Development of cross-curricular key skills using a 3D immersive learning environment in schools

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Abstract. Pedagogical opportunities offered by 3D immersive environments are not restricted to subject-based knowledge but also include non-disciplinary and cross-curricular key skills. This pilot study introduced a large 3D scene of a non-extant architectural exhibition into teaching and learning activities at three UK schools. From observation and qualitative data capture, a comparative case study identified a number of pedagogical opportunities and challenges. Despite diverse teacher and student approaches, a number of common factors were identified including constructionist teaching methods and the suitability of 3D environments for developing cross-curricular key skills and capabilities. In relation to the literature, this paper analyses how subject-aligned use of the 3D model met with differing levels of success, identifies four key skills that emerged from student use of the model across all three schools, and considers how challenges might be translated into further learning opportunities.

Keywords: Pedagogy, 3D visualization, Cross-curricular skills, Game-based learning, Collaboration, Creativity, Self-directed learning

1 Introduction

Whilst there is a growing body of research that focusses on pedagogical opportunities of 3D environments for the enhancement of particular, curriculum-based learning outcomes, few empirical studies consider their role in developing key cross-disciplinary skills and attributes such as collaboration, creativity, leadership, and emotional maturity. These capabilities are recognized across national curricula as intrinsic to the development of successful learners. Through a comparative case study of the use of a 3D environment in teaching activities in three schools, this paper investigates how 3D environments within the classroom can provide opportunities for developing key cross-disciplinary capabilities.

1.1 The REVISIT Pilot Study Methodology

Research Engagement through Virtual Immersive Tools for Learning (REVISIT) was a project with two primary aims: to develop innovative learning tools for schools using a dataset originally developed for higher education and research use; and to increase our understanding of the impact of immersive 3D environments for teachers and learners through a pilot study. The original dataset comprised a 2D digital collection and 3D model of the British Empire Exhibition which took place in Glasgow in 1938 [1]. The 3D scene re-creates over 100 individual building models (all but one of which are no longer standing) within the topology of Bellahouston Park, Glasgow, where the Exhibition took place. The digital collection includes photographs, architectural plans, ephemera, audio, and video.

For REVISIT, the 3D scene was delivered through VSim [2]. This (prototype) software was selected as it is specifically designed for pedagogical interrogation of 3D models; functionality includes real-time exploration alongside the ability to create narratives (linear 'tours' within the virtual space) and multimedia annotations, and the easy export of narratives and resources for classroom sharing and broader dissemination [ibid.]. Crucially when working with schools, VSim is free to use and standalone.

The existing 3D scene was optimized and converted to a COLLADA format, compatible with VSim. The archive of related cultural assets was organized into folders, targeting relevant curriculum areas as well as highlighting the most interesting items.

During the first phase of the project, teachers at three UK schools (one primary and two secondary) were introduced to the datasets and initial reactions and ideas for use were gathered through interviews. A firm aim of REVISIT was to avoid a 'top down' approach where university research data is simply delivered without being adapted to the new educational context, and is therefore of limited use. Therefore, the project sought to actively engage the teachers in the design of curriculum-aligned learning objects (i.e. VSim narratives) before delivery to the students. However, it was immediately apparent across all participating schools that there was a desire to use the Empire Exhibition 3D environment as a theme for cross-curricular learning, and for the pupils themselves to become co-creators of the narratives. Schools were therefore given autonomy in their use of the 3D scene and digital collection in lessons which reflects the constructionist approach recognized in other studies of teacher perceptions of 3D heritage data [3]. This resulted in three very different case studies, reflecting the different needs and approaches of the teachers and students who participated.

During the project's second phase, teachers organized teaching and learning activities which used REVISIT data (see **Table 1).** Qualitative data were collected including observations, interviews with teachers and focus groups with students. A survey was also performed with students at one secondary school (n=33). Audio recordings were transcribed and coded in NVivo [4] to perform inductive thematic content analysis. Other data include the narratives and resources created by the pupils themselves.[1]

This paper focusses on a theme that emerged strongly from the content analysis, that is, the opportunities afforded by 3D environments for developing cross-curricular skills such as collaboration, leadership, creativity, and emotional intelligence.

[1] Anonymized project outputs can be downloaded from http://research.gsofasimvis.com/revisit/

	Young's Primary (YP)	Hall's Secondary (HS)	Barrow Secondary (BS)
Pupil age	10-11	13-14	14-15
Pupils participating	26	106 participants (33 survey responses)	6
Learning context	Classroom, project-related activities	Classroom, 'creativity challenge'	Voluntary lunchtime club
Time period	Two months	3 days	Two 2-hour sessions
Teachers participating and input	2. High preparation, demonstration, and contextualization	8. Variable between teachers.	2. Low, some technical preparation, little pedagogical guidance

Table 1. Summary of teacher and student engagement in the pilot study. School and person names have been changed for anonymity.

2 3D Environments in Education

3D immersive environments are now accepted to have strong potential for creating engaging learning opportunities across a range of learner ages and situations. One review identifies pedagogical opportunities arising from these embodied experiences including increased motivation, the ability to contextualize learning objectives, and collaborative learning processes [5]. 3D models and environments have primarily been used in STEM subjects, however their growing use as surrogates for real-world environments is recognized, particularly where they model inaccessible historical or cultural spaces [6]. Although the majority of bespoke 3D educational environments still focus on particular disciplinary learning objectives, their value goes beyond increased cognition and also enhances motivation [7], and enables creative participation, digital/cultural production [8] and co-production [9].

In terms of immersive visuals, free exploration and interaction controlled by the user, and experimental, playful investigation, simulated 3D environments modelled on real places – defined by Dalgarno and Lee as "microworlds" [5, p.18-19] – share many of the characteristics of video games. Indeed, like good educational games, 3D learning environments can provide emotionally engaging, contextualized spaces for learning, even where there are no game mechanics present, as "the learner is able to construct a personal knowledge representation and iteratively refine this representation as he or she undertakes exploration and experimentation in a manner consistent with cognitive constructivist learning theories" [ibid]. The VSim 'wasd' navigational controls (similar to many gaming environments) and first-person viewpoint for exploration imbues the 3D scene with 'game-like' qualities; indeed, when introduced to classes of students, their assumption was clear:

> *"It was all 'aaahs' and 'wows' and they asked "What game is this?" they believed it was a game, "What game is this?", "Where can I get this?" "* (Daniel, YP, Year 6 teacher)

Due to their overlapping characteristics, much of the literature on educational digital games is also highly relevant to 3D immersive environments. In fact, some studies' definition of educational games fully encompasses 3D environments, despite their lack of overt game mechanics [10]. Similarly, most research on both games and immersive environments has moved on from questioning *whether* they can be fruitful tools for learning and now concentrates on *how* particular games, environments, and teacher practices can be best harnessed to meet curricular aims [11].

The microworld based on the real British Empire Exhibition of 1938 is highly appropriate for learning goals related to this particular subject, similar to other recent examples of subject-specific game-like 3D immersive environments [12, 12]. However, the REVISIT pilot study identified that such environments are particularly suited to the development of not only subject-based knowledge, but general key skills for learners, a topic currently under-served in the literature.

Fig. 1. VSim screenshot showing 3D scene with overlaid interactive narrative including tour nodes and multimedia annotations. Participants created their own 'tours' and annotations.

3 Challenges for Curriculum-Aligned Learning

The challenges of aligning learning activities in 3D environments are well documented [3, 5, 6] and were reflected in the findings of the REVISIT study. These include organizational support and the time required for teachers to prepare appropriate and contextualized learning activities, as well as the possible emergence of technological behaviors or goals that are unaligned with intended learning outcomes [10].

3.1 Curricular Flexibility

The varying success of the REVISIT pilot was highly correlated with the amount of institutional support and flexibility that teachers were (or were not) given. Particu-

lar challenges included several teachers feeling that using the 3D environment had been imposed upon them (by other members of staff) and/or simply did not have adequate time to plan for its effective use. At Hall's Secondary (henceforth HS), activities were planned as part of a three-day 'creativity challenge' towards the end of the school year, where it was seen to best complement the existing curriculum-based lesson plans. However this brought different challenges:

"If this was starting in September [it would be easier, whereas] we are at this stage where kids are doing exams in 3-4 weeks so they are going to be pretty stressed out about that." (Isaac, HS Learning and Teaching Director)

Conversely, at Young's Primary (henceforth YP), despite being extensively used in lessons over a two-month period at the same time of year, flexibility in curriculum planning resulted in greater levels of satisfaction from both teachers and students. This was explicitly acknowledged by the class teacher as well as the head teacher.

"I know for a fact that had that flexibility not existed throughout the last six weeks there are certain members of the class who would not have achieved what they have achieved so whilst there's a rigidity that remains in education I feel the more this kind of thing happens it will become more flexible and children will become more rounded individuals." (Daniel, YP Y6 teacher)

"As a leader you've definitely got to be supportive and make sure that there's time available for the teacher to be prepared, to find out more about it, to explore other things themselves, to talk with yourselves. That's got to be a whole school, high level decision." (Catherine, YP Head teacher)

At Barrow Secondary (henceforth BS), rigid timetables were surmounted by offering voluntary access to the learning activities via lunchtime workshops. Facilitated by one, highly-motivated but busy, teacher, this model of engagement limited the time available to engage with the 3D environment but ensured that students self-selected whether or not they participated. Describing the curricular challenges when working with innovative but computationally-demanding 3D environments, the teacher also identified other important resource limitations.

"In my subject, in Geography, it would democratize possibly the ability for me to teach the curriculum. […] I think 3D would enable me to do exactly what some of the richer schools do on a Saturday morning. […] it might bring some of the processes to life in a way that I can't in a classroom in inner-city Glasgow [because of lack of resources]." (Malcolm, BS Head of Humanities)

3.2 Constructive Alignment

Constructive alignment of learning activities with their intended outcomes is core to much of the literature across education. Specifically, reviews of the field note the importance of close integration of learning tools such as games and game-like environments into the curriculum in order to enhance learning objectives [15, p.177,198] as well as making efforts to align teaching activities with the preferences of students [15, p.160-161, 188]. The Empire Exhibition 3D immersive environment clearly possessed what the YP teacher called "the wow factor", however "To be effective, motivational tactics have to support instructional goals. Sometimes the motivational fea-

tures can be fun or even entertaining, but unless they engage the learner in the instructional purpose and content, they will not promote learning" [16, p.25]. Furthermore, the creation of relevant and meaningful learning activities enabled by 3D environments requires both adequate time for preparation and particular pedagogical skills [3] – a challenge when so few teachers have experience using 3D environments – and design of activities using heritage visualizations is affected by both a teacher's subject-specific confidence and their familiarity with cross-curricular themes [17].

Another challenge is the contextualization of both the learning activities themselves and the knowledge gained by students. "When using traditional computer-based learning tools, the teacher's role is recognized to be paramount in securing a successful learning experience. The outcomes of any lesson-based computer activity will depend on the introduction of the task, the interventions made during the activity and the way that the activity is set in the context of students' wider educational experience" [10, p.11]. Or, as more succinctly offered by Daniel at YP: "I think spinning a topic is crucial." In terms of cognitive challenges when using 3D environments, not only is acquisition of subject-specific knowledge highly dependent on the time that teachers devote to familiarizing themselves with the learning tools [10], game-like learning tools have been criticized for only imparting superficial knowledge [14, p.64] which then needs to be contextualized by a teacher. Therefore, to glean subject-specific knowledge from 3D environments, the continuing challenge is the need for teachers to become expert at not only using this technology but also in how their subject is presented through it.

It is worth restating at this point that the REVISIT 3D environment was initially created as research data and is not specifically designed to fit with school curricula. (The re-use of legacy research data in classroom contexts was a core research question of the project and will be covered in a separate publication.) As such, it posed challenges for the all-important curricular alignment in some learning situations and met with widely differing levels of success, dependent on the approaches of individual teachers. Whilst in some cases, curricular alignment was obvious to teachers and was implemented successfully, other teachers voiced concerns about the relevance of the dataset in terms of their subject and the exact curriculum:

"*[Linking it to the curriculum was] a little bit artificial. I think things like when Sally was saying they took Tait Tower down because of the war beginning that was completely linked to the curriculum [but] history at school is punctuated by events like the First World War, the Second World War. […] Where does the Empire Exhibition fit into that?"* (Malcolm, BS Head of Humanities)

Other staff described the 3D environment in terms similar to Dede's "a solution looking for a problem" [18, p.235]. As a school technician put it:

"*Forcing the curriculum to fit with technology is never going to be the best way. Having a technology that is flexible enough for a teacher to customize it to their classroom, that's when it becomes valuable."* (Adam, HS Technician)

Teachers at HS also identified that their students were strategic learners, focused on their assessments. It is widely acknowledged that assessments strongly influence the approach taken by students in Higher Education [19, pp.93-95; 20, pp.67-72] and this was borne out by the responses of some students, particularly at HS.

"I've learned a lot… I've enjoyed doing it as a one-off but I'm not quite sure if it helped particularly in the overall curriculum. It wouldn't particularly help with an exam or something 'cause it's not subject specific." (Jenny, HS student)

Therefore, although the qualitative data collected demonstrates that children at all three schools learned and retained a considerable amount of subject-specific knowledge about the Empire Exhibition, it was not always clear to them how this knowledge was relevant in terms of their day-to-day curriculum.

The success of enabling learning through 'customizing' 3D immersive environments for classroom purposes is dependent on a number of factors including the characteristics of the 3D data itself; the delivery software; teacher attitudes, competencies, and preparation time; and student learning styles. Possibly in response to some teachers having difficulties creating learning activities that were closely aligned with specific curricular goals, many of the teachers involved in the REVISIT study intuitively identified cross-curricular competencies that complemented subject-specific knowledge. These were based much more on the core characteristics of the Empire Exhibition as a 3D immersive environment, rather than on the subject of the Exhibition itself. The remainder of this paper considers the primary cross-curricular key skills and characteristics that were identified from the REVISIT pilot study and considers the factors for their success (or failure) in a classroom context.

4 Key Findings: Cross-Disciplinary Key Skills

4.1 Motivation to Learn

Whilst motivation to learn is not itself a key skill, it is widely accepted as being crucial to successful learning behaviors [16]. Motivation and engagement are core perceived characteristics of 3D environments, predicted by teachers and borne out by students' attitudes. Prior to developing learning activities, several teachers identified the value of the Empire Exhibition environment in motivating students:

"I think that for me the biggest selling point is the historical and the geographical knowledge but I think for the children one of the selling points is 'Hey this looks a bit like a game.' " (Daniel, YP Y6 teacher)

"The idea of having a virtual exhibition where kids could upload photos, videos, CAD models, that kind of thing is actually quite motivating for our children." (Lauren, HS Design teacher)

This enthusiasm for a novel learning style was echoed by students who displayed a high level of intrinsic motivation [21] when interacting with the 3D scene:

"I was really pleased we were going to do a fun topic, I didn't expect it to be this fun though, because you could engage with it really well and it was just, in a couple of clicks and you were on, so it was really fun, yeah." (Mohammed, YP student)

"It was different because there's not many games – it's not a game but it's like... there's not many programs like that and it's very easy to control, many things to explore and it's very interesting cause [the Empire Exhibition] is not here anymore, it's not existing so it's good to find out what it was like in history and what they thought it was going to be like in the future." (Rowan, YP student)

In general, secondary school students were positive but less effusive and more focused on specific learning goals, although one boy from HS described using the 3D scene as "much better than school". In all three schools some students were motivated to carry on learning outside formal educational contexts. Motivation was perceived to be derived directly from the form of the learning environment itself, encouraging students to dig deeper into the subject-specific learning outcomes being presented.

"Some of them have asked if they can download it at home, some of them have asked if they can stay in at lunch times and play times and they have done. Some have created work in their own time. And again I don't think I would have got that if I had said 'There's a book about the exhibition' so it has been fantastic really […] It was mind-blowing really because it's taken learning home and I think you can't underestimate the power of a good hook into a topic and for me that was the main benefit of the [3D scene]." (Daniel, YP Y6 teacher)

Furthermore, several teachers recognized the deep learning that had taken place as a result of highly motivated learners combined with well-contextualized learning activities. The YP head teacher observed that "the children have been absolutely absorbed and engaged with it and at a quite high level I think of enquiry, of challenge."

4.2 Theme Learning

Debates around cross-curricular teaching and learning in the context of 3D environments are usefully summarized by Lackovic *et al.* acknowledging that confusions can arise from an insufficiently-defined educational purpose (as discussed above) [17]. Reflecting Lackovic's findings, teachers at all three case study schools quickly identified the Empire Exhibition scene as a 'hook' for cross-curricular teaching activities and identified a wide range of ways in which to link activities back to curricula.

"I was thinking Geography initially but then there's a historical side but also when you look at the different industries [represented in the Exhibition], you get a scientific slant in it as well. And also looking at the numbers and things, numbers of visitors and the cost and how long it lasted. I'd like to do some maths behind it…" (Daniel, YP Y6 teacher)

This approach derived from the nature of the research data itself as well as individual school policies for enabling study through project work and/or multidisciplinary 'themes'. One factor that became clear during the study was that, by providing immersive spaces for learning, 3D environments are particularly suited to integrating subjects together on a project with teachers identifying the benefit of wrapping up subjects perceived as 'dry' (such as maths, information technology, or the evaluation of sources in history) with activities seen by the children as being more fun.

"Because you can weave all the topics together it's so much easier. The other day I did a lesson and they had no idea they were learning. They did two geography objectives and two maths lessons and they had no idea." (Daniel, YP Y6 teacher)

Where the integration of the 3D scene was most successfully implemented, teachers highlighted particular characteristics of 3D environments and recognized that this theme-based approach allowed a different mode of learning to take place, thereby reinforcing the cognitive processes of more traditional teaching methods.

"I thought it's good for the kids as well to get away from the, what I call the tyranny of the words […] having a different sort of medium to look at ideas I thought was really interesting. […] It's good to get the kids just to think outside the box and it's interesting because […] they're used to studying in a particular aspect, in particular subjects. When you can do something completely different kids go "I hadn't realized you can do this in history." Well of course you can." (Ralph, HS History teacher)

Within the primary school, the theme was used extensively for a period spanning two months. Acknowledging the critical factor of his own preparation of learning activities, the class teacher (who had no prior experience with 3D models of any kind) described the Empire Exhibition theme as the most successful he'd ever seen and went on to describe not only the way in which the 3D scene had been used to deliver the curriculum but also its longevity as a teaching tool.

"I just went through the national curriculum and looked at the expectations for the children and was able to plan a curriculum fully centered on the project and I think it's been highly successful. […] If you choose the right stimulus you are able to maintain a topic for a prolonged period of time and I think this has been going for seven weeks now and they are still going and they are still enthusiastic." (Daniel, YP)

However, 3D immersive environments are not only suited for theme learning but also encourage teaching and learning of non-disciplinary key skills, a fact which was recognized by teachers even where the integration of the 3D environment into their curricula was more problematic. Lackovic *et al.* identify three particular non-disciplinary benefits to the use of 3D models: relevance, scaffolded immersiveness, and encouraging constructivist learning experiences [17]. The REVISIT study resulted in significant evidence that use of the Empire Exhibition 3D environment had strong impact in developing the following four key skills.

4.3 Collaboration

The potential for fruitful collaboration between learners was identified early on, particularly in subjects which incorporate group working into the curriculum.

"It's got scope for teamwork because then they could create work as teams and then actually put an exhibition together. […] It's the collaboration and the fact that they can upload different media. I do really like that." (Lauren, HS Design teacher)

The three case study schools demonstrated different approaches to encouraging collaborative learning. At YP the theme learning approach led to a large number of teaching and learning activities including guided tours of the scene and related cultural archive by the teacher (using an interactive whiteboard), free exploration by groups of children, digital co-production, and grouped and individual creative or cognitive tasks that took place outside the 3D scene but were closely related (for example, calculations of visitor numbers and making models of pavilions). HS used a different approach where students were split into groups wherein only a few of the most engaged children worked directly with the 3D environment whilst others created digital material for the chosen narratives. BS students each worked individually on a single narrative within the virtual environment, collaborating informally between computers.

Collaboration appeared to be inherent in the student's use of the 3D environment, even where learning activities had not been explicitly designed to encourage it. A large factor was in learning how to use VSim itself. Although some had played computer games, the vast majority of students and teachers had never used a 3D model or environment within the classroom before. As noted with regard to digital games: "A period of learning **about** the game was required before learning **through** the game could become possible." [10, p.17] and strong collaboration between students learning how to use the software was evident across all three schools.

Hannah: *"I just learned the simple controls at first but then some people told me more about flying, how to go in fast mode – "*

Louie (interrupting): *"We were like interacting with each other and helping each other with stuff like that […] we learn off each other."* (YP students)

Collaboration was not restricted to sharing technical expertise; students collaborated on navigating the scene to find certain buildings and shared their discoveries with one another, outside the parameters of the particular activity being worked on.

"Somebody found something and he gets really excited and he tells everyone else and everyone else gets really excited" (Rowan, YP student).

The focus groups and survey undertaken with HS students indicate that using the Empire Exhibition 3D scene in their lessons increased collaboration with other students (63% agreed) and also identified collaborative working as one of the most enjoyable aspects of their participation.

4.4 Leadership and Self-Directed Learning

As noted above, a major challenge for using 3D environments in the classroom is the requirement for teachers to become expert users. Whilst this can certainly create problems, REVISIT data demonstrated that occasional frustrations from students regarding a teacher's lack of technical knowledge were far outweighed by opportunities for developing leadership skills in students. A case study of teaching with Minecraft identifies how such a challenge can be explicitly converted into a learning opportunity: "The teachers here position themselves as not-knowers of the game, which creates space for the students to position themselves as experts. By explicitly positioning themselves as 'learners' of the Minecraft game mechanics, the teachers provide authority to the students and open up for a multivoiced dialogue." [11, p.270]

Across all three schools, some students were allowed to flourish as experts when using the 3D scene, guiding others (and in many cases, their teachers as well).

"Some of the children are better on computers than I am and they quickly figured out a way to do things and that allowed me to have some children who were leaders and so they could help others so they were playing teacher." (Daniel, YP Y6 teacher)

As has been noted elsewhere [10, p.15] this allows certain students, who are perhaps not used to leading in academic situations, to become 'champions', acting as guides and tutors to others, developing confidence and authority, not only in terms of navigating the 3D environment but of discovering the content within.

Mohammed: *"Mr W. like he knew the most so he was teaching us but the more we got to do it like without him, like now we know more than him about it so – "*

Samir: *"We also got to know all the buildings without Mr W. starting to tell us. The first thing we did when we was learning, we went on and just messed about and 'cause we were messing about we knew what buildings there were."* (YP students)

Exploratory, immersive 3D environments also allow students to actively lead their own learning. In fact, even where guidance material had been prepared (for both technical and subject-based learning outcomes), the nature of the 3D environment appeared to encourage students to reject the worksheets and learn in their own ways, recognizing freedom and independence as both enjoyable and fruitful.

"You can't really teach it to people, it's more effective if people teach it to themselves when it comes to technology and stuff." (Mandy, BS student)

"Personally for me it's more engaging, like, being able to explore yourself, at your own pace. […] It's independent learning – that works for me." (Jenny, HS student)

This key skill was also acknowledged by teachers at all three schools and self-directed, independent learning was encouraged in learning situations, allowing students to direct curricular goals as well as technology-centered goals.

"I said "What do you want to know?" and then they wanted to know facts about the exhibition and so the very first maths lesson was real facts and figures from the exhibition, attendance figures, the cost." (Daniel, YP Y6 teacher)

"The idea of being able to move around without the teacher guiding them is something that is very important and we've tried to that in our faculty for a few years." (Malcolm, BS Head of Humanities)

Allowing students to lead their own learning not only increased self-determination in lessons but also the students' ownership and pride over the narratives produced as part of learning activities. Before planning his lessons, the YP teacher stated:

"I'd like to think this is going to be very child-centered and that I more the facilitator walking round troubleshooting rather that standing at the front saying 'do this'. I want them to come up with something that they own and that they are proud of." (Daniel, YP Y6 teacher)

The validity of this approach is confirmed by observational and qualitative data collected from students, with many demonstrating a high level of commitment to producing high-quality work for the virtual narratives ('tours'): "'I was like John and Dania, proud of the fact that we could make such a tour." (Imran, YP student)

4.5 Creativity

Incorporating creativity into learning was also identified as a core benefit. HS students returning the survey conclusively agreed (80%) that the 3D scene made learning more interactive and creative engagement was seen as the second-most enjoyable characteristic (after collaboration). Students identified creative activity at a number of levels in the designed learning activities, from the very nature of free exploration leading to playful engagement, to the ability to create their own digital and non-digital products using the content and inspiration provided by the 3D learning environment.

"Without the tour I think it would be a bit boring 'cause all you could do is just go around in the Scottish buildings and do nothing with them. But making your own tour you could feel proud of what you'd done, it's an achievement." (Rowan, YP student)

The capacity and desire for playful engagement was recognized by teachers as a core element of self-directed discovery and experiential learning.

"The fact that you could fly to the top of buildings it just made children feel like they were almost being naughty but in a constructive way. […] One child discovered that he could walk up the slide and slide down in the little playground that's hidden behind the building." (Daniel, YP Y6 teacher)

Creative engagement was seen as particularly relevant where creativity itself plays a role in developing the learners along curricular lines, for example, in design and computing at the secondary schools.

"We always build creativity into the curriculum, it's really, really important because otherwise if the kids don't have that confidence then when they get to A-level they'll just fall flat," (Lauren, HS Design teacher)

Students also independently linked their creative activity whilst producing narratives with learning outcomes, demonstrating, to a greater or lesser extent, their ownership and understanding of the value of the constructivist approach to learning.

4.6 Emotional Intelligence

The final key skill that was explicitly highlighted by teachers was the effect of using the 3D environment on their students' maturity and emotional intelligence.

"There is the academic side that they are learning the objectives fit for the national curriculum, fit for their age group, but also their emotional intelligence is growing, their artistic, cultural intelligence is developing so they are becoming more rounded by doing the project theme." (Catherine, YP Head teacher)

This perception held true, even when teachers were not fully convinced of the value of the 3D scene to their subjects. The HS Information and Communication Technology (ICT) teacher proposed that "They like the freedom and it builds their maturity and it builds their teamwork which is fantastic. […] They will grow from this as people more than they will grow from this as computer scientists."

Teachers noted that some children not only demonstrated leadership, as discussed above, but took on wider responsibilities in the context of lesson delivery, such as setting up the lab. Some also discussed the project outside school, bringing back further insights to share with other students. The widely-stated view that children were becoming more 'well-rounded' during the pilot is inherently tied in with the experiential learning delivered by 3D environments. Boydell's assertion that experiential learning "involves the learner sorting things out for himself" [22, p.19] was almost directly repeated by one student when he said "We mainly try to sort it out ourselves."

Another aspect of emotional intelligence, resilience, was raised in response to the VSim prototype crashing. Whilst this was certainly not ideal, several teachers noted positive side-effects (including the fact that the 3D immersive environment was intrinsically motivating [21] and increased resilience and persistence in pursuing learning tasks) alongside resilience in dealing with the frustrations of losing work.

"The children differ in mental strength and also in resilience and some children were like "Oh I have to start again" where others they were a little bit upset because they'd put work into it and that disappeared. But then trying to turn everything into

positive, I used that as a teaching point how even when you are an adult you need to save your work after every small part that you do so that you don't lose any." (Daniel, YP Y6 teacher)

Linking back to curricular alignment, the 3D scene was seen to have high cognitive authenticity [23, p.376, 388] to the learning domains the children function in, even in those cases where subject alignment was more tenuous or problematic. Most teachers acknowledged that close engagement with digital learning environments is very useful for children as they develop into adults with many noting that the advantages (and problems) of such tools "readies the children for life outside of school which is far more important than passing tests" (Daniel, YP Y6 teacher).

Finally, there was evidence that the mode of engaging and interacting with the scene (alongside the 2D archive of related media) increased imagination, identification, and emotional engagement for both teachers and students.

"I enjoyed the most about like you could just go anywhere, there was not boundaries, you could just explore everywhere, […] you could just imagine how it would be if you was there and many other people were there." (Rowan, YP student)

5 Conclusion

Technological innovation in classrooms is rich with opportunity but also accompanied by both pedagogical and technical risk. The REVISIT pilot study demonstrates the diverse approaches, successes, and difficulties of incorporating a 3D learning environment into lessons at three different schools. However, it also reveals that this game-like mode of learning is highly suited for the development of non-disciplinary key skills, in particular, collaboration, leadership, creativity, and emotional intelligence. The research identifies areas where the well-documented challenges of integrating 3D environments into school curricula can be converted into opportunities for enabling and encouraging these key skills. The results of this pilot study indicate that 3D environments can function as effective contexts for constructivist learning and co-creation activities, and may be more intrinsically motivating for some students. A fruitful further study would be to compare this model with other modes of learning known for developing cross-curricular key skills and to examine the specific affordances of 3D environments within this context.

6 Acknowledgements

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7 References

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