bring content closer to the learner. The use of non-immersive virtual learning environments, typically presented using regular computer monitors, has been associated with several learning benefits, including improved engagement, spatial awareness, contextual and collaborative learning [29, 30, 31]. Immersive virtual learning environments in turn are most commonly experienced using virtual reality headsets, such as the ones used in SpaceBuzz, and bring educational content so close that the learner feels that they are present inside it. This phenomenon is called presence, and has been linked to positive learning outcomes [32]. The realism immersive virtual learning environments provide has been suggested to amplify several learning benefits of their non-immersive counterparts [33]. With these environments, there no longer is a need for artificial input methods, such as keyboards, to explore educational content. Instead, body movement is naturally translated into the virtual experience, making it possible to literally pick up virtual content and intuitively explore it with an unprecedented level of freedom and ease.

Yet the learning benefits do not stop there. What was once hard to grasp using 2D pictures in a textbook can now be presented in full stereoscopic 3D and from any desired vantage point, which benefits learners with low spatial ability especially [34]. Collaborative learning in virtual learning environments is set to receive a boost as well, as a recent study has shown how groups of students can interact and learn within a shared virtual space while maintaining non-verbal communication through the use of mixed reality, which has the possibility to bring physical elements into the virtual experience [33].

Given the variety of benefits, it is unsurprising that virtual reality has shown learning gains compared to traditional forms of learning [35, 36]. Moreover, it has been suggested that the benefits of virtual learning environments are most effectively applied when they serve the intended learning goals [37]. In the example of SpaceBuzz, the match between benefits and learning goals is abundantly clear. Few other technologies make it possible to provide children with a realistic experience of becoming an astronaut and travel around the earth's orbit, and it is the very realism of the 3D experience afforded by virtual reality which is paramount to bringing about the overview effect.

Taken together, the vast range of possibilities of virtual reality and related immersive technologies might make them an ideal solution, particularly for K-12 education, where there is an ever-present need to provide novel ways to support, engage, and motivate learners.

5. INTELLIGENT TUTORING SYSTEMS

Serious games allow for self-paced learning, which has shown to increase effectiveness of learning and achievement in education [38]. Yet, guidance in the exploration and the opportunity for students to ask questions seems beneficial for learning [39]. Intelligent tutoring systems provide one-on-one sophisticated instructional advice comparable to that of a good human tutor, and allow for developing and testing models about the cognitive processes involved in instruction, thereby potentially providing a solution to Bloom's 2-sigma problem discussed earlier. One category of systems are conversational intelligent tutoring systems that use natural verbal and non-verbal conversation for tutoring purposes. The advantage of these systems is that they allow the user to explore a simulated world, while guiding them pedagogically [40].

These conversational intelligent systems have been around for over 50 years. Weizenbaum's ELIZA system already simulated a Rogerian therapist that was able to communicate with the user using a rule-based system [41]. The interaction was primitive, with ELIZA rephrasing the utterance of the user in a question using a text-to-text interface. Since then, conversational systems have improved considerably with embodied conversational agents interacting with their users, using synthesized speech and basic facial expressions and gestures. One such agent is AutoTutor, a computer tutor that teaches students topics such as conceptual physics and computer literacy [42]. AutoTutor is visualized as a talking head and asks a general question to the student, who can respond using natural speech. The computer system then extracts meaning from the student utterance, evaluates the quality of the student's input, and decides on pedagogical moves on the basis of this information. This way, every student can have their own personalized learning experience.

The evaluation of intelligent tutoring systems like AutoTutor has been positive. In a series of experiments the learning gains of students interacting with the intelligent tutoring system were on a par with those of human tutors, which were significantly better than those after students studied a textbook on the same topic [43, 44].

Yet, despite the promise of these systems, their embodiment has generally been that of a cartoon character with very rudimentary facial expressions and gestures and highly computerized speech synthesis, with written input from the student.

Modern day techniques such as photogrammetry (which generates a 3D model from pictures) now allow us to scan in individuals, in the case of SpaceBuzz the astronaut of the respective country, and use artificial intelligence algorithms to animate the face and gestures of the agent in a natural way so that it becomes hardly distinguishable from human non-verbal behavior [45]. Developments in speech recognition allow for speech input, so the conversation becomes more natural, and speech synthesis allows for recreating the voice of an actual individual [46]. Computational linguistic techniques in the meantime, allow for sophisticated syntactic parsing, distributional semantics and dialog management [47].

The enhanced embodiment of the agent provides lots of promise to these systems in the field of immersive education. AI techniques operate the non-verbal and verbal behavior of the intelligent tutoring system. Machine learning mechanisms allow these systems to learn over time, both improving their conversational skills as well as their knowledge and pedagogy.

6. LEARNING ANALYTICS

Current educational practice assesses students periodically, either without corrective measures, as in Bloom's conventional learning, or with corrective measures, as in Bloom's mastery learning. There are a number of important downsides to this current approach to assessment [48]: 1) It might interrupt and even negatively influence learning; 2) Little insight is provided into the learning process itself; 3) When assessment demonstrates suboptimal performance which would benefit from corrective procedures, intervening may already be (too) late. Ideally, assessment should include continuous and objective measurements of how students are progressing toward targeted goals without the student being aware of the assessment. This has been aptly called stealth assessment [49].

There has been an increasing amount of evidence that demonstrates the learning process can be measured non-intrusively, online, and objectively using sensing technologies [48, 50]. Sensing technologies consist of sensors which are able to measure neurophysiological, cognitive and affective processes. These sensors include, for example eye-tracking, recordings of language and speech, measures of head movements and measures of heart rate or brain activity such as electroencephalography (EEG). They are thought to be able to detect changes in how information is processed and therefore in how cognitively demanding a task is, an important transition occurring during learning [51, 52]. Indeed, a recent meta-analysis examining 113 experiments on non-invasive neurophysiological measures of learning demonstrated that these measures yield high effect sizes and are valuable for assessing learning. Additionally, learning analytics and educational data mining has shown success in detecting affect related to learning gains [48, 53].

As technological advancements take place, we expect the validity and applicability of assessment through sensing technologies to increase. For example, solutions for (automatically) dealing with noise and advanced open software tools for aiding in analyses of these types of datasets are available and are being enhanced [54], even supporting real-time analysis and monitoring [55]. As another example, wearable, portable, and compact sensors reduce set-up time and associated costs, and increase comfort, making wearables very attractive to apply for gaining insight in learning.

Taking this one step further, embedding sensing technologies in learning systems could progress applicability even more. Such systems have the potential to assess learning states and provide instantaneous assistance or adaptation of the learning material based on the recorded data [56]. As an example, Sood and Singh [57] have provided a framework on how to combine virtual reality and measures of brain activity in a serious game for robust and resilient learning and an enhanced learning experience.

Thus, embedding sensing technologies in virtual reality headsets is a way in which one can take advantage of combining two types of powerful technologies.

7. CONCLUSION

Developments in serious gaming, virtual reality, intelligent tutoring systems and learning analytics are promising and offer exciting ways to bring informal and formal education together, help those who are currently performing at baseline level, bridge the gap between high performance and low performance students, and offer opportunities to new forms of how science is taught and how it is assessed, complementary to traditional forms of education. The SpaceBuzz program has taken the first steps in this direction by providing children with an accessible interactive immersive media experience that has shown to yield learning gains in 9 to11 year-olds. Currently, the program is working on integrating the methods described above to develop the approach even further.

Thirty-five years ago, Bloom asked himself the question whether researchers and teachers can devise teaching-learning conditions that will enable the majority of students in conventional education to attain levels of achievement that can otherwise only be reached under good tutoring conditions.

The advancements in serious games, virtual reality, intelligent tutoring systems, and learning analytics have been such that the answer to Bloom's question does not lie in the development of teaching-learning conditions, the development of hardware or the development of software. It lies in combining efforts. Perhaps Bloom's question can be rephrased: How can the gaming industry, software companies, educators, policy makers, science museums, media companies, teachers, schools, and academia worldwide work together to embrace immersive teaching-learning technologies that will enable the majority of students around the globe to attain optimal levels of educational achievement? Answering this question ought not to take another 35 years.

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