Virtual reality for deeper learning: An exemplar from high school science

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Abstract

This paper uses qualitative data, from a study which embedded virtual reality (VR) in high school science classes, to produce an exemplar designed to illustrate how the technology can promote engagement and Deeper Learning for students. Application of the Deeper Learning conceptual framework to the exemplar provides unique insights into how VR can be deployed in curriculum-aligned ways to develop and combine content mastery, self-directed, collaboration and, perhaps most importantly, creative endeavour in high school science, especially in low income school communities.

Keywords: Virtual Reality, Children, School, Pedagogy, Curriculum, Learning, STEM, Science Education.

Index Terms: Human-centred computing — Human computer interaction (HCI) — Interaction paradigms — Virtual reality; Social and professional topics — User characteristics — Age — Children; Human centred computing — Human computer interaction (HCI) — HCI design and evaluation methods — Field studies

1 Introduction

The development of simulation technologies such as virtual reality (VR) are inextricably linked to industry contexts (especially military and medical), and their need to create effective and safe training environments [1, 2, 3]. The historical, and arguably current, emphasis on using VR for training purposes has led to limited scholarly attention being paid to how the technology can be harnessed for other (deeper) educational goals especially those related to schooling. Training involves learning a specific knowledge base and its concomitant skill set, and having practice opportunities that allow learners to develop and demonstrate competency. Education, on the other hand, is a philosophically-infused concept that involves exploring theoretical and practical knowledge and values, and the fostering of different types of thinking for the cultivation of self and the betterment of society [4]. As teachers begin to experiment with integrating VR and other immersive technologies into their classrooms, there is a need to extend our understanding of how these can be used for broader educational purposes that move beyond more bounded training scenarios.

The aim of this paper is to explore how VR can be used in schools to facilitate Deeper Learning [5]. Deeper Learning is a conceptual framework which combines the broader philosophical and social goals of education with learning science. The paper begins by briefly outlining research on VR and school education with a focus on the type of VR mediated through head mounted displays (HMDs). An overview of the Deeper Learning framework is then provided before proceeding to a detailed exemplar that illustrates how VR can be used to facilitate Deeper Learning in high school science classes. The exemplar is derived from research conducted in Australian high schools. It highlights how VR can be integrated into curriculum to develop: (1) mastery of content knowledge; (2) higher order thinking, collaboration and communication skills; and, (3) a degree of technological competence.

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2 Literature on VR and School Education

Theoretically, there is an excellent body of work to assist educators in understanding the learning affordances (properties) of VR [6, 7]. Mikropoulos & Natsis [8] provide an overview of how the affordances of VR can assist with learning, including:

- **First order (person) experiences** that support social constructivist conceptions of learning.
- **Natural semantics** or understanding the basis of something before learning about its symbols and abstractions.
- **Size and scale manipulation** where users can change the size of themselves, objects or environments to interact with micro/macro worlds.
- **Reification** or transforming fairly abstract ideas into perceptible representations.
- **Transduction** or extending user capability to feel 'data' that would normally be beyond the range of their senses or experiences.

Recently, there have been three major research reviews on VR and education. Hew and Cheung [9] focused on immersive virtual worlds in K-12 and higher education. Of the fifteen empirical paper they reviewed, 30% reported on studies carried out in school settings, with most being descriptive in nature. The authors suggest that future research should concentrate on filling gaps in the literature related to: the unique affordances of virtual worlds for learning; providing effect sizes for learning outcomes; and understanding whether student and teacher perceptions of virtual worlds changed over time.

A second review [8] of fifty three articles on educational virtual environments found that the majority (40/53) related to science, technology and mathematics education. There were only three studies where the learning problem was chosen in collaboration with teachers and only one where the study involved students in a school. The authors state that teachers and students share a positive attitude towards VR but that 'technological characteristics like immersion and individual factors like age, gender, computer experience, psychological factors affecting presence need to be studied in relation to learning outcomes' (p.777). They recommend that more research be conducted on how the features of virtual environments can be pedagogically leveraged for learning.

A third review [10] of the educational potential of 3-D multi-user virtual worlds for STEM education (predominantly delivered via desktop computers) reported that 17 of the 50 studies published between 2000 to early 2016 related to school education. The authors found that 3-D multi-user virtual worlds offered potential for collaborative problem-solving, higher order thinking activities that engaged learners. They also noted technical barriers could interfere with learning and that students often had the difficult task of coming to grips with the features of virtual environments while learning content.

Research on the use of VR mediated by HMDs in school classrooms is only just emerging. This is not surprising given the recent commercial availability of the technology and the time needed to develop appropriate content (Google Cardboard was released in late 2015 and high-end VR Oculus Rift or HTC in early 2016). There are studies using HMD-mediated VR with dance software to teach middle school (predominantly) girls computational thinking and programming in an after-school program (n=8) [11] and a summer camp (n=16) [12]. The same research team conducted an experiment with 36 middle school students (4M, 32F) to investigate how the presence or absence of character customization influenced learning outcomes [13]. The research found that participants with customizable characters had better learning outcomes. Other school-based research, while not using a HMD but polarised glasses and haptic devices, found that using augmented simulation to learn abstract scientific concepts was associated with a significant effect on achievement [14].

A recent study [15] of high school students (n=54) using Oculus Rifts with Minecraft VR in STEM classes found that more attention should be paid to the affective and cognitive responses of students while they are in VR and how these interact with attention to task, processing of task-related information, and whether such effects persist as students become more familiar with the virtual environment and its affordances. The study also found that even when students were on-task or off-task in VR, most were involved in collaborative activity. This suggested that the embodied sociality of networked IVR could be harnessed for effective learning.

In summary, research on HMD-mediated VR and learning in schools is nascent. More sustained scholarly attention is required to understand how the technology can be integrated into the curriculum and pedagogically harnessed so that students can meet learning outcomes [7]. Research on how students can use the technology to master content knowledge and develop higher order thinking and collaboration skills is required.

3 Deeper Learning Theory

The Deeper Learning movement from the United States combines an interest in 21st Century Learning [16] with earlier progressivist, child-centered theories regarding the purpose of education: Education should develop student's capacities to pursue a good life within a democratic sociopolitical context (for example, see John Dewey's [17] influential body of work). Deeper learning is a 'combination of (1) a deeper understanding of core academic content, (2) the ability to apply that understanding to novel problems and situations, and (3) the development of a range of competencies, including people skills and self-control' [5]. According to the *Deeper Learning for All* network, the six outcomes of the framework are:

- **Content mastery**: Students acquire knowledge that they then apply or transfer to real world situations. Content mastery is about learning for life;
- **Effective communication**: Students develop and demonstrate active listening, clear writing, and persuasive presentation;
- **Critical thinking and problem solving**: Students consider a variety of approaches to produce innovative solutions.
- **Collaboration**: Students work with their peers, assume leadership roles, resolve conflicts, and manage projects.
- **Self-directed learning**: Students use teacher feedback to monitor and direct their own learning, both in and out of the classroom (This might better be conceived as teaching students metacognitive skills [18] both individually and in groups.
- **Academic mindset**: Students feel a sense of belonging and the motivation to persist through their school work. (https://deeperlearning4all.org/).

Deeper learning offers a conceptual framework to think beyond limited 'input-out' conceptions of technology-enhanced learning. This type of input-output (or technicist) conception focuses on adding technology to a learning context and then narrowly defining success through measurement of individual, narrow knowledge and skills acquisition and application (output). Deeper learning is the converse of technicist learning which ignores pedagogical dynamics (what happens *between* input and output), the impact of individual social differences on learning processes and outcomes, and the broader philosophical purpose of education [19]. Furthermore, while Deeper Learning is for all students, it has been specifically developed to address the profound equity issues (captured by the deceptively simple term 'the achievement gap') that endure across many Western education systems [20].

Evaluations of Deeper Learning have indicated that, compared to similar students in comparison schools, students from Deeper Learning schools: achieved higher scores on the OECD PISA-based tests; reported higher levels of collaboration skills, academic engagement, motivation to learn and self-efficacy; and had high school graduation and college entry rates [5].

Dede [21] has suggested that simulation technologies can offer powerful tools for teachers to deliver Deeper Learning but that more research is required to explore this:

> '(I)mmersive media can be used in a number of ways to promote deeper learning, such as by facilitating case based instruction, collaborative activities, simulated apprenticeships, and the development of scientific inquiry skills, including the collection and analysis of data to provide warrants for specific claims. Simulations allow students to learn skills under controlled conditions that may be difficult to replicate in the real world…but which convey some degree of authenticity, allowing what is learned in one setting to transfer to the other.' p.18.

This paper take up Dede's challenge to explore how immersive virtual environments can be deployed in schools so that students have authentic opportunities to develop Deeper Learning outcomes.

4 The Research

The exemplar described in this paper is drawn from research conducted in 2018 as part of the ongoing VR School Study (www.vrschoolresearch.com). The study is set in three high schools situated in low-income communities. A key aim of the research is to explore how HMD-mediated VR can the integrated into curricula so that the affordances of technology can enhance learning opportunities and outcomes for students facing life challenges.

The exemplar is drawn from research conducted at the two government high school junior campuses of Callaghan College (Australia) which are located in an urban setting. Both campuses are considered low-income schools with between 44-48% of students from the lowest socio-economic status (SES) quartile. While 2.3% of Australia's population identify as Indigenous, 12-15% of students at the schools are Indigenous. Research based on standardised test scores indicates that, in general, there are persistent and significant gaps of between 2-3 years in literacy and numeracy achievement between high SES students and those from low SES and Indigenous backgrounds [22]. In addition, students in low income school communities, such as Callaghan College, do not always have access to the latest mobile devices or data required to assist their learning, especially at home: the issue of digital inclusion for learning is a serious concern in the Australian context, especially with many schools have BYOD policies. This sets the academic and equity context for the VR School Study.

Fifty six Year 9 students (aged 14-15 years) from two science classes (one on each campus) participated in the VR component of the study. Forty four per cent of participants were female. Informed parental/carer consent and student assent were obtained. The research was approved by the University of Newcastle Human Ethics Committee (Approval No. H-2017-0229) and the New South Wales Department of Education (Approval No. 2017396).

The study was conducted over a 6-7 week period in June-August 2018 when a project-based unit of work on biology was implemented. The unit of work, 'Living World', comprised approximately 21 one-hour lessons with students having access to the VR equipment for between 9-12 lessons. The remainder of the lessons were for lab-based and explicit content deliver lessons.

Three Oculus Rifts (CV1) with Touch controllers were networked in designated VR rooms attached to the classrooms. Students worked in groups of three to research a body organ, build a model of it in Minecraft VR (Win 10 or Pocket Edition), and make a video or conduct a guided tour of it with a detailed oral explanation of the function of the body organ and its parts. This was a formative assessment task. For safety reasons and to allow all groups to have access to the equipment, students had a maximum of 15 minutes in VR in any hour period, Therefore they needed to research and build their model on a desktop or mobile computing device and import it in VR or, in the case of this exemplar, host it on a mobile device that then connected to Minecraft VR. Mixed methods were used to collect data including: pre and post-test content achievement scores (there was a control non-VR group on each campus; pre and post test engagement survey; hand-held video of student interaction and communication in VR including their guided tour; screen capture of student interaction in the virtual environment; student and teacher interviews and focus groups; and student work samples.

This paper uses student work samples which are screenshot from the screen capture video and verbatim transcripts from videos of students in VR to compile the exemplar. Excerpts from teacher interviews have also been included. The exemplar represents one of the most successful cases of Deeper Learning in the project. There were a number of other student models that might have been included (for example, three girls produced an incredibly detailed internal model of the heart); however, the brevity of this type of paper and the focus on documenting a detailed case study precluded inclusion of these. Of course, as in all classrooms, some student's work demonstrated greater Deeper Learning, especially the development of 21st Century Learning Skills [16], than others. Comparative analysis is currently underway to determine if and how this was related to the VR component of the unit of work in biology.

5 VR For Deeper Learning: The Exemplar - 'A Skyscraper of a Brain'

This exemplar illustrates how three male students demonstrated aspects of the Deeper Learning when undertaking a formative assessment task to create a model of a body organ in VR in science. The syllabus learning outcome was: 'A student can analyse interactions between components and processes within biological systems'.

The three students collaborated to research, annotate and build and model of the brain and spine in VR. Over the course of the unit of work, the students meticulously researched the brain and nervous system to develop an intricate model of a brain. The model, which was over 40 metres high in VR (Figure 1), included: a key or legend which indicated which types of Minecraft materials were used to represent different parts of the brain (Figure 2); a spine with spinal fluid encased within it with ribs and representations of nerves coming out from the ribs, and an elaborately constructed, detailed brain sitting atop the spine. On either side of the brain were viewing platforms so that if an avatar grew weary of flying, it could rest and take in the view. The sheer scale of the model and the extraordinary experience of flying up and around it in VR, led the teachers and I to describing it as a 'skyscraper of a brain'.

The brain itself was cleverly designed in two halves (Figure 3). One half was of transparent to show how certain functions within the brain, such as how neurons, worked. The students, who were knowledgeable about the engineering properties of Minecraft, added a 'T flip flop' circuit switch to the spine that they could turn off and on – they stated that this switch 'represented stimuli' which activated the 'neurons' in the brain. The impulses of the neurons were represented by the electrical dust called 'Redstone' which was regulated by 'repeaters' (the twin torch like material) (see Figure 4 and Figure 5).

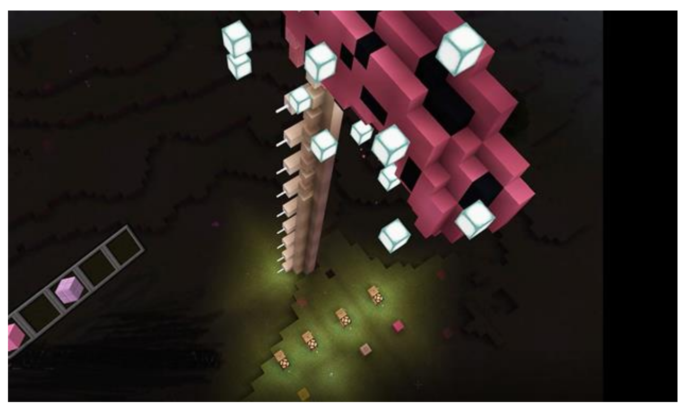

Figure 1: Screenshot of brain from above at night.

The solid half of the brain (Figure 6) had parts that were activated by the Redstone. Light cubes floating outside of the brain lit it up during night time (see Figure 1). The students stated that the lights represented thoughts emitting from the brain. The medulla was represented through the use of a wool textured Minecraft block, an idea that the students had gotten during an animal brain dissection that was part of the lab component of the unit of work. In addition there was spinal fluid going all the way through the centre of spine represented by Minecraft glass blocks and only visible if the outer casing of the 'bone' was removed.

Figure 2: Screenshot of part of the legend at the base of the model indicating the type material used to represent different parts.

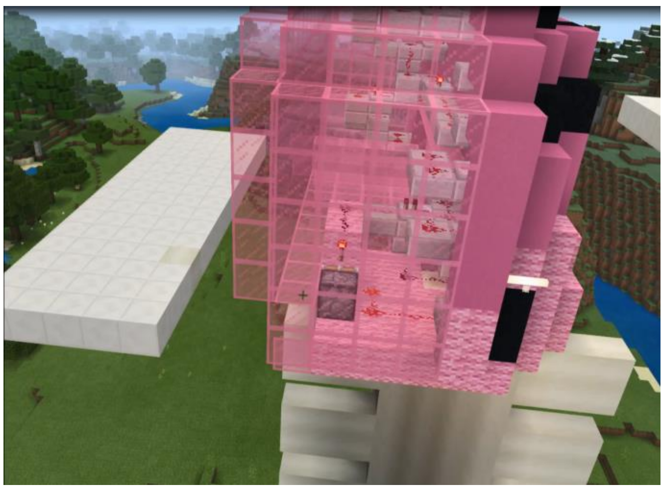

Figure 3: Screenshot of transparent (left) and solid (right) halves of the model

Figure 4: Screenshot showing student avatars in transparent side view of brain.

Figure 5: Screenshot showing close-up interior of transparent side of brain with Redstone 'neural impulses'.

At the conclusion of the unit of work, students took the teacher and researcher on a guided tour in VR. The tour was approximately 15 minutes in duration. During this time the students articulated detailed, accurate explanations of the parts and function of the brain and spine *from memory*. They did this unaided by notes or annotations (except for the simple legend at the model's base). During the tour, the researcher and the teacher asked questions designed to gauge comprehension and application of knowledge. The following transcribed extract of the tour illustrates a high degree of content mastery, as the students answer probing questions while in VR:

Student 1: So on the side of the spinal cord we have some of our nerve endings. Normally these would go on to other parts of the body like the heart and lungs, and if we move up a bit further we have got our ribs and they come up out the side of the back and they would be connected at the front by the sternum, obviously.
Student 3: Then there is the front side of the brain with the nerves and stuff….if you press the button (on the spine) the lights (in the brain) go on and off.
Teacher: So what's that meant to represent?
Student 3: The nerves in the brain. Go around the other side of it and see what's inside it. (Go to) the see-through bit.
Student 1: We wanted to use Redstone in our brain to represent the way that…nerves send signals out to the rest of the body….
Researcher: So what does the brain do?
Student 1: The brain is pretty much the central hub that controls the body. So, stimuli from the environment filters through the brain to help out body's out in appropriate ways. Say we get scared, our brain immediately sends us into…the flight or fright…actions…Here is some of the spinal juice (fluid) here going up the central column…of the spine.
Researcher: What does that do?
Student 2: It really protected the nerves and the bone protects it (the nerves) from hits and stuff like if you get hit in the back…it's protected by that gloop (spinal fluid)….
Student 1: …Then we learnt about the oblongata medulla (in a dissection lab).
Researcher: So is the medulla represented in the brain?
Student 2: Yep. So (it is) the pink wool bit.
Researcher: What does the medulla do?
Student 1: It's kinda like for balance, walking, so kinda day-to-day things that we don't think about….
Teacher: Like breathing….
Student 2: When we dissected the brain we saw the wrinkles in the medulla and we thought we could represent that pretty well using wool (blocks) because it's pretty wrinkled like the medulla.

Beyond knowledge acquisition (or content mastery) the students also reflected on the development of collaboration and problem solving skills, attributing these to the VR component of their learning. The following excerpt from a transcript of the guided tour illustrates these aspects of Deeper Learning from the student perspective:

Student 1: I've learnt a lot in this VR project but it's also made it much more engaging then writing notes down in a book. It makes you want to connect more with the learning that you are doing.
Researcher: So you only had (Minecraft) blocks to build with. What did you think of that?
Student 1: …Blocks don't really limit you. It just makes you think about it in a more creative way. So instead of making just spherical shapes you have to think about it more to get curves and stuff. Scale is a pretty big thing… so you need to build at an appropriate scale.
Researcher: Did you have to do a lot of problem solving, since we're talking about that?
Student 2: The first time we constructed the brain it was very small, low.
Student 1: The first time we constructed the brain (and saw it in VR) the front part was… pretty much down to the third row of the spinal (cord) and we thought that was really funny. And then we had to go back and fix it up… We pretty much got rid of the whole thing and then rebuilt the shape to make it look like the brain.
Student 2: We made an outline first before we built it… by putting the blocks on the edge… to make a decision on how it looked.
Researcher: How did you make decisions in your group?
Student 1: One of us put up and idea and then we'd all talk about it… I would most likely try to show an example of what our ideas would look like and then we would all agree on that and then if that didn't look right, like the first time we built the brain, we go back (and) help each other out and try to adapt what we built to out idea.
Teacher: What would you say was the most difficult part?
Student 2: Originally we had water going down the spine (as spinal fluid). The water (blocks) soaked everywhere… and so we got rid of the water entirely and (replaced) it with glass (blocks).
Researcher: What would you say to other students about learning in VR?
Student 1: Well, VR is a very immersive experience. And I feel like if you really take a liking to it, it can be a very useful tool when learning content because it's just not sitting down making you write words. It makes you actually interact with the things you are learning about.
Student 2: It makes you want to go further with it….
Student 1: It makes you want to keep building, keep making your ideas physical with VR…. You can actually see it right before your eyes…And it makes you feel like you've done something amazing at the end of it. Just being able to see this brain and all the work we put into it in front of our very own eyes.
Researcher: There were a lot of technical issues with this project. You weren't worried about those? You weren't demotivated?
Student 1: … the love for the VR project really just wanted us to keep trying to do stuff. When we first started we had a lot of issues with the accounts and the Worlds (referring to networking of Minecraft from the mobile device to the Oculus Rifts). But we kept trying to find ways to fix it. And I feel like it was all worth it at the end because we figured it out and we built this brain.
Student 2: Yeah and it looks really cool.

The students' perspective on their learning was supported by teacher observation. As the teacher, who was present during the guided tour, remarked:

> It's incredible. That's all you can say. They are talking at levels that are far beyond…the Stage 5 syllabus (the expected curriculum level), their understanding of it. The fact there were no notes (used during the guided tour) really showed not only do they have deep learning, but throughout the process where they have collaboratively problem-solved, they actually are having to have discussions where they have taught each other…as a teacher that's one of those fuzzy feelings that gets you through some of the more difficult times because… these kids got this (learning) experience and they are taking that away. They will be able to communicate that to other people in the outside world and that is ultimately the main goal.

Figure 6: Screenshot of the sold half of the brain with pale pink 'wool' representing the medulla region.

DISCUSSION: USING THE EXEMPLAR TO UNDERSTAND DEEPER LEARNING THROUGH VR

The exemplar detailed above provides an excellent case to illustrate and explore how sandbox VR environments can be used to promote Deeper Learning. This type of case pushes the use of immersive technology beyond the well-documented training (knowledge/skills recall and application) scenario. In this exemplar, an immersive technology is not so much a pedagogical 'tool' but a whole learning environment in which students can use the affordances of VR to 'actually interact with the things' they are learning about and this extends their higher order thinking, problem-solving skills and ability to collaborate, especially when combining bodies of scientific knowledge and creative endeavor.

The revised Bloom's taxonomy of thinking skills [23] (see Figure 7 last page of this paper) is a useful framework for interpreting the kind of thinking skills being developed by students. To use the categories (italcised below) of the revised Bloom's taxonomy of thinking skills, students demonstrated: (1) good recall (*remembering*) of facts about the brain without notes to prompt memory; (2) an excellent *understanding* of the function of the brain and its parts, assessed through expert questioning; (3) the ability to analyse (*analysing*) and apply (*application*) their research about the brain by *creating* a symbolically rich and engaging representation of it in a virtual model. Students were *evaluating* the experiential aspects of their model (especially when first designing their model which was originally too small).

While the revised Bloom's taxonomy is a powerful lens to gauge content acquisition and the types of thinking this can involves, it is perhaps less useful for understanding other aspects of learning, especially intra and interpersonal [21] facets. This is where the Deeper Learning framework proves beneficial. In the case of the exemplar, students demonstrated the following aspects of Deeper Learning by harnessing the learning affordances of VR:

Content mastery: Content mastery was evident in the depth of research conducted by the student and their ability to select, explain and symbolically represent information (abstract ideas made 'real' 'right before your eyes' in VR). To create the model of the brain they needed to deeply understand and integrate three bodies of knowledge from biology, to engineering (using the assets of Minecraft) to VR learning affordances (first order experiences, manipulation of size and scale, on reification). Two of these bodies of knowledge - biology of the brain and affordance of immersive VR - were new to the students (as was learning the technical aspects of working in immersive VR and getting the computing to work during the many times the network failed). In addition to mastering and integrating different bodies of knowledge, students applied what they had learnt during one context to another - the lab dissection of a brain showed them the medulla which they then researched and symbolically represented in their model. The ability to undertake self-directed activity in a fun virtual environment was highly motivating to the students, making them 'want to go further' with their learning in science and in VR. This is no mean feat given the difficulty of engaging many students from low income schools to undertake STEM subjects. The teacher remarked that: '(T)hese kids got this (learning) experience and they are taking that away. They will be able to communicate that to other people in the outside world and that is ultimately the main goal.' This meets a key aspect of the content mastery– the need to create learning experiences that equip students for life outside school.

Effective communication: One of the skills required for life beyond school, is effective communication. Students demonstrated high level communication skills during the project. They researched, analysed, wrote up and persuasively presented their model in ways that demonstrated Deeper Learning – teachers agreed that they were working at a curriculum stage higher than expected. During the guided tour, the flawless narration about aspects of their model and the processes involved in developing it, was exceptional. When asked comprehension question, answers were accurate and students assisted each other by adding extra facts or points of clarifications. The only mistake the students made was one of nomenclature when calling spinal fluid, 'spinal juice' or 'gloop'.

Critical thinking and problem solving: Students demonstrated critical thinking in their online research, selection of aspects of the brain to represent and in their decisions about how to symbolically represent fairly abstract ideas such as neural impulse, stimuli and thought (bridging the biological conception of the brain with the philosophical idea of the mind). The worked together to explore how to use the engineering properties of Minecraft to produce an innovative model. Their critical thinking is evident in the decision to split the brain into two halves: this cleverly allowed for an inside and outside view to be represented and experienced within VR. Such decision-making indicates a pedagogic mindset – critically engaging with how others might experience the model to learn the most about the brain. The students talked about ongoing problem solving during the design process and in tackling the many technical problems that plagued the project. This commitment to problem solving indicates true resilience, a key component of an academic mind set.

Collaboration: The students demonstrated high levels of collaboration in research, decision-making, task allocation, and problem solving. They responded to challenges as a team, motivating each other 'for the love of the VR project'. The collective pride in their work was evident. Immersive VR is sometimes conceived of as a 'lonely' experience; however, as this exemplar demonstrates, networked environments can provide highly engaging opportunities to build teams and develop collaboration skills.

Self-directed learning: These students valued the autonomy they were given during the formative assessment task. They got to choose which body organ they would research and how they would model and present it to others in VR. It must be remembered that students had fairly limited time to go into VR to develop and evaluate their models (pragmatically there were limited Oculus Rifts, limited lessons, and limited time in VR). They demonstrated high levels of metacognitive self-regulation by: planning and keeping on schedule; responding to design and technical issues in a timely and organised fashion; using their limited time in VR to maximum design effect; and spending time outside of VR to really think through how abstract ideas could best be represented and how others might experience this.

Academic mindset: The exemplar shows how students can engage with game-based learning and exploration of the learning affordances of immersive VR to persist in the face of challenges. Their engagement with abstract, symbolic representation and the pedagogic potential of the model indicates sustained higher order thinking. They felt immense pride in their accomplishment, making them want to go 'further' with their learning in ways that felt fun and authentic. The power of this type of immersive learning was clearly explicated by the student who stated: '(VR is a) very useful tool when learning content because it's just not sitting down making you write words. It makes you actually interact with the things you are learning about.'

6 CONCLUSION

The purpose of this paper has been to provide an in-depth exemplar designed to illustrate how VR can be used to promote aspects of Deeper Learning for high school students. The aim of applying the Deeper Learning framework to the exemplar is to demonstrate how immersive technologies for education can move beyond training purposes to encompass higher order cognitive and (oft-cited) 21st Century learning skills. The exemplar provides unique insights into how VR can be used for self-directed, collaborative and, perhaps most importantly, imaginative learning, even in high school science classes where creativity is not the norm (one would venture to say that this is also true of science in adult education settings). Harnessing the learning affordances of VR in a curriculum-aligned way and combining this with sound learning science, will be vital if immersive technologies are to extend into schools for transformative learning. This is especially important for students facing life challenges who should be provided with opportunities to explore immersive technology for content mastery and the development of communication, problem-solving and metacognitive skills. All students should be allowed to play with immersive technology to develop a love of learning that they can be genuinely proud of.

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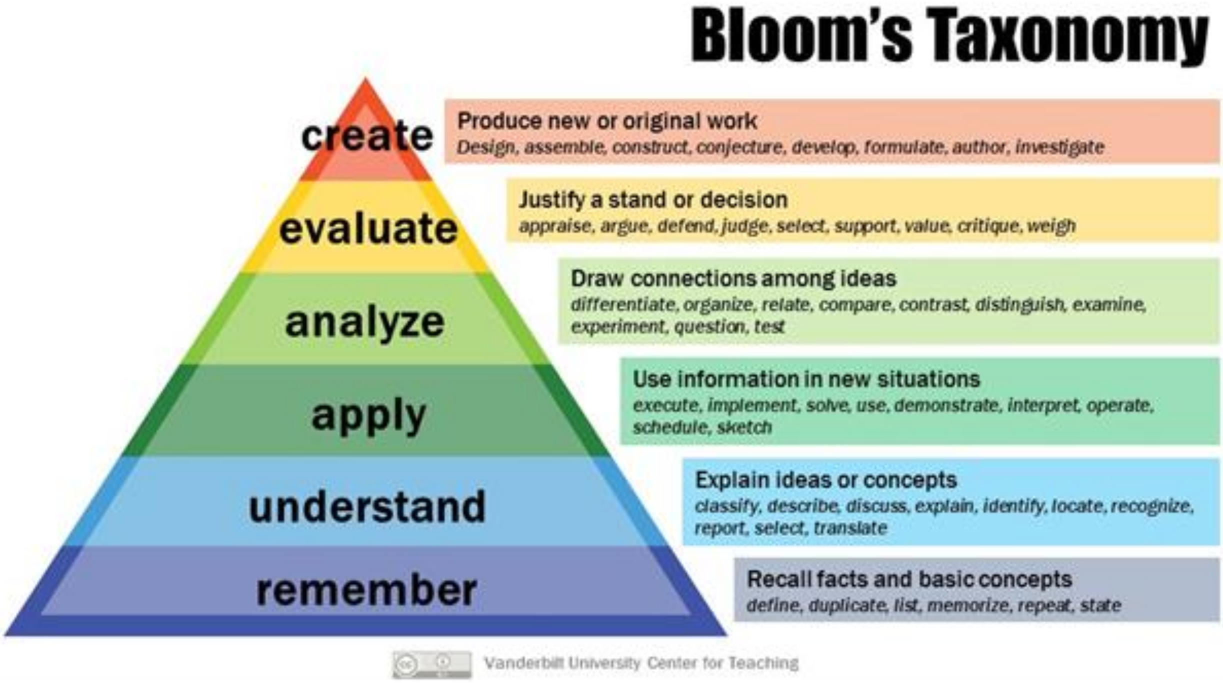

Figure 7: Revised Blooms Taxonomy
https://cft.vanderbilt.edu/guides-sub-pages/blooms-taxonomy/)