Southgate, Erica; Grant, Steve; Ostrowski, Simon; Norwood, Andrew; Williams, Monica; Tafazoli, Dara. 'School students creating a virtual reality learning resource for children'. IEEE VR 2022: the 29th IEEE Conference on Virtual Reality and 3D User Interfaces (Auckland, New Zealand 12 March, 2022).

School students creating a virtual reality learning resource for children

Erica Southgate*
University of Newcastle, Australia

Steve Grant
Trinity College Adelaide, Australia

Simon Ostrowski
Trinity College Adelaide, Australia

Andrew Norwood
Trinity College Adelaide, Australia

Monica Williams
Association of Independent Schools of South Australia, Australia

Dara Tafazoli
University of Newcastle, Australia

Abstract

There is increasing interest in shifting the focus of virtual reality (VR) in education from consumption activities to content creation where students can produce and share their own virtual environments. This paper reports on a pilot study where junior secondary science students created a 360° VR learning resource for primary (elementary) school students. The study used a mixed methodology, participatory research approach to explore learning outcomes for students. While technical set-up and time constraints affected the research, secondary students generally enjoyed the experience with the teacher observing good levels of engagement. The virtual environments produced by female students were graded higher than their male classmates. There was no increase in the content knowledge of primary school students after viewing the VR learning resource but most reported good systems usability. The pilot study indicated that having students create learning content for an authentic audience, such as younger students, is feasible with the potential to generate positive learning outcomes if organizational and time constraints can be addressed.

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

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

1 Introduction

Educators and researchers have become increasingly interested in empowering school students in active learning through new media content creation including learner design of immersive virtual reality (VR) [1]. Immersive VR is mediated via a head mounted display, colloquially called a headset (in this paper VR refers to immersive VR). Immersive VR is a commercially young technology with its integration into school classrooms still at an early stage [1] and with relatively scant research on the learning, curriculum, and pedagogical implications of deploying the technology with teachers and students [2]. As visions for, and investment in, the development of a metaverse proliferate, it is important for children and young people to be involved not just as consumers of VR but creators of it. Moreover, for VR content creation to be most meaningful, an authentic audience is required. The beauty of VR is that this audience can potentially be anywhere experiencing the VR product at any time. Despite the potential learning efficacy of school students as VR content creators, very little is known about how to facilitate this approach or its effect on educational outcomes.

Reflecting this focus on student learning through VR content creation, this paper reports on a pilot study in which junior secondary students (aged 13-14 years) created a 360° virtual reality learning resources to educate primary (elementary) school students (aged 11-12 years) on the science of energy. The paper begins by briefly reviewing the literature on VR and school education before providing an overview of the pedagogical frameworks informing the study. The curriculum and research design are then outlined. Results from, and the implications of the study, are discussed with a focus on the enablers and constraints to integrating VR into school classrooms in ways that move beyond a consumption approach.

2 Literature on Virtual Reality and School Education

A systematic review on VR in K-12 and higher education located 46 journal articles published between 2009 - 2020, of which 21 reported on research conducted in schools [2]. The review found that students in many K-12 studies could learn complex material through VR and develop creativity, problem-solving, and metacognitive skills. Only two of the 21 studies had a collaborative or participatory methodology, which assumed more than teachers simply supplying a class for researchers to undertake their study with.

There is evidence that consumption of VR experiences can have positive learning outcomes for elementary and secondary school students [3, 4] and even increase interest in science careers for secondary students, including girls [5]. Other research comparing the effects of learning the same material with VR versus another type of media or approach has more equivocal results [6, 7]. Most of the research in the field involves university researchers providing students with VR applications (either in their labs or at school) to measure impact on specified areas of learning such as content knowledge acquisition, procedural mastery, or influence on affective domains. Exceptions are work by Chang and colleagues [8] who document the positive effect of peer feedback on improving VR design, and Yiannoutsou et al.'s. [9] investigation of embodied pedagogy a non-visual VR mathematics application for children with visual impairment.

While research rarely involves teachers as genuine co-researchers or focuses on students as VR content creators, there are exceptions to this. The pilot study reported in this paper is part of the *VR School Study* (https://vrschoolresearch.com/), a project that has been investigating the integration of VR into primary and

* erica.southgate@newcastle.edu.au

secondary school classrooms, across subject areas, since 2016. The *VR School Study* differs from experimental, short-term intervention research as it is conducted over extended periods of time (6 months to 2 years) in classrooms with teachers as co-researchers. To date, it has yielded findings on the ethical and safe use of VR in schools [10], organizational facilitators and constraints to embedding the technology in classrooms, [11], peer-to-peer collaboration, metacognition, problem-solving, and creativity through VR content creation [1, 12]. A key focus across school sites and subject areas has been theorizing curriculum development and pedagogical practice that can leverage VR for deeper student learning [1].

3 STUDY BACKGROUND, AIM AND RESEARCH QUESTIONS

The pilot research is part of a two-year study into student 360° VR content creation in STEM-related secondary school subjects. This is a research collaboration between: the VR School Study (of which Southgate is the Chief Investigator); the Association of Independent Schools of South Australia (AISSA), which is the peak body for non-government (excluding Catholic) schools in that state; three school communities in South Australia (Trinity College, SEDA College and Pembroke School); and VRTY, a 360° VR start-up company based in Sydney, Australia. AISSA provided funding for the pilot study reported herein which was conducted at Trinity College. The pilot study reflected the participatory research model of the *VR School Study* which has teachers as co-researchers.

The aim of the pilot study was to explore student learning for science using 360° virtual reality (VR). The research questions (RQs) were:

1. What are the learning outcomes for junior high school students when creating a 360° virtual environment as a science educational resource for younger learners?
2. How do high school students experience and creatively leverage the learning affordances of VR when producing the science education resource?
3. What are the experiences of primary school students in using the VR education resource and does the resource increase scientific content knowledge acquisition?
4. How can 360° VR and its associated area of immersive storytelling be used in a curriculum-aligned way to facilitate scientific literacy communication?
5. What are the experiences of teachers in using 360° virtual reality in the classroom?

This paper addresses RQ1, RQ2 and RQ3.

4 PEDAGOGICAL FRAMEWORKS INFORMING THE STUDY

The conceptualization of learning in the study is based on the Deeper Learning framework which has six outcomes:

- *Content mastery*: Students acquire knowledge that they then apply or transfer to real world situations.
- *Effective communication*: Students develop and demonstrate active listening, clear writing, and persuasive presentation.
- *Critical thinking and problem solving*: Students consider different approaches to produce innovative solutions.
- *Collaboration*: Students work with peers, assume leadership roles, resolve conflicts, and manage projects.
- *Self-directed learning*: Students use teacher feedback to monitor and direct their own learning (this is a metacognitive skill).
- *Academic mindset*: Students feel a sense of belonging and the motivation to persist through their schoolwork. (https://deeperlearning4all.org/)

The study utilizes Southgate's pedagogical frameworks on VR for education [1]. She argues that while industry and education stakeholders debate technical differences between 3 Degree of Freedom (3DoF) and 6 Degree of Freedom (6DoF) VR, they pay less attention to differentiating the pedagogical uses of the technology. To this end, she suggests that VR applications can be variously conceived of as: (1) an episodic (usually on-off) learning experience that act as a stimulus in a lesson; (2) an instructional tool for learning a bounded set of declarative or procedural knowledge (procedural simulations can be an example of this); (3) a total learning environment such as a fully functioning virtual lab; or (4) a form of new immersive digital media for student content creation. The study reported in this paper draws on the concepts of VR as a form of new digital media as secondary students created a VR educational resource, and, as an episodic (one-off) learning experience for primary school students experiencing the learning resource created by their older peers.

Southgate [1] also provides a non-hierarchical typology of VR environments differentiated by the potential for learner interaction and autonomy when using the environment or application (Table 1).

Table 1: Typology of immersive VR environments by degree of learner interaction and autonomy.

Swivel	A ready-to-use environment relying on a relatively stationary learner rotating their head/body to experience the surrounding virtual world.
Explore	This type of ready-to-use environment allows for unguided or guided exploration either through a handheld controller or gaze to explore a fully simulated or 360° photograph or video environment.
Discover	An environment with embedded, fully interactive activities and tools to enable learners to independently undertake learning and assessment tasks that are usually curriculum or competency-based.
No Code Create	Sometimes called a sandbox, the learner is supplied with an authoring or content creation tools which allows them to produce their own 3D objects, models, designs, prototypes, and artwork without needing to code.
Code to Create	The learner uses game engines (e.g., Unity, Unreal) and other programs that require coding to create virtual objects/worlds.
Social VR	Mainly commercial (mostly free to enter) permanent 3D virtual worlds that allow people in 3D (and sometimes 2D mode) to socialise, play games, and meet for leisure and learning.

The pilot study used the 'no code create' 360° VR platform, VRTY (https://vrty.io/) because students do not need any coding knowledge to be able to create foundational, interconnected 360° video or still photo scenes, storyboard their creations, and embed a range of media (text, pictures, video, gifs and sound files) into these scenes. The platform was useful because students could easily share their VR environments with others using a URL or QR code. In addition, the platform gave students the option to interact with the virtual creation on-screen or in a VR headset: This is important because some students do not like the feelings of immersion in headsets or experience disorientation or cybersickness in VR. This accessible type of 360° VR offered a fun and interesting entry point for content creation that provided appropriate cognitive and creative challenge for students as they select existing or photograph new foundational 360° video or still scenes, develop linear or non-linear narratives, and produce additional content that can be embedded into the scene to tell a learning story.

Our focus on students as VR content creators for other students had the potential to develop the Deeper Learning outcomes of:

- Content mastery – secondary students must know their content to produce a learning resource for other students.
- Effective communication - the VR learning resources needed to communicate scientific facts to an authentic audience in an engaging and age-appropriate way.
- Problem-solving and collaboration - students needed to work together as a whole class to create the foundation scene and make decisions about what to include in it and their customized version of the virtual environment, and they had the option of pairing up for the customized task.
- Self-directed learning - students would work relatively independently of the teacher to develop their customized virtual educational resource and needed to reflect on how a younger student might experience and learn from the resource (develop a metacognitive awareness).

5 CURRICULUM FOR THE STUDY

The VR content creation task was integrated into a curriculum unit of work on energy for Year 8 science. This aligned with the Australian National Curriculum outcome for students to understand that: 'Energy appears in different forms, including movement (kinetic energy), heat and potential energy, and energy transformations and transfers cause change within systems (ACSSU155)'. There was a total of 6 x 50-minute lessons using the VRTY platform over 2.5 weeks and students also did homework. The teacher facilitated a whole class brainstorm on types of energy that could be illustrated in a 360° still photo of the playground. They staged the scene and photographed it with a Insta360 camera. They photographed the scene twice as the first one was critiqued during a whole class discussion. Using the second scene as a foundation, students worked independently to research and create other content to embed into it to build an educational resource on energy for Year 6 students. Under the guidance of the teacher, they also developed a knowledge quiz that the Year 6 classes would complete before and after experiencing the resource. It was envisaged that after this initial Year 6 viewing of the educational resource that Year 8 students would have access to the pre/post quiz results and audio recorded comments from the younger students to iterate on the design of their educational resource based on this feedback. However, due to delays in technical set-up and curriculum constraints, this did not occur as time ran out for the complete implementation of the project. Two Year 6 classes did view one student's VR educational resource in a one-off 50-minute lesson.

6 SETTING, PARTICIPANTS AND METHODOLOGY

The study was conducted at Trinity College, an independent (non-government), low-fee Anglican College. Trinity College has five school campuses: four catering for kindergarten to Year 10, plus a senior campus (Years 11 and 12 students). The College is predominantly of middle socio-economic status and sits on the average band for the Index of Community Socio-Educational Advantage [13]. A quarter of students have a language background other than English, with 2% identifying as Indigenous. Parental/carer consent and child assent was obtained for the research, and the study approved by the University of Newcastle Human Ethics Committee (Approval No. H-2017-0229).

The VR content creation part of the study was conducted with a mixed-ability Year 8 secondary science class with twenty-three consenting/assenting students (11F, 12M) aged 13-14 years. Of those that answered the prior VR experience question, all had some experience (Table 2) but did not mention VR content creation when describing this offering gaming and passive leisure VR (e.g., virtual rollercoaster ride) as examples of prior use. Male students were more likely to have used VR more than 10 times.

Table 2: Number of times Year 8 students had used VR prior to research.

	F (n=11)	M (n=12)
No response	3	1
Never	0	0
1-5 times	8	6
6-10 times	0	0
More than 10 times	0	5

Fifty-three Year 6 students (23F, 28M, 2 Other gender identity) provided information on VR experience prior to the study (Table 3).

Table 3: Number of times Year 6 students had used VR prior to research.

	F (n=23)	M (n=28)	Other (n=2)
No response	1	2	-
Never	6	6	-
1-5 times	14	12	-
6-10 times	1	3	1
More than 10 times	1	5	1

The research was mixed methodology with a range of approaches and instruments used to collect data as described in Table 4.

Table 4: Student group by foci, method and type of analysis

Group	Foci, instrument, analysis
Year 8	~ Experience of creating 360° educational resource for other students – Pre/mid/post student reflection sheets (post reflection was missing) and videoed vox-pop interviews in class. Qualitative thematic analysis [14] ~ Educational quality of the 360° video resource – Teacher-developed assessment rubric.
Year 6	~ Experience of using VR educational resource (software and technical system) – Child-friendly System Usability Scale (SUS) by Munsinger and Quarles [15] adapted from Brook's widely used survey [16]. Analysed using scoring framework developed by Brooks [17] with simplified adjective descriptors from (UIUX Trend, N.D https://uiuxtrend.com/measuring-system-usability-scale-sus/#interpretation) ~ Experience of using VR educational resource – Qualitative voice recorded comments post VR experience. Thematic analysis [14]. ~ Content knowledge acquisition – 13 question multiple choice quiz developed by Year 8 students with teacher – pre and post administration. Descriptive statistical analysis.

7 RESULTS

7.1 Secondary school students

The secondary (Year 8) student content creation component of the study revealed both the potential of the technology for learning and tensions which exist when embedding VR into classrooms for the first time [11]. There were delays in the technical set up of the project which meant the Year 8 students did not have access to the smart phones and VR headsets that would allow them to develop their virtual environments with an understanding of immersive potential of the technology. They did not have access to the smart phones that are used not only to experience VR but create content for the foundation environment (e.g., original photos, videos and sound files). The project ran out of time due to the curriculum demands of science, which meant that the teacher needed to move on to another topic which did not allow the Year 8 students an opportunity to iterate their design based on user Year 6 feedback. The time issue impacted the collection of the post-project Year 8 student reflection data with students providing pre and mid reflections only. The teacher did, however, observe that many students felt confident that they could independently undertake the VR task (half decided to work by themselves) and that there was a "sweet spot" in terms of the intersection between the relative comprehensibility of the energy topic and students' confidence in using the VRTY software to problem solve. The teacher made several observations regarding student understanding of the task and, interestingly, on how some seemed to experience a state of 'flow" when working on it:

> "It's a spectrum. Some students at the forefront of their minds is this (VR project) is about educating Year 6s and that's sort of like your stronger student who keeps that focus. (Academically) weaker students, at the other end (of the spectrum) as just trying to make this VR thing and they are not thinking… about is it suitable for a Year 6? All their cognitive load is just on making something…. The majority of students are engaged on the task…When given the option to work with a partner or by themselves, I'm slightly surprise how many people opted to work by themselves and not with a partner…. (I'm) positively surprised. Which is good. If students choose to work by themselves there is a degree of confidence (and) a degree to which they feel they can succeed… There's a nice balance with this between the energy topic not being too deep…. It's more about identification of these energy types and being able to explain but then about them identifying them in a new sense that's less traditional than a photo or pre-made picture… It really nails the zone of proximal development where they need to keep track of different types of energy but it's not too many, they are all easy enough to understand…. And the software means that they need to be on their toes… and it get them to a point where they are in a state of flow, where they are losing track of time, they are kind of problem solving (with the software) – there are little problems, but they can solve it – so we have luckily hit a sweet spot in that proximal development zone." (Teacher interview, 25 June 2021).

Vygotsky's [18] zone of proximal development refers to the current level of functioning compared to what is possible if a learner is assisted. In this case the comprehensibility of the topic (it not being too difficult) combined with the reasonable intuitiveness of the software (with teacher guidance when called for) created a 'positive' learning experience evidenced by 'flow' [19]. Flow refers to a sense of absorption in an activity which is linked to challenge, control, enjoyment in digital learning tasks [20]. The mid-project reflections of some Year 8 students supported the teacher's observation on learner engagement:

> "I think (using VR) helps students engage more in their learning and actually want to learn more because it's something that's intriguing to them using more modern-day technology instead of reading articles and writing all sorts of PowerPoints and documents and stuff like that." (Male student).

> "Learning with VR is a lot easier and funner than learning with a Powerpoint (sic)." (Female student).

The teacher's assessment rubric had criteria for inclusion, identification, and explanation of types of energy in the 360° scene. It did not assess creativity. Based on the rubric, over 50% of students scored in the top range (A or B) with females generally achieving higher grades than males (Table 5).

Table 5: Year 8 grade range

Grade	F (n=11)	M (n=12)
A	1	2
B	8	2
C	1	6
D	0	2
E	1	0

Figure 1: Screenshot of foundation scene developed by teacher and students with energy markers

As time was running out for the project the teacher selected a quality 360° scene to use in the Year 6 component of the research. The selected scene included pop up facts, pictures and animations on each type of energy (Figures 1 and 2). Most other student 360° scenes included text and pictures but not animations.

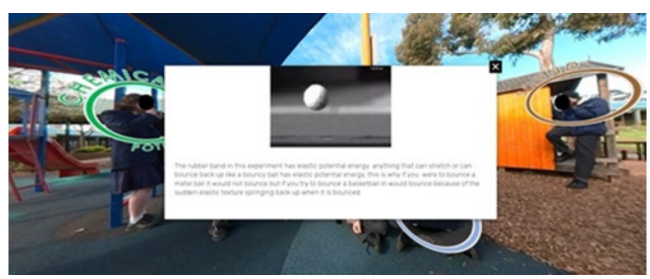

Figure 2: Screenshot example of pop-up energy markers on potential energy with animated ball that bounced up and down.

7.2 Primary (elementary) school students

The primary school student experience of the Year 8 VR learning resource was explored using: a pre-post content knowledge quiz comprising 13 multiple choice questions developed by the Year 8 class; a child-friendly version [15] of the Systems Usability Scale [16]; and student audio comments recorded through the school's learning management system during the VR lesson.

Based on their pre- and post-test scores, a paired sample t-test was conducted. This showed no significant difference between students' content knowledge about energy before and after using the VR resource: pre-test (M= 7.26, SD= 1.83) to post-test (M= 7.66, SD= 1.76). We cannot explain Year 6 students reasonably high prior knowledge on the topic, but the short (one lesson) exposure time to the learning resource in the exciting atmosphere of the lesson may not have been optimal for declarative knowledge acquisition.

Over 70% of Year 6 students provided a high rating on the System Usability Scale (SUS) descriptive adjective version (34% as excellent and 38% as good) with the remainder having more difficulty in using the system (21% poor and 7% awful). A SUS score of 68 and above indicates acceptable system usability [16]. Students who had previously used VR scored higher on the SUS; however, many with minimal exposure also rated system usability at an acceptable or higher level (Figure 3).

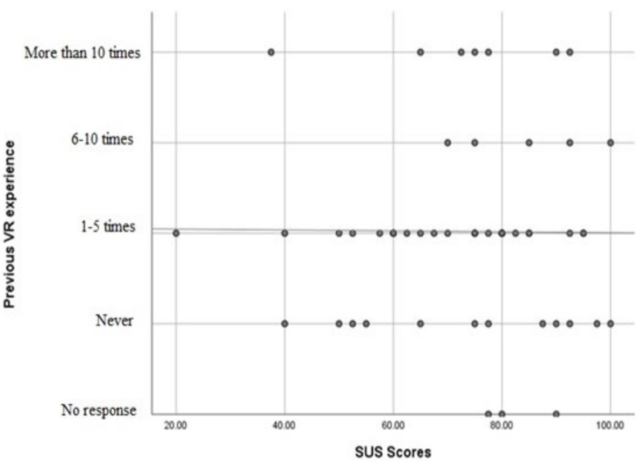

Figure 3: SUS score by Year 6 student previous VR experience

As the usability results suggest, there were students who provided audio recorded comments on the VR experience that were very positive such as: "really fun", "helpful", "pretty good", "cool", "very educational" and a great learning experience" that "grasps kids' attentions", and "makes the education better". As one student remarked: "I hope you do use this (with other students) because if you don't, you just missed the big opportunity". Some learners did find the VR "hard" and "complicated" and described feeling "dizzy" and "motion sick", having "a headache" and "blurry eye-sight".

8 Discussion

Research question 1 focused on secondary student learning outcomes and question 2 on how these students creatively leveraged the affordances of VR in designing a learning resource for younger students. Findings related to these research questions need to be considered within the time and technical constraints encountered during the pilot study. The project was originally conceived as an iterative and immersive design process with Year 8 students having access to mobile phones and VR headsets during the development of their virtual environments, with Year 6 user experience feedback allowing the older students to improve upon their design. However, Year 8 students did not have access to the equipment when designing their VR scene and so were unable to develop their own sound, video, and image files to embed into the foundation 360° scene and time-related curriculum constraints curtailed the design cycle. Such constraints are not unusual when integrating VR into schools [11]. In terms of research question 2, the creative potential of the project was only partially realized. Students, with their teacher, did collectively (as a whole class) apply existing content knowledge about types of energy to envisage how it might be represented. They imaginatively and collaboratively re-created this in a 360° photograph of the playground that formed the foundation for their learning resource (in fact they re-photographed the scene after a class discussion critiquing its educational potential and this indicated guided critical thinking). However, without access to the immersive VR experience during the design process students were restricted in their ability to understand how to leverage the spatial features of the technology for delivering information and optimizing user experience.

In terms of research question 1, despite constraints, the teacher did observe that many students were absorbed in the VR task to the point of experiencing a flow state and, the mid-project student written reflection were generally positive. As a mixed ability class, it is not surprising that a range of grades were recorded for the task, although more than 50% of students were assessed in the higher range (A or B).

Females generally scored higher than males on the rubric and this may be due to the combination of accessible 'no code create' software that can build confidence in using new technology and the creative, communicative nature of the task. This is supported by research indicating that the creative outputs of girls can be enhanced through VR [21], although other research does not show this effect [22]. Further investigations on gender and learning with different types of VR is required as using new technologies creatively may be part of the solution to attracting girls to school technology subjects which show male gender bias, nationally [23] [24] and internationally [25]. In the next stage of the research, the team will work to integrate criteria for creativity when developing STEM rubrics as this should complement the assessment of content mastery and may reveal what underpins such gender dynamics.

Research question 3 focused on the experiences of primary school students in using the VR learning resource. Content knowledge acquisition did not increase amongst primary school students, and this may be due to the relatively short exposure time to the VR resource, the exciting condition under which the resource was experienced (there was a real buzz in the Year 6 classroom which may have been distracting), or the design of the resource itself. The VR content knowledge quiz designed by Year 8 students for their younger peers appears to have been relatively easy (with most getting around 50% correct at the pre-VR exposure stage. This suggests that it might have been a good idea if the primary school teacher provided feedback on the quiz during its development. The primary school student generally enjoyed the VR experience although some commented on physical discomfort. The VRTY platform allows for immersive (headset) as well as screen-based viewing and, in retrospect, it may have been better to give the Year 6 students a more explicit choice of how they wanted to experience the learning resource. The Year 6 usability survey results indicated most children had a positive experience in using the system but that there were still some that needed assistance. The overall good usability rating is a reassuring result for the research team. In future studies we are interested in understanding educational VR content creation for authentic learner audiences and the approach of having older students develop VR learning resources for younger learners holds promise in terms of developing and demonstrating the Deeper Learning objectives of content mastery and critical thinking as well as metacognitive knowledge and skills.

9 Conclusion

This paper reports on a pilot study that utilized 360° VR content creation for Deeper Learning in secondary and primary school science. The study highlighted both the educational potential of the technology and contextual constraints that limited the full realization of the project. Early attention to technical set-up and carving out enough curriculum time to embed VR for peer-to-peer educational content creation is key to ensuring success in the classroom. The pilot study does suggest that providing opportunities for secondary students to use a type of accessible 'no code create' VR platform can create positive learning experiences especially for girls who are underrepresented in the information and communication technology subjects.

References

[1] E. Southgate. *Virtual reality in curriculum and pedagogy: Evidence from secondary classrooms*. Routledge, 2020.

[2] N. Pellas, S. Mystakidis and I. Kazanidis. Immersive virtual reality in K-12 and higher education: A systematic review of the last decade scientific literature. *Virtual Reality*, Jan 5:1-27, 2021.

[3] J. Calvert and R. Abadia. Impact of immersing university and high school students in educational linear narratives using virtual reality technology. *Computers & Education*, 159: 104005, 2020.

[4] B. Wu, X. Yu and X. Gu. Effectiveness of immersive virtual reality using head-mounted displays on learning performance: A meta-analysis. *British Journal of Educational Technology*, 51(6):1991-2005, 2020.

[5] G. Makransky, G. B. Petersen and S. Klingenberg. Can an immersive virtual reality simulation increase students' interest and career aspirations in science? *British Journal of Educational Technology*, 51(6):2079-2097, 2020.

[6] J. Parong and R. E. Mayer. Learning science in immersive virtual reality. *Journal of Educational Psychology*, *110*(6):785-797, 2018.

[7] G. Makransky, N. K. Andreasen, S. Baceviciute, and R. E. Mayer. Immersive virtual reality increases liking but not learning with a science simulation and generative learning strategies promote learning in immersive virtual reality. *Journal of Educational Psychology*, 113(4):719-735, 2020.

[8] S. C. Chang, T. C. Hsu and M. S. Y. Jong, Integration of the peer assessment approach with a virtual reality design system for learning earth science. *Computers & Education*, *146:*103758, 2020.

[9] N. Yiannoutsou, R. Johnson and S. Price. Non-visual virtual reality: Considerations for the pedagogical design of embodied mathematical experiences for visually impaired children. *Educational Technology & Society*, 24(2): 151-163, 2021.

[10] E. Southgate, S. Smith & J. Scevak. Asking ethical questions in research using immersive virtual and augmented reality technologies with children and youth. In *Proceedings 2017 IEEE Virtual Reality* (VR), pages 12-18, 2017.

[11] E. Southgate, S. Smith, C. Cividino, S. Saxby, J. Kilham, G. Eather ... & C. Bergin). Embedding immersive virtual reality in classrooms: Ethical, organisational and educational lessons in bridging research and practice. *International Journal of Child-Computer Interaction*, 19:19-29, 2019.

[12] E. Southgate. Virtual reality for Deeper Learning: An exemplar from high school science. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, pages 1633-1639, 2019.

[13] The Australian Curriculum, Assessment and Reporting Authority (ACARA). *Guide to understanding the Index of Community Socio-educational Advantage (ICSEA).* ACARA, 2020.

[14] V. Braun and V. Clarke. *Successful qualitative research*. Sage, 2014.

[15] B. Munsinger and J. Quarles. Augmented reality for children in a confirmation task: Time, fatigue, and usability. In *25th ACM Symposium on Virtual Reality Software and Technology*, pages 1-5, 2019.

[16] J. Brooke. SUS: a retrospective. *Journal of Usability Studies*, 8(2):29-40, 2013.

[17] J. Brooke. SUS - A quick and dirty usability scale. *Usability Evaluation in Industry*, 189(194):4-7, 1996.

[18] L. S. Vygotsky. *Mind in society: The development of higher mental process*. Harvard University Press, 1978.

[19] Csikszentmihalhi, M. *Finding flow: The psychology of engagement with everyday life*. Hachette, 2020.

[20] B. Choi and Y. Baek. Exploring factors of media characteristic influencing flow in learning through virtual worlds. *Computers & Education*, 57(4):2382-2394, 2011.

[21] H. C. Lin, Y. Chang and W. H. Li. Effects of a virtual reality teaching application on engineering design creativity of boys and girls. *Thinking Skills and Creativity*, 37, 100705. 2020.

[22] Z, Yu. A meta-analysis of the effect of virtual reality technology use in education. *Interactive Learning Environments*, Online First, 1-21, 2021.

[23] J. Kennedy, F. Quinn, F and T Lyons. (2018). Australian enrolment trends in technology and engineering: putting the T and E back into school STEM. *International Journal of Technology and Design Education*, 28(2):553-571, 2018.

[24] C. Lang, J. Fisher, A. Craig and H. Forgasz. Computing, Girls and Education: What we need to know to change how girls think about information technology. *Australasian Journal of Information Systems*, 24, https://doi.org/10.3127/ajis.v24i0.1783, 2020.

[25] U. N. Sultan, C. Axell and J. Hallström, J. (2019). Girls' engagement with technology education: A scoping review of the literature. *Design and Technology Education: An International Journal*, 24(2):20-41, 2019.