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Exploring participant engagement during an astrophysics virtual reality experience at a science festival

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ABSTRACT
Virtual reality applications turn abstract concepts into experienceable phenomena and present exciting opportunities to transform science education and public outreach practices. While research has started to look into the affordances of virtual reality (VR) in the formal science education context, the potential of these technologies to enhance public engagement with science is largely unexplored. To improve the way that VR may be used in informal learning and public outreach contexts, the purpose of our study was to undertake evidence-based investigations that shed light onto the relationship between VR and public engagement. Aiming to identify and develop the benefits of VR technologies, we propose a conceptual framework for engagement with VR at a science festival that comprises four aspects of participant activity: immersion, facilitation, collaboration, and visualisation. This framework guided the research design of our exploratory case study of one VR tour at a science festival. Data included visitor surveys, video recordings, VR screen captures, and focus group interviews with outreach and science professionals. Our findings reveal important ways that VR supports visitor engagement at a science festival. More generally, these findings and our framework contribute to the ongoing efforts of engaging the public with science in more diverse informal learning contexts.

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KEYWORDS
Virtual reality; astronomy education; informal science education; public outreach; science festival; engagement; immersive learning; visualisation

Introduction
In recent years, awareness of the importance of public engagement with science has increased. Based on the understanding that science education and public outreach (EPO) efforts should be recognised as a central component of all scientific activity, scientists are putting increasing emphasis on broad dissemination as part of their research projects (Grimberg et al., 2019; Jensen & Buckley, 2014; LSC EPO group, 2017; NANO Grav, 2019). In line with these efforts, science educators try to identify best practices to inspire, inform, engage, and educate a variety of audiences (Bondell & Myers, in press; NANO Grav, 2019). By pushing the boundaries of what is possible in the real world, emerging new technologies such as virtual reality (VR) present exciting opportunities to transform EPO practices.
While science educators have started to explore the affordances of VR in the context of formal science learning in classrooms and university laboratories (Evangelou & Kotsis, 2019; Ibáñez & Delgado-Kloos, 2018; Olympiou & Zacharia, 2012; Southgate et al., 2019), the potential of these technologies to transform EPO practices is largely unexplored. What we need are evidence-based investigations into the opportunities and challenges of employing VR-technology in the service of EPO. An important opportunity may be that the use of VR enhances public engagement with science. However, little is known about the relationship between the use of VR and public engagement and how we might develop and identify the benefits of VR.

The purpose of our study was to explore public engagement with science through the use of VR. Wishing to improve the way that VR might be used in informal learning and public outreach contexts, we set up our research design as an exploratory case study of one VR tour at a science festival. Specifically, this study utilised the setting of a public science festival to explore participant engagement with an astrophysics VR-experience in the form of a virtual tour of the Universe. We asked: **How do visitors engage with a virtual reality tour at a science festival?**

In the following section, we review the literature on VR in science education and public outreach, present science festivals as informal learning spaces that provide interesting opportunities to engage the public through VR experiences and describe astrophysics as a particularly active area of EPO efforts. We then synthesise the literature and present the conceptual framework that we developed to inform the research design.

**The potential of virtual reality in science education and public outreach**

Technologies that merge real and virtual worlds have the potential to deeply transform learning and instruction by connecting new perceptual experiences to abstract concepts (Lindgren & Johnson-Glenberg, 2013; Southgate et al., 2019). Since advancements in technology and education drive change in each other, researchers have become interested in studying both the benefits and limitations of physical and virtual learning environments (Merchant et al., 2014; Pande & Chandrasekharan, 2017; Potkonjak et al., 2016).

A core aspect of technology-mediated education is the underlying idea that visualisations are powerful tools for science learning (López & Pintó, 2017; Smetana & Bell, 2012). However, there is a broad spectrum of potential advantages of using VR beyond merely providing new visualisation opportunities (Smetana & Bell, 2012). By creating contexts that are typically far from our natural sensory capabilities or that are not accessible in the real world, virtual reality resources have vast potential to support the communication and understanding of scientific concepts (Bakas & Mikropoulos, 2003). By promoting spatial abilities, practical skills, and inquiry learning, virtual worlds offer educational affordances that are particularly useful in learning domains of science (Ibáñez & Delgado-Kloos, 2018; Potkonjak et al., 2016). Moreover, VR has the potential to make learning and instruction more interactive, authentic, engaging, and playful (Lindgren & Johnson-Glenberg, 2013; Ramasundaram et al., 2005). At a deeper level, these technologies can transform interactions with abstract scientific visualisations into engaging and embodied experiences. When engaged through VR, learners are not merely an external observer or interpreter of the visualisation. Instead, they are able to navigate, manipulate and make sense of the representation from within.

Mixed and virtual reality technologies typically involve the fluid interaction of real-world objects, such as our bodies, with some type of digital, often head-mounted, display (Lindgren & Johnson-Glenberg, 2013; Southgate et al., 2019). To date, there is no accepted definition of highly immersive virtual reality (Southgate et al., 2019). However, two features are common to technologies that merge physical and virtual worlds: first, an interface that is responsive to the movements of a participant and second, an immersive technology experience that places the learner into the context to be learned (Lindgren & Johnson-Glenberg, 2013). These two features are closely linked to the notions of immersion (the ability to move and interact within the technology-mediated environment) and presence (the sense of ‘being there’) (Southgate et al., 2019).
Naturally, as the use of technology-mediated forms of learning gains momentum, VR continues to create new contexts for research in science education. Nevertheless, the potential of VR in the context of EPO remains mostly unexplored. In this study, we address the context of VR education and public outreach at a science festival so that the findings can inform how VR can be used effectively in EPO practices.

**Science festivals as a setting to engage the public through VR**

Science festivals are informal learning spaces where science education, science communication, and public outreach come together in an authentic and direct way. The recent years have seen a global growth in the development of public science events leading to an increased interest to compare different kinds of events and identify common themes (Bultitude et al., 2011; Canovan, 2019; Jensen & Buckley, 2014). Because of their socially active and transitory nature, science festivals provide unique settings to gain insights into the successes (and failures) of engaging the public through VR-technology. Though VR is currently being explored for its potential to support learning in both informal contexts like museums (Carrozzino & Bergamasco, 2010; Cheng et al., 2011) as well as in more formal settings like classrooms (Markowitz et al., 2018; Southgate et al., 2019), science festivals present a distinctive but underexplored context with its own advantages. There are several reasons for the distinct nature of science festivals.

First, science festivals are socially active because they target a broad public audience (van Beynen & Burress, 2018). Due to the diversity of the audience, researchers can study how different groups of visitors with different backgrounds and expectations interact and engage with VR-technology. This diversity is an advantage to traditional educational research that often looks at affordances of VR-technology limited to one specific age group such as in science classrooms (Southgate et al., 2019). Moreover, visitors have agency in deciding what constitutes a successful science experience for them because they have chosen to visit the science festival. In response to these diverse expectations, science festival providers try to engage visitors by designing activities that facilitate experiences and outcomes beyond the development of science knowledge (van Beynen & Burress, 2018). VR-technology has the potential to provide such experiences that promote curiosity, interest, and fun in addition to conveying science content knowledge (Lindgren & Johnson-Glenberg, 2013; Southgate et al., 2019).

Second, science festivals are transitory because they involve the coming together of people, furnishings, technology, emotions, etc. (Davies, 2019). This transitory nature provides rich possibilities to create emotional connections with complex and abstract scientific concepts (Grimberg et al., 2019) and leads to different interactions than one finds in other informal learning spaces (Bultitude et al., 2011; Davies, 2019; van Beynen & Burress, 2018). Activities at science festivals are characterised by short-term interactions that often arise spontaneously in collaborative settings. Because these festivals are temporary, typically lasting only a few days, they may be given the status of a special and unique event which supports intense engagement (Jensen & Buckely, 2014). This contrasts with museum exhibitions which may run for months or longer.

Third, science festival activities are often facilitated by science professionals, which allow visitors to interact directly with experts on current topics of scientific research (Jensen & Buckley, 2014). Such experts have in-depth knowledge and enthusiasm about the specific topics they share with visitors. These forms of interaction are well suited for VR-activities that are often designed as guided tours that visitors can take either individually or in groups.

**Astronomy education and the virtual Universe**

The first observation of gravitational waves in 2015 has led to an increased public interest in astronomy and has brought a new educational focus on the field as well (Key & Hendry, 2016). This focus presents enormous opportunities and substantial responsibility for science educators because
astronomy is a learning domain in which concepts are notoriously difficult to visualise (Azevedo & Mann, 2018; De Hosson et al., 2014; Eriksson et al., 2014; Kersting, 2020; Kersting et al., 2018). We have no direct experience of astronomical phenomena such as gravitational waves. Therefore, these phenomena often present learners with imaginative challenges (Steier & Kersting, 2019). Moreover, the nature of many astronomical phenomena seems to be counterintuitive or even contradictory to our previous knowledge of the world (Kersting et al., 2018). Besides, topics of astronomy challenge us because of the vast scale of the Universe and its multidimensionality (Bakas & Mikropoulos, 2003; Conlon et al., 2018; Eriksson et al., 2014; Kersting, 2020).

Because of the abstract nature of the scientific concepts, VR is well suited to elevate EPO practices in astronomy. Through its Education and Public Outreach programme, the Australian Research Council Centre of Excellence for Gravitational Wave Discovery (OzGrav) embraces the opportunities of gravitational astronomy1 using virtual or augmented reality applications. The OzGrav EPO team develops outreach programmes, school incursions, and instructional materials to capitalise on the historic first detections of gravitational waves and to educate, engage, and entertain the public with astronomy (Bondell & Myers, in press).

In this study, we focus on the OzGrav VR tour Bigger Than Big, which brings the invisible Universe to festival visitors through wireless head-mounted VR-headsets. Each headset is connected to a shared computer so that groups of visitors can take the tour simultaneously. The headsets allow for movement outside of a fixed position to give visitors a sense of presence and immersion while they lean into or away from the scene. The tour provides different scenes, each of which invites visitors to explore different astrophysical phenomena such as the planets in our solar system or the scale of cosmic objects. Science professionals cycle through the scenes and guide visitors through the tour.

### A conceptual framework for engagement with virtual reality at a science festival

The purpose of this study is to explore participant engagement with a VR installation at a science festival. While many science educators share the conviction that ‘in an increasingly scientific and technological world, the need for a population engaged in and appreciative of science and technology has never been greater’ (Shaby et al., 2019b, p. 1), the study of engagement has been hindered by a lack of consensus on the different types of engagement (Reschly & Christenson, 2012). Since engagement is a broad and multidimensional concept comprising observable behaviour, internal cognition, and emotions (Shaby et al., 2019c), different researchers have conceptualised engagement in many different ways depending on the context and focus of the science learning. Although science educators have undertaken interesting attempts to approach the notion of engagement in the context of science museums and science centres (Faria & Chagas, 2012; Shaby et al., 2019c, 2019b; Shaby et al., 2019a; Yoon & Wang, 2014), few studies have looked at engagement in the context of science festivals.

In fact, recent studies that do address engagement at science festivals hardly define or specify their theoretical approach to engagement (Canovan, 2019; Grimberg et al., 2019). An exception is van Beynen and Burress (2018) who approached engagement of children at a science festival through basic operational measures such as how the children interacted with exhibits (waiting, doing, looking), with whom they interacted at the exhibit (scientist exhibitor, adult guardian, or peers), and the length of interaction time. Here, engagement was measured by unobtrusive behavioural observation. While such an approach towards engagement offers insights into how festival visitors navigate a science festival, it does not shed light onto the actual experience of the visitors as expressed or reported by them.

To answer our research question, we realised that we needed a new framework to operationalise engagement suited to the unique affordances of VR at science festivals. We thus drew on learnings from the literature to bring structure and direction to our exploratory research. This synthesis resulted in a conceptual framework made up of four aspects of participant activity: immersion,
facilitation, collaboration, and visualisation. In the following, we introduce the four aspects of this conceptual framework and show how the framework guided our data collection and analysis.

(1) First, we approached engagement through the aspect of immersion. By immersion, we refer to the extent to which participants were inhabiting the virtual experience and treating it as lived experience (Southgate et al., 2019). There are multiple dimensions of one’s immersive experience including immersion within a spatio-temporal setting (i.e. the perceptual experience seems real) and immersion within a narrative trajectory (i.e. immersed in a story) (McRoberts, 2018; Thon, 2014). For the purposes of this study, we draw on Thon’s (2014) distillation of immersion as being ‘the illusion of immediacy’ (p269). Immersion in a VR setting thus characterises the extent to which a visitors’ attention and sense of presence are located in the virtual experience.

(2) Second, we looked at engagement through the aspect of facilitation. Facilitation is a core aspect of learning in all settings. In the context of science festivals, facilitation includes interactions between festival staff or science professionals and visitors. This aspect emphasises the expertise and guidance of the science professionals in getting participants excited about the activity, in answering questions, and generally guiding them towards meaningful experiences. The number and scope of such involvement of science professionals during festival events play a key role in positive visitor impacts (Jensen & Buckley, 2014). Indeed, research suggests that interaction between visitors and science professionals is the strongest predictor of better outcomes and positive learning impacts for visitors (Science Festival Alliance, 2020).

(3) Third, we approached engagement through the aspect of collaboration. Just like facilitation, collaboration is a core mechanism for learning (Johnson-Glenberg et al., 2014). Although many still view VR as an individual experiential technology, there is compelling evidence that VR environments facilitate tasks that lead to richer and more effective collaborative learning (Dalgarno & Lee, 2010; Johnson-Glenberg et al., 2014). As technology develops, we recognise more opportunities for important collaboration and social interaction between participants within and across virtual experiences, for example by allowing participants to directly communicate with each other inside and outside of the virtual space (Johnson-Glenberg et al., 2014; Steier, 2020).

(4) Fourth, we considered engagement though the aspect of visualisation. Since science often deals with the unobservable, visualisations available through VR are particularly valuable in scientific domains where concepts are difficult or impossible to perceive directly (Bakas & Mikropoulos, 2003; Brinson, 2015; Kersting, 2020; López & Pintó, 2017; Smetana & Bell, 2012). Scientific entities are sometimes too small, such as atoms and DNA molecules; or too big, such as stars and galaxies; they unfold over timescales that are hard to grasp, such as chemical reactions or evolutionary processes; or they are not directly observable in the physical environment, such as the Earth’s axis and orbit around the Sun or gravity as the curvature of spacetime (López & Pintó, 2017; Pande & Chandrasekharan, 2017; Steier & Kersting, 2019; Sullivan et al., 2017).

Research setting at the science festival science Alive!

Science Alive! is the largest single interactive science exhibition in Australia, targeting mainly families with children.² Science Alive! hosts several events across Australia every year. In this study, we joined the festival at the Ghmba Stadium in Geelong in the Australian state of Victoria that took place from 24th to 26th May 2019. According to the organisers, total attendance at the three-day festival was 6,718 visitors. The OzGrav stall was situated on the second floor of the stadium and consisted of one large table with VR-experiences at each end. To deliver the virtual tour Bigger Than Big, six Lenovo Mirage Daydream headsets were connected to a big screen. Thus, six visitors could experience the virtual tour of the Universe at the same time. Other visitors could follow along on the big screen, which allowed for an inclusive and collaborative activity between visitors inside the VR-environment and visitors standing by. This set-up was particularly popular with
families and groups of people who could see what their friends and family members were experiencing in the virtual tour. The set-up also allowed the OzGrav science professionals to guide the visitors through the tour. Each day, the research coordinator and science communicator of the OzGrav EPO team was overseeing the activities and delivering the tours with two science professionals joining as tour guides.

Data collection and data analysis

A science festival is a socially active informal learning space that prompts a variety of interactions and unpredictable events (van Beynen & Burress, 2018). It is likely that the use of VR adds to this complexity of activities because of the potentially novel engagement processes that can unfold in VR environments. Acknowledging the need to diversify measures to capture the breadth of interactions, we integrated multiple data sources into our research design in line with our conceptual framework. The data collection included visitor surveys, video recordings of visitors in VR, screen capture, field notes, and focus group interviews with the OzGrav EPO team and the volunteering science professionals. Importantly, our methodological choices reflected the need to consider visitor and organiser perspectives to explore engagement with VR at the science festival. Survey data allowed insights into the overall visitor experience and, in particular, the experience of visualisation and immersion in the VR-environment. Video data shed light onto the aspect of collaboration and facilitation and how groups of visitors collectively engaged with the VR-tour. Screen capture data helped to link the video data to the visualisations inside the VR-tour. Focus group data revealed the perspectives of the OzGrav EPO and science professionals who shared their experiences of facilitating the VR-tours and who discussed the potential of visualising astronomical concepts through VR. The first author took field notes during the science festival to capture her observations of the venue, the visitors, and the engagement with the VR-tour. At the end of the festival, the first author organised these notes in the form of a short researcher reflection report to summarise her observations and to identify possible challenges and opportunities of using VR in the context of science festivals. Table 1 presents an overview of our collected data and shows how the data maps onto the four aspects of our conceptual framework.

We developed the visitor survey based on a pilot questionnaire that was trialled at the 2019 Australian Grand Prix and the 2019 Brisbane World Science (Booker, 2019). We asked visitors to complete the survey on tablets after they had completed the Bigger Than Big tour. Since many families experienced the VR-tour together and since many children were too young to complete the survey on their own, families and groups often submitted one response that reflected their collective experience. The questions of the survey are listed in Table 2; on average, it took visitors 5:06 min to complete the survey.

Table 1. Overview of the collected data in line with the four aspects of our conceptual framework for engagement with VR at a science festival.

<table>
<thead>
<tr>
<th>Data type</th>
<th>Scope</th>
<th>Conceptual framework</th>
</tr>
</thead>
<tbody>
<tr>
<td>screen capture</td>
<td>13 h 20 min</td>
<td>immersion and visualisation</td>
</tr>
<tr>
<td>video data</td>
<td>11 h 40 min (327 visitors in VR)</td>
<td>facilitation and collaboration</td>
</tr>
<tr>
<td>visitor survey</td>
<td>74 responses</td>
<td>immersion and visualisation</td>
</tr>
<tr>
<td>focus group interview EPO</td>
<td>45 min audio and video, 6800 words transcription (4 participants)</td>
<td>facilitation and visualisation</td>
</tr>
<tr>
<td>focus group interview</td>
<td>1 h audio and video, 9800 words transcription (8 participants)</td>
<td>facilitation and visualisation</td>
</tr>
<tr>
<td>professionals field notes</td>
<td>1600 words, the first author took the field notes during the festival and prepared them in the form of a short researcher reflection report</td>
<td>immersion, facilitation, collaboration, and visualisation</td>
</tr>
</tbody>
</table>
To collect video data, we installed a small camera on a tripod and placed it behind the big screen on which the screencast was shown. A screen-casting programme captured the VR-scenes and the movement of the visitors within the VR-environment. Signs around the stall informed visitors that we were filming the stall and recording the VR-screens and that they should inform us if they did not want to be filmed. Moreover, information sheets about the research project were given to visitors with information about the purpose of the research project, data storage, and anonymising data.

To attend to the perspectives of the OzGrav team, we conducted two focus group interviews shortly after the festival – one interview with the OzGrav EPO team that had developed the VR-tour Bigger Than Big and one interview with the team of volunteering science professionals that facilitated the tours during the festival. The EPO team consisted of a science educator, a science communicator (who was overseeing the activities at the science festival), a content developer, and a digital artist. The science professionals were doctoral and postdoctoral researchers who were experts on gravitational wave astronomy and who had volunteered to help deliver VR-tours at Science Alive!. The interviews were semi-structured with open questions relating to EPO activities within OzGrav, VR-technology, learning astrophysics through VR, and participating at Science Alive!.

To analyse the survey and interview data, the first author transcribed the focus group interviews and imported the transcripts together with the survey data into the Atlas.ti software for qualitative data analysis. First, we followed an inductive approach to analysing data through thematic analysis (Braun & Clarke, 2006). The codes and themes that we identified were then compared to our conceptual framework with each theme eventually being linked to one of the four aspects of immersion, facilitation, collaboration, and visualisation. To analyse the video data, the first author reviewed the total corpus of data and categorised the data by identifying segments in which (groups of) visitors interacted with the VR-tour. Each segment was tagged with a timestamp, a short description of the number of visitors and the type of visitor interaction, and remarks on the quality of the audio and video data. Segments in which visitors actively collaborated were noted for closer analysis. In total, we filmed 327 visitors taking the VR-tour Bigger Than Big. The identified segments lasted between 15 s and 12.20 min with an average length of 4.10 min inside the VR-environment.

Findings

In this section, we first briefly present some overarching findings in relation to the demographics of the festival visitors and their overall experience of the VR-tour. We then explore more nuanced findings based on our conceptual framework, that is, through the lens of immersion, facilitation, collaboration, and visualisation.

Being asked to rate their overall experience on a scale from 0 to 5, visitors gave Bigger Than Big an average rating of 4.6, which suggests a very positive experience for many visitors. 40% of the visitors had never been in a virtual environment before. Even those visitors who had previous experience with VR were impressed by the experience:

Table 2. Questions in the visitor survey.

<table>
<thead>
<tr>
<th>Visitor survey questions</th>
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<tbody>
<tr>
<td>Overall, how would you rate your VR-experience with OzGrav?</td>
<td></td>
</tr>
<tr>
<td>Was this the first time you were in a VR-environment? What was your overall impression?</td>
<td></td>
</tr>
<tr>
<td>Can you describe what it felt like to be present in the VR-environment?</td>
<td></td>
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<tr>
<td>How did you experience your movement and your interaction in the VR-environment?</td>
<td></td>
</tr>
<tr>
<td>What scientific phenomenon was particularly noteworthy? How did the VR-environment allow you to experience this phenomenon?</td>
<td></td>
</tr>
<tr>
<td>Did the VR-tour add to or alter your previous knowledge of astronomy?</td>
<td></td>
</tr>
<tr>
<td>How old are you?</td>
<td></td>
</tr>
</tbody>
</table>
Festival visitor: “It was not my first time but it was incredible, it was lifelike.”
Festival visitor: “Was first time using VR, was highly engaging.”

The technology of VR thus seemed to have had a very positive impact on the visitors and provided great opportunities for engagement. Figure 1 shows the age distribution of visitors who completed the survey. The distribution is in line with the assumption that the main target group of the festival were families with young children. Moreover, more than 80% of the festival visitors that completed our survey answered that they had a general interest in science, which can be expected from visitors who attend a science festival in their free time. According to the survey, one of the main reasons for this interest was a fascination with astronomy and the night sky, which shows that topics of astronomy have a great potential to engage the public.

**Engagement through immersion**

A unique feature of engagement with VR-environments is the experience of being immersed. By immersion, we refer to the illusion of immediacy, that is, the extent to which a visitor’s attention and sense of presence are located in the virtual experience. The VR-tour *Bigger Than Big* placed festival visitors into a virtual Universe in which they could move around and interact with astronomical phenomena. Two questions in our survey addressed the concept of immersion. We asked visitors to describe what it felt like to be present and how they experienced their movement and interactions in the VR-environment. *Bigger Than Big* succeeded in conveying a sense of immersion that kept visitors engaged and that helped them put scientific ideas into perspective:

Festival visitor: “Totally immersive! Didn’t want to leave.”
Festival visitor: “Really immersive, really useful to put things in perspective.”

Although most visitors experienced a strong sense of immersion during the VR-tour, it is interesting to note that opinions on whether or not these experiences were realistic were divided. According to the survey, features of the VR-environment that rendered the experience realistic included a dynamic and responsive environment, easy and natural manoeuvrability, and the imperceptibility of the VR-technology:
Festival visitor: “Quite accurate movement and easy to manoeuvre around.”
Festival visitor: “It was very smooth and realistic with the graphics.”

Many responses, therefore, align with Thon’s (2014) characterisation of immersion as being ‘the illusion of immediacy’ (p269). On the other side, some visitors described the VR-experience as surreal and weird, mostly because they were not able to see or use their hands:

Festival visitor: “I couldn’t see my hands so it felt really weird.”
Festival visitor: “It was a bit weird not being able to point at stuff.”

Attention to hands and pointing suggests that there is an important bodily aspect to immersive VR environments and that they are not purely visual experiences. The sense of immersion and the resulting engagement with the VR-environment was thus clearly linked to the ability of visitors to move around and interact with that environment. Besides, the need felt by some visitors to see their hands, and particularly to point, might be an indication of their desire to collaborate and to share their experiences with others.

Irrespective of whether they perceived the VR-environment as realistic or not, almost all visitors described their immersive engagement as a positive experience that was linked to fun, enjoyment, and entertainment:

Festival visitor: “Awesome! I loved looking down and trying to touch everything.”
Festival visitor: “The spinning star was amazing. It was like I was there.”

More specifically, many visitors described their presence in the solar system as a sense of flying or floating through space:

Festival visitor: “I felt like I was floating by looking down and floating in general.”
Festival visitor: “Seems I was flying in space. Got good experience of space.”

Yet, as one of the OzGrav EPO professionals stated during the focus group interview:

EPO professional: “It’s not necessarily positive for everybody. And even that sense of floating, for some people, that’s great, for other people it’s disconcerting.”

Indeed, some festival visitors expressed such a sense of disconcertment:

Festival visitor: “It gives you vertigo.”
Festival visitor: “Always a little disorienting.”

This is an important finding in the context of a science festival where a large and diverse number of visitors will be guided through the VR-experience: while the immersive nature of VR has the potential to engage many, it is important to look out for those visitors who might feel uncomfortable, dizzy, or unbalanced.

In addition to engaging festival visitors, our findings suggest that the feature of immersion also helped visitors understand scientific concepts more easily. In the survey, we asked visitors if Bigger Than Big had added to or altered their previous knowledge of astronomy. 80% responded that the VR-tour had indeed done so because the tour was both informative and immersive. Even those who said that they had not learned something new admitted that the virtual tour had improved their experience of astronomy.

Festival visitor: “Yes, this added more information to my knowledge of astronomy.”
Festival visitor: “Altered it [knowledge of astronomy] as it was so immersive.”

In summary, the aspect of immersion had a positive and very engaging impact on most visitors because it gave them a sense of ‘being there’. This experience left visitors wanting to stay in and explore the VR-environment. Very few visitors, though, experienced the movement in the VR-environment as disorienting. It is important to watch out for those visitors and to offer alternative ways of engaging with the
VR-tour, such as a screencasting option. Moreover, it seems that the immersive nature of the VR-experience helped visitors to understand astronomical phenomena more easily. Immersion is, therefore, a key to using VR activities successfully for engagement in an EPO context.

**Engagement through facilitation**

The aspect of facilitation emphasises the expertise and guidance of the EPO and science professionals to get festival visitors excited about the VR-tour, answer questions, and guide participants towards meaningful experiences. To examine engagement through facilitation, we observed the interactions between visitors and the science professionals at the festival. We followed up with two focus group interviews to attend to the perspectives of the science professionals and the EPO team. Our analysis shows that VR-technology served as an essential tool to build connections between scientific ideas and everyday experiences of the festival visitors and between science professionals and festival visitors. Thus, VR-technology transformed abstract concepts into experienceable phenomena and offered a unique way of facilitating engagement with scientific concepts by bringing visitors and science experts together to interact in authentic ways.

The science professionals that guided the visitors through the VR-experience were experts in gravitational wave astronomy. Therefore, facilitation through authentic interactions was a crucial aspect of visitor engagement with *Bigger Than Big*. The authenticity of interaction in the presentation of science content appeared to make an important contribution to the engagement of the visitors. During the interview, the science professionals described the conceptual conversations they had had with visitors and how they felt that these conversations engaged the visitors and facilitated more in-depth scientific knowledge. The engagement through facilitation was, in fact, a mutual experience. The science professionals felt highly engaged throughout the festival and expressed personal benefit from the experience because they got to share science with the public and felt the excitement of the visitors:

Science professional 1: “(...) the expression on people’s faces, especially young kids. I mean how amazed they are and the feeling when, when you get amazed by seeing how amazed they are. It’s a loopback thing.”

Science professional 2: “Yeah, that's right what you said about loopback, like feedback. You're excited, they're excited, they get each other excited, and then it just kind of moves into, yeah, more excitement.”

The finding that science professionals experienced excitement and satisfaction in facilitating tours at *Science Alive!* adds an important dimension to previous research that shows that interaction between visitors and science professionals is a strong indicator of positive visitor impact (Jensen & Buckley, 2014; Science Festival Alliance, 2020). We suggest that the mutual engagement through facilitation created emotional connections to the science content similar to the emotional connections due to the mutual interplay between science and arts that Grimberg et al. (2019) observed at a science-art festival.

**Engagement through collaboration**

The context of the science festival allowed visitors to engage in collaborative experiences within and across the virtual environment through shared screens and talk between participants and observers. Indeed, the OzGrav EPO team acknowledged the importance of such social interaction. In the focus group interview, the EPO team repeatedly stated that they wished for their VR-tours to be a collaborative rather than an individual activity:

EPO professional 1: “We seem to have streamlined our public outreach programs so that we can bring VR to the masses in a way that is a collective activity, not necessarily an isolating activity where people can feel engaged with the science communicators that are sharing the content with them.”
EPO professional 2: “I think personally, I would like them to experience it as a group event, not as an individual isolated thing. So I’d be more interested in people getting together like we have with the big events, and having a shared experience than somebody sitting at home just looking at stuff.”

The video data allowed us to investigate the extent to which Bigger Than Big set up an experience that fostered engagement through collaboration at Science Alive! We identified 130 video segments in which 327 visitors interacted with the VR-environment. The average group size was 2.4 visitors with 21 segments (16%) capturing individual visitors taking the VR-tour. Although individual visitors often engaged actively with their OzGrav tour guides, we focused on the collaboration among festival visitors while reviewing the video material (Figures 2–5). Based on the classification of the video segments, we identified four types of collaborative engagement with the VR-tour:

1. **Active guiding**: In many groups, one visitor, often a parent, took on the role of a tour guide (Figure 2). These visitor guides did not wear VR-headsets but followed along on the screens while their family members or friends explored the VR-environment. They often prompted their children or the rest of the group to explore features of the environment and asked questions to guide them. The VR-experience thus became a shared experience in which engagement occurred in the form of collaboration across the VR-environment, the screencasting, and the festival space.

2. **Separate explorations**: In groups in which all visitors wore headsets, we observed a different pattern of collaboration. Here, each visitor explored the virtual Universe inside their own headsets while talking to their group members to communicate their experiences (Figure 3). For example, visitors would often express their sense of wonder and surprise or ask others if they saw similar scenes.

3. **Passing on**: Many groups exhibited a type of collaborative engagement in which one group member was in the VR-environment before passing on the headset to the next member (Figure 4). Often, kids got excited and passed the headset on to siblings or parents to share the experience.

4. **No collaboration**: Not all groups showed patterns of collaboration. In some groups, each group member explored the VR-environment on their own or listened to the OzGrav

![Figure 2. Active guiding: Two mothers guide their kids through the VR-experience. Both children wear VR-glasses while the mothers watch the VR-scenes on the big screen in the right corner of the frame. Through active guiding, the VR-experience turns into a shared experience in which the engagement with astronomy occurs.](image-url)
guide without talking to the other group members (Figure 5). Some of these participants may have interacted at a later time when our data collection could not capture the collaboration.

During the focus group interview, the science professionals acknowledged the different types of collaborative engagement, for example, the active guiding by visitors:

Science professional: “They could sort of talk and parents were saying, ‘What do you see?’ So that was really good that the parents were kind of taking on the role of being explainer.”
In summary, the collaborative nature of the VR-tour allowed festival visitors to engage with each other and with the virtual Universe in diverse ways. We observed and identified three types of collaboration in which sharing and communicating features of the VR-tour became an important part of the festival experience. In particular, the active guiding among visitors, often between parents and children, was a successful way of engaging with the VR-experience. Designing VR-experiences in a way that invites festival visitors to collaborate is, therefore, a promising route to foster engagement.

Engagement through visualisation

One challenge of facilitating engagement with scientific content lies in the very nature of science. As the Bigger Than Big tour demonstrates, the scale of astronomical phenomena such as the scale of the solar system is hard to grasp intuitively. Besides, many phenomena are conceptually abstract such as black holes. Guiding festival visitors towards meaningful experiences of these phenomena is, therefore, a challenging task. VR-technology responds to this challenge by offering new visualisations of science concepts. In the interviews, the OzGrav staff and science professionals identified two critical aspects of VR-technology that engaged the festival visitors through visualisation.

First, relying on headsets, the VR-tours offered an unusual and visually striking experience and presented science content in a format that festival visitors were interested in. The VR-experience at Science Alive! thus served as a hook to bring people in because the VR-headsets captured the attention of many:

Science professional: “So, it is like giving them what we want them to see but in the way that they want. So, they love technology, we’re giving them technology.”

EPO professional: “From a design point of view, we try to make things very beautiful. If something’s engaging visually, people are more likely to (…) spend more time on it. Whereas if you have a boring scientific schematic, which may be ugly and hard to interpret, people are less likely to understand and engage with the science and therefore be less inspired by it (…). So yeah, we aim for things to be visually striking.”

Second, the VR-technology offered new ways of visualising science phenomena that allowed festival visitors to engage with the science content more directly. Thus, the VR-experiences linked the science content to the lived experiences of the visitors:

EPO professional: “I guess in terms of what we like about VR is it gives you a way of showing people things. Some people are visual and they like to be able to see things. So it gives
you a way of showing them something; that they’re doing a lot of hand waving, and that it gives the ability to be able to interact with things. So to be able to not just look at something passively, but to be able to interact with it and see what happens, how it changes. That’s a good side of VR.”

Science professional: “Astronomy is something like, it happens in such a big scale it’s very difficult to get it in your head. Imagine to visualize it is so difficult and that’s what I think disconnects many people from astronomy. Because they can’t really visualize it. It’s not easy. VR is that bridge that helps establish this connection between those very big things. It levels it down to your understanding, how you work it and understand it.”

When being asked about the most memorable astronomical phenomenon of the VR-tour, black holes were the phenomenon that visitors mentioned most often with the scale of planets in the solar system and the scale of other cosmic objects ranking second and third in the survey. Since all of these phenomena are hard to visualise it seems that VR, indeed, offered visitors ways of engaging with science concepts in new and meaningful ways.

**Discussion and conclusion**

The overarching research question that guided this study asked: How do visitors engage with a virtual reality tour at a science festival? We explored this question by operationalising engagement as four aspects of participant activity: immersion, facilitation, collaboration, and visualisation.

The findings analysed through the aspect of immersion indicated that the immersive nature of VR-technology kept visitors at Science Alive! engaged, provided fun and enjoyable experiences, and promoted knowledge of astronomical concepts by making these concepts experienceable. According to festival visitors, features of the VR-environment that made their experience realistic included responsiveness and manoeuvrability of the VR-environment that felt natural to the participant. A small number of participants found the immersive nature of the VR environment uncomfortable. Despite this challenge, almost all participants said that the immersive nature of the VR-experience altered their understanding of astronomy. We speculate that the ability of the participants to move and interact within VR-environment and their felt presence, or the sense of 'being there' (Southgate et al., 2019) contributed to their changed understandings.

The findings analysed through the aspect of facilitation indicated that VR-technology served as a bridge to connect experts and non-experts and to connect scientific ideas to the experiences of the festival visitors. Facilitation by the experts appeared to make an essential contribution to the engagement of the visitors. The science professionals described conversations with visitors as being conceptually rich and engaging with a focus on learning astronomy concepts. Besides, the engagement through facilitation was mutual with the science experts expressing excitement and satisfaction concerning their role as facilitators. We suggest that this mutual engagement created emotional connections that may support the learning of scientific concepts (Grimberg et al., 2019).

The findings presented through the aspect of collaboration indicated that the collaborative nature of the VR-tour at Science Alive! allowed festival visitors to engage with each other and with the virtual Universe in diverse ways. Johnson-Glenberg et al. (2014) described the effects of collaboration in virtual environments as complex, multi-causal and dynamic. We observed and identified three types of dynamic collaboration in which sharing and communicating features of the VR-tour became an important part of the festival experience. Visitors acted as guides for their group or participated in separate explorations that they then shared and discussed, or passed on their headsets to each other in a ‘show and tell’ format. We propose that all of these different types of collaborations reinforced and enhanced engagement with the science content.

The findings presented through the aspect of visualisation indicated that the VR-technology served as a hook that drew visitors in to engage with science because the VR-environment seemed fascinating and visually striking to many. VR overcame the challenges of astronomy as a scientific field where concepts are beyond our tangible experiences in the world, beyond what we can see
and feel, and thus beyond what we can typically visualise. In the focus group interview, the science professionals expressed the view that the public might often disengage with astronomy and science because these fields are difficult to visualise. VR seemed to facilitate the visualisation process by enabling visitors to picture and experience abstract concepts such as black holes or the scale of the solar system. This visual experience, in turn, resulted in enhanced engagement and possibly in enhanced learning as well (López & Pintó, 2017; Smetana & Bell, 2012).

It is a strength of exploratory case studies to investigate contemporary phenomena in-depth and within their real-world context (Yin, 2018). The need for our case study arose out of the desire to shed light onto the relationship between the use of VR and public engagement at a science festival and how we might identify and develop the benefits of VR technologies in the EPO context. As such, our analysis identified broad patterns and themes of activity while science festival visitors engaged with a virtual tour of the Universe. Although we cannot generalise these patterns to broader populations or other informal learning contexts, we believe that our findings demonstrate the feasibility of using VR in outreach settings and that our conceptual framework captures aspects of engagement that may be quite broadly applicable.

Specifically, the four aspects of the conceptual framework revealed important features that characterise successful use of VR in the context of EPO. The immersive and visually striking nature of the VR-experiences linked the science content to the lived experiences and experiential knowledge of the visitors which the science professionals, in turn, used to facilitate deeper engagement. The same features of immersion and visualisation also contributed to increased collaboration between the festival visitors. Dalgarno and Lee (2010) listed engagement, collaborative learning, and experiential learning as key learning benefits of VR-environments. The Science Festival Alliance (2020) added interaction between visitors and science professionals as one of the strongest predictors of positive learning impacts for visitors. Our study, thus, presents empirical evidence that the unique affordances, capabilities, and features of VR-environments can be successfully used in the EPO context. Moreover, our findings contribute to a growing body of research that places science festivals as an important informal learning space onto a sound theoretical and empirical footing (Bultitude et al., 2011; Canovan, 2019; Grimberg et al., 2019; van Beynen & Burress, 2018). We anticipate future research that will further unpack the complex engagement processes that occur in VR-environments in informal learning spaces and public outreach events.

Notes
1. https://www.ozgrav.org/education
2. www.sciencealive.org.au

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