ARISE
Action Research and Innovation in Science Education

[PROJECT NAME]: teaching science concepts in schools using Minecraft

Type

Research paper

Keywords

engagement, interactive learning, informal learning, outreach, Minecraft

Abstract

Background
[PROJECT NAME] is an outreach project based at [UNIVERSITY], UK. It uses the computer game Minecraft, alongside interactive discussion and hands-on demonstrations, to engage children with scientific research topics and science learning.

Material and methods
As part of ongoing evaluation, the efficacy of this approach as an educational intervention was tested via pre- and post-activity questionnaires for two session topics,with 492 children participating through schools in 2017 and 2018.

Results
Statistically significant mprovement in subject knowledge was seen in post-intervention scores for both topics. There was some variation in both absolute and improvement score results between boys and girls, and primary and secondary school students.

Conclusions
Participation leads to improved subject knowledge and understanding, regardless of prior existing knowledge.

Explanation letter

Dear Editors,

Thank you for your further response to our manuscript ARISE-00012-2019-02. Please accept the slight delay in responding due to summer leave and part-time working.

We have now responded to the reviewer comments; please see the table attached for elaboration. We sincerely hope that the manuscript is now acceptable for publication.

Many thanks

ARISE-00012-2019-02_revisions 2.docx

[PROJECT NAME]: teaching science concepts in schools using Minecraft

Introduction

While it is essential that children develop a range of skills and knowledge that enable them to understand scientific and technological aspects of the world around them ('scientific literacy') (Harlen, 2018), school science often fails to engage children (e.g. Archer et al., 2012 and references therein). There is strong evidence that children's interests in science form by age 14 (Archer et al., 2012 and references therein) with decline beginning around age 10 (Murphy and Beggs, 2005). Decline is less apparent when children are involved in practical, investigative activities (Murphy, Beggs, Carlisle, and Greenwood, 2004); teachers suggest that the best way to improve science teaching and learning is to increase its relevance to pupils' experience (Murphy and Beggs, 2005). Cultural biases such as perceptions of scientists as 'brainy' also lead to people feeling that science is not 'for them' outside of formal education settings (e.g. Archer et al., 2013; Science and Technology Committee, 2017). Therefore, initiatives which complement science learning in formal education and encourage young people to engage with science are vital (Science and Technology Committee, 2017).

The [PROJECT NAME] outreach project is one such initiative, using the computer game Minecraft to communicate scientific concepts and inspire interest in and enthusiasm for science in children. Drawing on the knowledge of the increased efficacy of learning when it is fun (Lepper and Cordova, 1992) and long history of using computer games to enhance education (e.g. Betz, 1995; Amory, Naicker, Vincent, and Adams, 1999; Jayakanthan, 2002), the project currently engages upwards of 6000 children per academic year, working in schools, at public events ([AUTHOR] et al., in press(a)) and in dedicated Minecraft Clubs

([AUTHOR] et al., 2019). With a Widening Participation focus, it aims to reach children who may experience barriers to accessing Higher Education. These barriers include, but are not limited to, disability, low family income, being of the first generation in their family to attend university, being of Black, Asian and Minority Ethnic background, and being in care/a care leaver (Lancaster University, 2019a). Extensive work is undertaken with children with Autism Spectrum Disorder (ASD) in particular ([AUTHOR] et al., in press(b)); alternative methods of communication such as computer games can be valuable for people with conditions such as ASD, who may face challenges with face-to-face interactions (Mazurek, Engelhardt, and Clark, 2015; Ringland, Wolf, Faucett, Dombrowski, and Hayes, 2016). Further detail can be found in [AUTHOR] et al. (2018a; 2018b; 2019).

This evaluation assesses work in schools, through which sessions are delivered in primary, secondary and specialist schools in the United Kingdom. Due to the range of educational levels involved, sessions are designed to be flexible so that delivery and content can be adapted for varying ages and needs. While topics are covered that children may not experience in such detail until much later, or indeed at all, in their school careers, the skills and concepts supported are linked to the relevant stage of the National Curriculum, as is key content (Department of Education, 2014).

Minecraft is an effective medium for communicating scientific concepts (e.g. Nebel, Schneider, and Rey, 2016; [AUTHOR] et al., 2019); [PROJECT NAME] does this within a specifically designed framework. Data from activities at public events, which employ the same approach as delivery in schools, demonstrate that children hugely enjoy [PROJECT NAME] sessions ([AUTHOR] in press(a)). As enjoyment can have an impact on learning (Lepper and Cordova, 1992), and data collection on children's understanding can be better controlled in a school environment than at public events, the focus of this evaluation was to explore the efficacy of the project's approach in improving children's knowledge of scientific topics.

Theoretical framework

Minecraft is an open-world game in which players are free to explore, building creations using a wide range of blocks with a variety of textures and properties. It replicates a range of ecological and physical settings and processes analogous to those in the real world, providing a virtual platform in which concepts such as formation of volcanic rocks, which cannot be directly investigated in reality due to constraints of time, resources, ethics, location and safety, can be safely explored. Minecraft is extremely popular with children (Lane and Yi, 2017) and employed across a wide range of educational contexts, (e.g. literacy – Lancaster University, 2019b; Short, 2012; and chemistry – Hullcraft, 2016). It is accessible for classroom use due to its simplicity and relatively low cost, facilitating active construction of knowledge and affording children opportunities to collaborate and engage with questions within its interactive environment (Nebel et al., 2016). While boys are more likely to play the game, start playing it at a younger age and spend more time on it than girls, it has appeal to both boys and girls (Mavoa, Carter, and Gibbs, 2018, and references therein). Thus, Minecraft is an ideal tool with which to communicate scientific principles and increase scientific literacy and engagement (Nebel et al., 2016; Lane and Yi, 2017; Short, 2012; [AUTHOR] et al., 2018a). The project's pedagogical approach to this utilises learner-centred constructivism (Brooks and Brooks, 1995; Rovai, 2004) characterised by a teaching environment that facilitates a positive impact on learning (Rosen and Salomon, 2007). Students are enabled to direct their own learning, in line with their interests and solving problems through use of Minecraft. A clear emphasis is placed on constructing understanding and meaning from the information given, within the context of the game. A scientific topic is introduced using hands-on activities and interactive discussion. Children are then challenged to complete a related task in Minecraft, such as building a volcano, exploring the concepts discussed and developing their learning and understanding by creating related builds. While they receive guidance and support from the project staff, the ultimate outcomes are directed by the children, according to creativity and imaginations and the aspects of the topic that most interest them. Setting a task related to a specified theme considering a real-world problem or demonstrating a real-world process, and allowing children to decide how they address this in Minecraft, enables them to test and explore concepts in a way that is not possible in reality and pursue their own interests by focusing on aspects of the topic that most engages them. Thus, anchored instruction (The Cognition and Technology Group at Vanderbilt, 1990) and constructionism (Papert and Harel, 1991) are applied by contextualising the themed building challenge in a real-world situation and building upon knowledge to explore the topic and advance understanding (AUTHOR, 2019). Minecraft is operated in its ‘creative’ mode; users have access to an unlimited supply of building blocks. Research areas covered include parasite ecology, food security, volcanology, plant biology, flood management, animal adaptations, insect ecology, and bioluminescence. Scaffolding and collaborative learning approaches (Vygotsky, 1978; Mercer and Littleton, 2007) help children construct meaning with each other through the dialogue they engage in through learning and play (Bruner, 1974). Enhancing participation and involvement can lead to children feeling more in control and more motivated to learn (Brown and Kennedy, 2011). This also allows the adults working with the children to avoid epistemic injustice (adults listening ‘for’ the right answer rather than listening ‘to’ what the child organically and meaningfully contributes (Murris, 2008)). Using the information given and the discussion they engage in, tailored to their educational level, children can maintain interest in and understand a scientific topic, consequently feeling that science is 'for them' ([AUTHOR] et al., 2018a). The style of teaching not only draws upon social constructionist models and dialogic styles, but also gives a voice to the children involved; this participatory pedagogy treats children as active learners rather than passive. The individual is acknowledged and appreciated for the valuable information they bring with them to discussion, motivating children to learn (Brown and Kennedy, 2011).

Further detail on the project's pedagogical approach can be found in [AUTHOR] et al. (2018a).

Evaluation of efficacy for learning

The efficacy of this approach in enhancing children's knowledge and understanding of scientific topics was assessed as part of the project evaluation using short pre- and post-intervention questionnaires. The working question for this evaluation was *"does participating in [PROJECT NAME] sessions lead to an increase in knowledge of the subject under discussion?"*. All participants were from Widening Participation backgrounds, with most having Special Educational Needs. Some children were in specialist schools and the project team were aware from teachers that, as is often the case throughout the project, many of the children participating had difficulties engaging in or benefiting fully from standard school lessons. Therefore, a statistically significant increase in correct answers following the project (rather than a set level of correct answers) would be taken as a successful outcome.

Secondary school students have had more opportunities for prior learning about topics than primary school students as they are older. Analysis of our audiences at public events shows no significant difference in interest in Minecraft between boys and girls who attend ([AUTHOR] et al., in press(a)), however monitoring data shows that more boys than girls attend our public events (through choice) and school sessions (chosen by teachers); gaming has been stereotyped as a male pastime (Shaw, 2010 and references therein) and many girls see Science, Technology, Engineering and Maths (STEM) subjects as 'not for them' (MacDonald, 2014). Therefore, potential differences in impact between primary and secondary school students, and boys and girls, were also explored.

Therefore, the null (H_0) and alternative (H_1) hypotheses were:

H0: participating in [PROJECT NAME] sessions does not produce a statistically significant change in subject knowledge

H_1): participating in [PROJECT NAME] sessions produces a statistically significant change in subject knowledge.

Methods

Evaluation approach

Between June 2017 and July 2018, 492 children in school years 3 to 10 (ages 7 to 14) from 32 schools taking part in [PROJECT NAME] 'volcanoes' and 'habitats' topic visits, answered short questionnaires before and after their session. These topics were selected because they:

- had at least one year of preceding delivery, allowing practitioners to select questions ensuring consistency across data collection as relevant content was guaranteed to be covered in sessions;

- were key topics for delivery during the sampling period, providing sufficiently-sized samples (Bartlett et al., 2001);
- cover different scientific areas (earth sciences and ecology), representing the project as a whole.

Table 1 gives details of sample and population sizes.

[PROJECT NAME] is an outreach project; data collection was collected for efficacy evaluation purposes. This secondary analysis of the data has been approved by the [UNIVERSITY] Faculty of Science and Technology Ethics Team. Suitability for the audience is essential in activity evaluation (e.g. University of Manchester, 2012); it was vital that data collection did not interfere with children's experiences of the outreach intervention, including impacting on their enjoyment and time available for participation in the content delivery. All responses were anonymous, recording only children's school year and whether they were male or female for evaluation purposes.

Children were assured that their answers would not impact them, as this was an assessment of the project's performance, not theirs. To preserve anonymity, schools are not named here. Details of types of schools involved are given in Table 2. Basic demographics of children are given in Table 3.

Questionnaires consisted of three questions relating to the topic, the correct answers to which were taught during sessions as determined during the pre-sampling period. The number of questions was limited to three because:

- questionnaires had to be suitable for a range of educational levels, with a larger number of questions potentially excluding some students;
- completion of questionnaires had to be integrated into sessions without impacting on participants' enjoyment of the activity or time available for core delivery.

Children answered these questions at the start of the session, before any delivery of content, and again after the session to enable comparison between scores before and after participating. One 'point' was assigned per correct answer and the total points improvement averaged across all participants for each topic. Statistical analysis was performed using SPSS Statistics 24 (https://www.ibm.com/analytics/spss-statistics-software, RRID:SCR_002865). Non-parametric tests were used for analysis as data did not meet the parametric assumption of normality. Paired sign tests were performed to determine whether there was a significant change between before and after scores.

Mann Whitney U tests were performed to assess whether there were significant differences between the scores of boys and girls, and primary and secondary school students. Significance was set to the 0.05 level.

The 'volcanoes' topic

In Minecraft, interaction of lava and water mimics that of the real world in that when lava and water come into contact, the source block (the first block placed, i.e. the hottest part) of the lava flow will form obsidian. In reality, obsidian is an acrystalline, volcanic glass which can form when lava is cooled sufficiently rapidly – e.g. in contact with water – that crystals do not have time to form and grow. In Minecraft, this takes place on the source block only; lava that has flowed away from this point has begun to cool down in the (virtual) air and therefore crystals can grow.

During a 'volcanoes' session, in varying levels of detail, children are introduced to volcanic rock samples. These include obsidian, facilitating discussion of how it forms in Minecraft and how this relates to real-world processes as described above. This dialogic teaching style is a relational and dynamic approach that allows for exploratory talk and provokes thoughtful answers. It involves question forming, active participation and the children learning from any mistakes made (Brown and Kennedy, 2011). They also handle a sample of rhyolite, a lava rock containing crystals for comparison to the acrystalline obsidian, and pumice from a pyroclastic flow (another volcanic hazard). The features of volcanoes and mechanics of eruptions, including the difference between magma and lava, are discussed, and children consider the relative risks of volcanic hazards. They then complete a building challenge in Minecraft; dependent on age and ability this could be to create obsidian in the game, build a volcano, create an eruption or manage hazards to protect a home, farm or village (Figure 1).

Children were asked multiple-choice questions relating to terminology (molten rock being called magma before eruption), hazards (pyroclastic flows presenting the highest risk to life of the hazards listed) and lava-water interactions (obsidian being a product of this). The first question relates to information that is taught via the National Curriculum. The second concerns a common misconception that occurs during these sessions which requires understanding of the properties and processes of volcanic hazards to address, and the third relates to a fact (obsidian forming due to interaction of lava with water) which some children know through playing Minecraft without being familiar with the real-world processes involved, and others have no knowledge of because, outside Minecraft, this is post-statutory school education knowledge. Therefore, a difference in results for each question might be expected and questions were analysed separately as well as summatively. All of these questions are answered in each [PROJECT NAME] 'volcanoes' sessions, regardless of adaptations for age and ability, and are consolidated by even the most basic exploration in Minecraft within the sessions, as simply placing lava and water blocks facilitates investigation and discussion of lava placement, movement (including in relation to the behaviours of other hazards) and formation of obsidian or rock in contact with water.

Therefore, all participants are able to consolidate understanding of the concepts presented and considered in the questions through using the game. More experienced or able players can build an internally representative volcano through layering blocks, create different types of eruption using various blocks and processes, and experiment, for example, with using different materials as protective barriers around houses to find which is most effective. A fuller description of the ways in which the project uses Minecraft in Earth Sciences is given in Author (2018b).

The 'habitats' topic

Minecraft contains a range of geographical biomes and a variety of animals. During 'habitats' sessions, adaptations of animals to different environments are demonstrated and discussed, linking to virtual biomes and animals found in Minecraft. Children then select a premade Minecraft world containing the habitat of their choice, such as snow, desert, savannah or rainforest, and use knowledge of animal adaptations to habitats acquired in the introduction to either build an animal that would live in that environment, or design their own animal which is adapted to that environment. During this phase, they consider the habitat the animal should live in, living conditions of the habitat, and the animal's body shape, colouration and eye position (Figure 2). Although children are building within a single biome, the processes involved in creating an adapted animal support consolidation and understanding of adaptations to other habitats that they have learnt about in the topic discussion.

Children were asked multiple-choice questions about adaptations of animals to their environments; reason for polar bear fur colour, reason for desert hare ear size and identifying polar bear skin colour. These three questions address knowledge and understanding that require comprehension of concepts such as heat absorption and surface area to volume ratios, as well as specific scientific terminology which they may or may not have addressed in school or encountered through gameplay. As with the volcanoes topic, there is opportunity for understanding of the underlying concepts involved to be consolidated through the Minecraft part of the session, whichever setting and approach are chosen. Again, questions were analysed separately as well as summatively.

Results

Volcanoes

Results of pre- and post-intervention questionnaires for the ‘volcanoes’ topic are shown in Table 4. Mann-Whitney U tests conducted to determine whether the demographics of the students taking part affected their pre- or post-activity test scores are given in Table 5. No significant differences were found between results for primary and secondary school students. As a significant difference was found between the scores of girls and boys at the pre-activity stage ($p < .05$, Table 5), their answers were also compared at the primary and secondary school levels. Girls in primary schools ($n=84$) had a mean total score of 1.5 ± 0.1, while boys ($n=86$) had a mean score of 1.9 ± 0.1; a Mann-Whitney U test determined that this was significant ($p=.004$). At secondary school level, both girls ($n=26$) and boys ($n=73$) had a mean total score of 1.8 ± 0.1, with a p-value of .692; there was a significant difference between the mean pre-activity scores of girls and boys at primary school level, and no significant difference at secondary school level.

Girls at primary school level achieved lower scores than boys across all three ‘volcanoes’ pre-test questions. However, the only question for which this difference was statistically significant (Mann-Whitney U test, $p < .001$) was question 3, for which the mean pre-test score for primary school girls was 70.2% ± 5.0% and that for primary school boys was 93.0 ± 2.8%.

There were significant differences ($p < .001$) between pre- and post-activity mean total scores. Results showed an average 30.5% improvement from a mean starting point of 57.5% correct answers pre-activity (maximum possible improvement 42.5% if all children scored 100% post-activity).

Habitats

Results of the before and after 'habitats' questionnaires are shown in Table 6. Results of Mann-Whitney U tests performed on the data to assess whether there were significant differences in scores depending on the demographics of the students are shown in Table 7. No significant differences between scores for boys and girls were found. As there were significant differences between pre- and post-activity scores for primary and secondary school students, the rates of improvement for primary (mean improvement = 1.4 ± 0.1) and secondary school (mean improvement = 1.6 ± 0.2) students were compared. No significant difference ($p = .221$) between improvement rates was found.

There were significant differences ($p < .001$) between pre- and post-activity mean total scores; a 46.8% improvement from a mean starting score of 19.4% (maximum possible improvement 80.6%).

Discussion

Overall impact

Substantial and significant improvement in children's knowledge and understanding of both topics followed participation in [PROJECT NAME] Minecraft sessions. Expected relative differences in levels of prior knowledge for the three ‘volcanoes’ questions are reflected in the average starting scores for each question (Table 4). Significant improvements were seen for all questions for both topics. These outcomes demonstrate that participation in [PROJECT NAME] school sessions, using the project’s specific pedagogical approach combining interactive discussion with creative Minecraft play to consolidate concepts, has a clear positive impact on subject knowledge and understanding.

Effect of student demographics on outcomes

Mann-Whitney U tests demonstrated no significant difference between male and female students, at any stage for the ‘habitats’ sessions, and a significant difference between primary school boys and girls, with girls achieving lower scores, for the pre-activity ‘volcanoes’ questions. There was no significant difference between scores for boys and girls after the ‘volcanoes’ sessions.

While primary school aged girls scored lower than boys across all three questions in the ‘volcanoes’ pre-testing, there was only one question for which this difference was statistically significant. This was question 3, which asked what (out of four possible answers) forms when lava erupts into water. As described above, the answer to this question was obsidian and the process can be observed in Minecraft.

Primary school girls did not have poor knowledge of this; their mean pre-test mean score was 70.2% ± 5.0% and this was the question that they performed best on. The difference arises because their male counterparts, also demonstrating that this is the question about which they had most existing prior knowledge, returned a mean score of 93.0 ± 2.8%. This question is the only of the six asked for which the relevant knowledge could be obtained through playing Minecraft alone; there was no significant difference between results for boys and girls for any of the other 'volcanoes' or 'habitats' questions. While the reason for this difference cannot be extracted from these data, anecdotally we know that children who are already aware of obsidian and how it forms have this knowledge through playing Minecraft. We show them a piece of real obsidian during sessions, and when they can name it we ask them how they know what it is; the answer is invariably that they've encountered it in Minecraft.

While girls also have good knowledge and are also playing Minecraft, schools send more boys than girls to our Minecraft sessions. This is not a unique issue; Mavoa et al. (2018) highlighted the need to ensure that girls do not miss out on opportunities to learn through digital play. The mean pre- and post-test results here demonstrate that playing Minecraft can be an effective learning activity and this difference between boys and girls could suggest that prior gameplay enables children to have higher pre-existing knowledge on which to build when attending our sessions, and from which boys are benefitting to a greater extent; this is an area for future exploration. Regardless of the reason for the difference in knowledge pre-activity, these results demonstrate that our sessions brought girls' results to parity with boys'.

It is unclear why the difference between girls and boys decreased at secondary level. Possible reasons are:

- girls are more likely to play Minecraft as they get older (Mavoa et al., 2018), which could increase their pre-existing knowledge;
- as interests in science are formed by age 14 (Archer et al., 2012 and references therein), with decline in interests beginning at around age 10 (Murphy and Beggs, 2005), secondary school teachers have a clearer sense of which children are interested in science and are selecting those children to take part, so that they are

more likely to have pre-existing knowledge and interest while girls who would score lower on the pre-activity questionnaires are not being chosen to take part.

It is well known that many girls do not see STEM subjects as being ‘for them’ (MacDonald, 2014) and therefore this selection is likely to disproportionately affect girls. Teacher bias may also play a part in this; there is substantial evidence that teachers perceive boys as being better and more naturally able at science than girls (MacDonald, 2014 and references therein) and may therefore be preferentially selecting boys alongside only those girls who show a clear interest in STEM subjects, thereby restricting the opportunities of other girls. Conversely, girls and children from other under-represented groups – including white and black boys from low socioeconomic status backgrounds (Archer, DeWitt, and Willis, 2014) – who do not see science as ‘for them’ would particularly benefit from taking part in [PROJECT NAME] activities. A core aim of the activities is to help children identify with science and scientists and there is a strong representation of female scientists from Widening Participation backgrounds on the project team.

Analysing the impact of specific prior Minecraft experience and habits of participants in the sample is beyond the scope of this study, the aim of which is to determine whether or not there is an impact on learning for participants in [PROJECT NAME] sessions across all children; this is a potential area for future exploration, particularly as a separate analysis conducted by the project of 174 school students aged 4-18 ([AUTHOR] in review) revealed that an equal proportion of boys and girls had high interest in using Minecraft for learning about a scientific topic. Regardless of the underlying reasons for differences between results for boys and girls found here and despite stereotyping of gaming as a male pursuit, 42% of the UK’s gamers are female (UKIE, 2018) and girls do play Minecraft (Mavoa et al., 2018, and references therein); increased play by females and through the generations provides a solid platform for [PROJECT NAME] to inspire disadvantaged children and girls about science. There were no significant differences in scores between primary and secondary school students for the 'volcanoes' topic, while there was significant difference between the test scores for these two age groups for the 'habitats' topic, both pre- and post-activity. While both cohorts significantly improved their scores between the pre- and post-test questions (there was no significant difference in overall improvement between primary and secondary school students), secondary school students scored significantly higher than primary school students both before and after the activity. This indicates that secondary school students came to the sessions with substantially more pre-existing knowledge than primary school students, which was not the case with the 'volcanoes' topic. This is most likely due to the increased coverage and level of complexity with which content relevant to the 'habitats' topic is addressed over the key stages of the National Curriculum (for example, first learning about camouflage and later being introduced to terms such as prey and predator, and introduction of concepts such as surface area to volume ratio at secondary school level), whereas volcanoes are covered, at least at some level, earlier in the curriculum and thus most primary school students will have some exposure to the facts and concepts related to them.

Conclusions

These outcomes suggest that there remains a need to ensure that girls (and other groups that don't see science as 'for them') are included in science engagement interventions. Nevertheless, participating in a [PROJECT NAME] school session leads to improved subject knowledge and understanding, regardless of prior existing knowledge; Minecraft and the

[PROJECT NAME] approach to using it constitutes is an effective teaching tool for improving scientific knowledge and understanding. Thus, H_0 is rejected, and H_1, that participation in [PROJECT NAME] sessions has a statistically significant effect on subject knowledge, is accepted. This impact is positive. Given the wide range of possibilities presented by the functionality of Minecraft, there is much scope for further research and future expansion of this approach for increasing scientific literacy.

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Table 1. Populations and sample sizes required (Bartlett et al., 2001), for each topic and relative to all Minecraft sessions school delivery (not including assemblies) for a confidence level of 0.95 and 0.05 confidence level, during the sampling period (June 2017-July 2018).

Topic	Population	Sample size required	Sample size achieved	Difference between sample size required and achieved
Volcanoes	547	226	269	43
Habitats	432	204	223	19
All school session delivery	2465	332	492	160

Table 2. Types of schools involved in topic evaluations.

Topic	Primary school (Years Reception-6 / age 4-11)	Secondary school (Years 7-13 / age 11-18)	Special schools	Total schools	Total children
Volcanoes	13	8	1	22	269
Habitats	8	1	1	10	223

Table 3. Basic demographics of children involved in each topic evaluation.

Topic	Male	Female	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Volcanoes	159	110	51	0	56	63	43	22	21	13

Habitats	120	103	25	0	52	112	14	18	0	0

Table 4. Frequency and percentage of correct answers and paired sign test results for each 'volcanoes' question pre- and post-activity, along with mean and modal total scores.

Question	**Pre-activity correct answers**	**Post-activity correct scores**	**Improvement**	**Paired sign test results**
1 (magma terminology)	198 (73.6%)	245 (91.1%)	47 (17.5%)	Z = -6.23 ,p < .001
2 (volcano hazards)	50 (18.6%)	214 (79.6%)	164 (61.0%)	Z = -12.65, p < .001
3 (obsidian formation)	216 (80.3%)	251 (93.3%)	35 (13.0%)	Z= -5.34, p < .001
Mean total score (%)	M = 57.5, SD = 1.53	M = 88.0, SD 1.33	M = 30.5, SD = 2.02	Z = -12.59, p < .001
Modal total score	2	3	1	

Table 5. Differences between mean pre- and post-activity test scores, with Mann-Whitney U test results, to determine whether scores differed significantly between boys and girls, and primary and secondary school students for the 'volcanoes' session.

Group	**Girls (n=110)**	**Boys (n=159)**	**Mann-Whitney U test results**	**Primary school students (n=170)**	**Secondary school students (n=99)**	**Mann-Whitney U test results**

Pre-activity test mean score	52.1 ± 2.5%	61.2 ± 1.9%	U = 7269, p = 0.010	56.1 ± 2.0%	59.9 ± 2.4%	U = 7865, p = .327
Post-activity test mean score	88.5 ± 2.3%	87.6 ± 1.6%	U = 8084, p =0.177	85.7 ± 1.8%	91.9 ± 1.7%	U = 7473, p = .050

Table 6. Frequency and percentage of correct answers and paired sign test results for each 'habitats' question pre- and post-activity, along with mean and modal total scores.

Question	**Pre-activity correct answers**	**Post-activity correct scores**	**Improvement**	**Paired sign test results**
1 (reason for polar bear fur colour)	73 (32.7%)	148 (66.4%)	75 (33.6%)	Z = -7.47, p < .001
2 (reason for hare ear size)	11 (4.9%)	100 (44.8%)	89 (39.9%)	Z = -9.33, p < .001
3 (identify polar bear skin colour)	46 (20.6%)	195 (87.4%)	149 (66.8%)	Z = -12.13, p <.001
Mean total score ± standard error	19.4 ± 1.66%	66.2 ± 2.00%	46.8 ± 2.60%	Z = -12.01, p < .001
Modal total score	0	2	2	

Table 7. Differences between mean pre- and post-activity test scores, with Mann-Whitney U test results, to determine whether scores differed significantly between boys and girls, and primary and secondary school students for the 'habitats' session.

Group	**Girls (n=103)**	**Boys (n=120)**	**Mann-Whitney U test results**	**Primary school students (n=189)**	**Secondary school students (n=34)**	**Mann-Whitney U test results**
Pre-activity test mean score	20.7 ± 2.39%	18.3 ± 2.30%	U = 3781, p = .351	18.0 ± 1.78%	27.5 ± 4.33%	U = 2513, p = .023
Post-activity test mean score	66.3 ± 3.00%	66.7 ± 2.70%	U = 6129, p = .911	63.7 ± 2.19%	80.4 ± 4.25%	U = 2198, p = .002

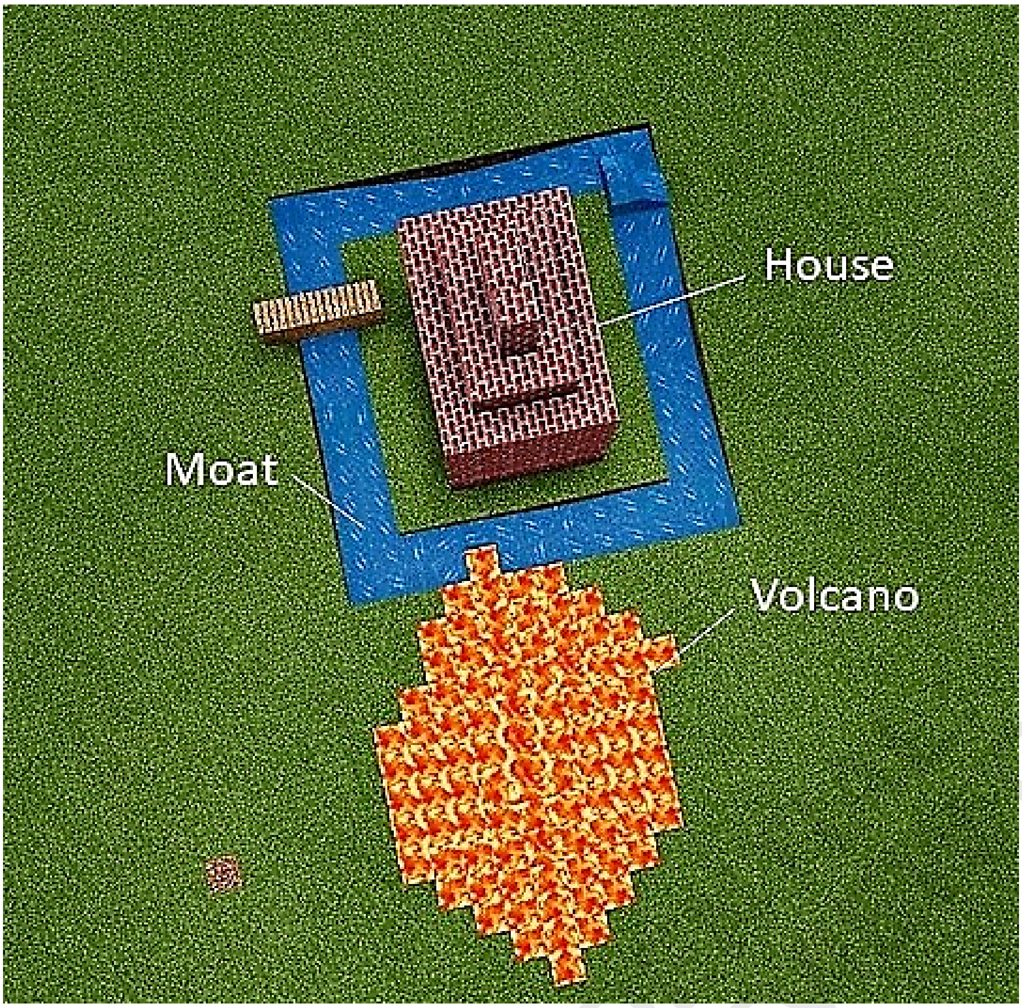

Figure 1. A house built in Minecraft is protected from a Minecraft volcano by a water-filled moat. This management of the virtual hazard demonstrates understanding that interactions between water and lava will cool the lava, therefore a moat could solidify lava, impeding its progress.

Figure 2. A crab built in Minecraft shows adaptations to its habitat. Its colouration camouflages it in relation to its surroundings, complex blocks represent compound eyes which enable efficient detection of motion and light and the eyes sit on stalks, giving a wide field of vision.

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Figure 1. A house built in Minecraft is protected from a Minecraft volcano by a water-filled moat. This management of the virtual hazard demonstrates understanding that interactions between water and lava will cool the lava, therefore a moat could solidify lava, impeding its progress.

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Figure 2. A crab built in Minecraft shows adaptations to its habitat. Its colouration camouflages it in relation to its surroundings, complex blocks represent compound eyes which enable efficient detection of motion and light and the eyes sit on stalks, giving a wide field of vision.