Planetary Marching Cubes for STEM Sandbox Game-based Learning

Enhancing Student Interest and Performance with Simulation Realism Planet Simulating Sandbox

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Fig. 1. Screenshot of HelloPlanet, a STEM sandbox game developed using our novel marching cubes algorithm, Planetary Marching Cubes. It aims to act as a development basis for future STEM games with planetary scale.

***Abstract*— Games have grown to be an important part of our society and naturally, its incorporation with education has become a rising trend. Together with the strong need for STEM talents, this paper proposed that STEM sandbox game-based learning video games could enhance students' interest and performance in the four disciplines. It is further argued that simulation realism, creativity and interactivity are three important components for this purpose. To promote their development, Planetary Marching Cubes (PMC), a development basis for STEM games has been discussed, along with a game developed with it, HelloPlanet. Students in primary and secondary schools have been invited to play HelloPlanet, and one of the main contributions of this paper is to demonstrate the improvement in both students' interest and performance in STEM. Students and teachers feedback are both very positive, implying that the education sector is fully ready to integrate game-based learning. When comparing with other methods of planet generation, most students picked PMC. This consolidates the argument of the importance of the three components, while also demonstrates the potential of PMC as a development basis for educational sandbox games.**

Keywords*— game-based learning; STEM education; STEM Interest; STEM Performance; sandbox game;

I. Introduction

Incorporating education with gaming has become an increasing trend recently and with the rising demand for STEM (science, technology, engineering, mathematics) talents, there is a strong motivation for using gaming to stimulate interest in the four disciplines. On the other hand, sandbox simulation edutainment is regarded as effective in provoking interest in the disciplines due to its experimental nature which enables creativity and interactivity [1, 2]. Also, sandbox simulation edutainment echoes with the current interest in simulation game among the younger generations. We firmly believe that sandbox game-based learning game is one of the crucial ways to promote and enhance STEM education.

We advocate that for a STEM sandbox simulation game to be successful, another prerequisite aside from providing creativity and interactivity is that it needs to reach simulation realism (SR). Meaning that the game's development focus is to be able to mimic the real world as close as possible. This is important because if the simulation is not well done, it cannot convey the four disciplines' knowledge accurately. Furthermore, it will hinder the player's interest as they will feel the simulation is pointless.

We would like to encourage the development of SR games to boost STEM education. We have taken note that there has been a lack of STEM games that features on a planetary scale, for example, a game that could demonstrate ecology from a planetary perspective. It is believed that this is mainly due to a

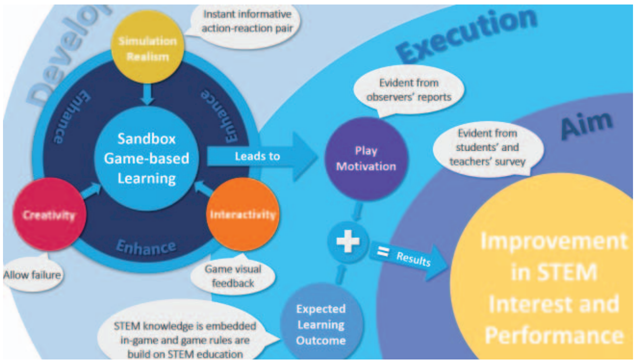

Fig. 2. It is advocated that SR, creativity and interactivity forms a strong basis for motivating students to play the sandbox game. Combining that with expected learning outcome, an enhancement of STEM interest and performance among students could be found.

lack of a development base that could facilitate their development. From our previous stance that SR is of great importance, it could be derived that a planetary scale game needs to resolve the game engineering problem of how to implement a sufficiently accurate, scalable and dynamic interactive foundational data structure in order to support a SR orientated development.

We believe there is no satisfying method that could achieve that. Specifically, there is no method for generating a complex terrain on a sphere. Although there is a substantial amount of terrain generation tools in popular game engines such as Unity and Unreal, they are only for using on a "flat area". To resolve this challenge and encourage the development of planetary scale STEM game, we have proposed a novel way of revitalizing marching cubes, a mesh generating algorithm, into one that could support mesh generating in planetary scale. It is named as Planetary Marching Cubes (PMC).

Additionally, as MR technologies are emerging while educational interest on them is also increasing [4], there is a need for a development base that could be easily compatible with them. As such, PMC also caters to MR.

To evaluate PMC, we have taken the initiative to apply it by developing a SR planet simulating sandbox game, HelloPlanet (Fig. 1), with it. In the game, the player will be able to observe and interact with a simulated planet that has a dynamic ecosystem. It will simulate organisms, non-organisms, terrains, and more. It is the aim of this game to provide a sandbox edutainment to learn general STEM and stimulate interest in the field by demonstrating the possibility of engineering to mimic reality closely.

The game has evolved into what it was originally conceived, a game that is SR focused, enabling creativity and interactivity, captivating and useful for STEM education. Aside from receiving recognition from Microsoft ImagineCup and many Hong Kong journalists, our game developed with our novel algorithm is evaluated by players with the goal of learning planet-related STEM. The returning result is encouraging and the educational value of our contributions is validated. The result also heavily implied that the terrain generation achieved by PMC made a considerable impact on the positive educational value.

One of the main contributions of this paper will be demonstrating those data that indicate PMC-developed game and PMC itself is useful for STEM game-based learning education. The data implies that PMC has a strong impact on students' interest, able to deliver scientific knowledge efficiently, and is well liked. Feedback from teachers also hints that the education sector is eager to introduce sandbox game-based learning, with or without PMC, to promote the four disciplines among their students. Another main contribution of this paper is to demonstrate that sandbox game-based learning might raise student interest in STEM. Study on the relations of interest and game-based learning, let alone a sandbox game-based learning, seems to be lacking. Lastly, this study has found that game-based learning games seem to have an effect on female student's interest in game engineering while combining with VR could raise their interest in technology.

In addition, as mentioned, we envision our novel algorithm could facilitate the development of new STEM sandbox edutainment. The positive results prove that our algorithm is worth considering by game developers as a dependable development basis for a planetary scale education game. This study, henceforth, also serves as a framework for future game-based learning games. We argue that SR, creativity and interactivity are important components (Fig. 2). A SR sandbox game-based learning game could well fit all those components and be effective as an education game that could both enhance student interest and performance.

II. Literature Review

Video games are becoming increasingly an integral part of our culture with a considerable population playing it as part of their daily lives [3]. As shown in [4, 5], a strong growing trend in the gaming community will likely to continue in the future. A casual observation of this cultural growth could be made with the rise of worldwide popular games like Minecraft and Pokémon GO. Games are also intrinsically interesting to young people [6], and naturally, incorporating games with education is an intriguing proposition to teachers who want their students to be more engaged in the course curriculum. In fact, there are studies suggest that education could learn from games on how to convey knowledge and "teach" [7]. Games could be a powerful medium in education and one of the methods of incorporation between digital entertainment and education is of course what we refer to as digital game-based learning [8]. It has been found that students reacted very positive to this idea [9].

In recent years, academia and society, in general, has taken a strong and growing interest in digital game-based learning [10, 11, 12]. Various research has been done on investigating its potential, mainly, on improving students' performance, motivation and self-efficacy for a specific course.

Games have been found to made impact on students' academic performance as learning gains have been observed. According to [13], it has been found that students who receive game-based learning have a better performance in science concepts than those who receive expository text-based learning. Similarly, in [14], [15] and [16], it has been found that students have made learning gains via a game environment. With Crystal Island, a common researched game-based learning game, [17] has shown that students could make a significant gain in scientific learning. It further advocates that as more research are involved in game-based learning, games will become increasingly in line with school curriculum and have a pivotal role in influencing future generations' education.

They are also found to improve the motivation of students [18]. [19], specifically, has found that the game approach is more motivational than non-game approach for computer memory concept. [20] even suggesting that allowing students to apply their creativity could further enhance their motivation than simply playing the game. [21] states that the more students enjoy an education game as a game, not a learning medium, the higher their motivation will be. The argument in favour of game-based learning regarding the impact on motivation, however, is not one-sided [16, 22]. But, as stated in [16], this could be the result of different interpretation of the meaning of motivation. Does motivation refer to the level of engagement in the game-based learning, or refer to the students' motivation towards studying a specific course? This could lead to different results when observing the change in motivation.

Some studies have taken a focused approach to investigating the self-efficacy of the students. It refers to one's belief in oneself to do something. An individual motivation to act on something is made by several components. Self-efficacy is one such important component [23, 24], and therefore, some research has narrowed their focuses on it. Game-based learning has been found to have a positive feedback on self-efficacy as well [17]. [25] has also found an increase in self-efficacy while highlighting that the degree is determined by the design of the game. Supporting the argument to a lesser extent, [26] implied that it is possible that an improvement of self-efficacy exists due to student behavioural change in-game.

Likewise, interest is part of students' motivation, but one that is important [27]. Despite studies have advocated the pivotal role interest took in learning and academic performance [28], unlike motivation or self-efficacy, research on interest with game-based learning is relatively lacking, even virtually non-existing, let alone the specific research on provoking student interest on STEM. There are, however, studies regarding how to provoke students' interest with teaching directions [29], videos [30], and activities [31].

Similarly to the research on interest, sandbox for game-based learning is a rarely investigated topic. [32] uses MinecraftEdu to provoke students' interest in Science and ICT. We argue, however, that its method of evaluating is not well-formulated. Our main concern is that the survey consists of questions that seems to be not methodically sound and that the data related to interest are not statistically presented. It also did not evaluate whether the students made an actual knowledge gain in-game. Additionally, the paper focused on the application of commercial games to education while our study, on the other hand, takes note of what game elements forms the basis of a good game-based learning for future education game development. A focused study has also been conducted on whether Minecraft is suitable to increase interest in programming among students [33].

For our avocation of SR, there are previous studies that form the foundation to support our claim. [34] states that "educational games should be designed in a way that provides complexity for students to engage in problem-solving tasks, with sufficient autonomy for students to make choices and attainable challenges to help them move closer to their intended goals", which is similar to the idea of SR. The importance of creativity and interactivity is also hinted again. [35] shown that the improved post-test career motivation is related to students' satisfaction with the game. There is also a common concern regarding that there exists a trade-off between realism and entertainment value, and games lean towards the latter [3]. SR is a development direction that could resolve this concern. The fact that SR, by itself, could support a good experiment platform also make the game more fun. Jantke [36] states that "the fun of gaming is the fun of learning". This implies that learning and having fun in a SR game could support each other.

Combining with the research gaps stated in the above literature, this paper position itself to, via PMC, investigate the SR sandbox game-based learning's impact on student interest and performance in STEM. Considering that there is virtually no similar research, this study could be considered as exploratory. Perhaps due to this fact, additional findings regarding sex differences is discovered during this study. Also, data that provides a strong research direction in the future is also presented.

III. Methodology

In this chapter, the technicality of PMC will be briefly described.

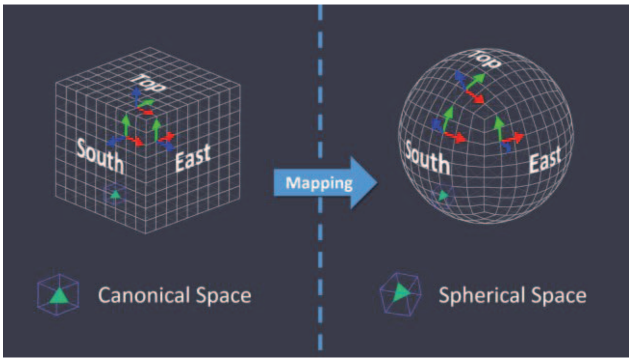

Fig. 3. PMC utilized six localized yet cooperating space. The marching cubes will be built with the spherical space on the right.

Marching cubes traditionally is used in a canonical 3D axes system. Although this could still be used for generating the mesh of the planet, the sampling will not be fair as the normal of the planet's surface does not align with any of the axes. Thus, similar surface models will behave differently on different surfaces on the planet because the marching cubes will use different parameters to generate the mesh. This gives disadvantage in simulation as, for example, the same surface model cannot be simulated as the same feature at different positions of the surface.

To resolve this issue, PMC will not use a canonical 3D axes system. The axes used will instead be determined by where it is at on the planet's surface. As shown in Fig. 3, the planet surface will firstly be divided into six faces using a mapping algorithm. Each of the faces will have its own well-defined local coordinate, with a "depth" axis always pointing away from the centre of the planet. Later, or in many instances when adding game mechanic, there is a need to convert between face local coordinate systems. For PMC, we have devised the conversion in such a way that it could be done by some simple adding, multiplication and flipping operations. The benefit for simulation of building marching cubes on these six localized spaces will be described later.

With the local coordinate for each face, the marching cubes will be built on it. The hierarchy of world, chunks, voxels and voxels' edges is suggested to organize in such a way that neighbouring chunks should be connected to one another by overlapping one another with the bordering voxels. Repeated overlapping voxels on the same face should be removed, but the same should not be done for overlapping voxels on the border of the faces. Instead, they should be left overlapping because marching cubes utilize edges to generate a localized mesh in a cube. However, due to different faces using different coordinate systems, edges on a faces' border, may although overlap, might represent different directions. It is suggested that this issue could be resolved by pairing those overlapping voxels and then pairing their edges similarly but in more specific predefined rules.

When applying marching cubes to a game, usually the expectation would be that the game will feature an editable terrain. With this novel way of marching cubes implementation, there is a need to resolve the issue on how to know which chunks to involve, and which voxels and edges to edit. Assuming that the editing volume is a sphere, its diameter could be compared with the depth (from the depth axis) to approximate which chunks are involved; its centre could be used to form a triangle with an edge to approximate the isovalue to mark where the surface is cut.

It is easy to use PMC to generate a navigational mesh by simply visiting the topmost mesh surface of the planet. It seems that despite marching cubes' relatively lengthy history surprisingly, most games implementing terrain generation empowered by marching cubes need to use a physics-based approach to traverse their agents. As most physics-based methods assume the gravity to be having a unified direction and precise movement of agents are usually needed by simulation games, there exists a strong need in creating navigational mesh. PMC could support the generation of said navigational mesh that caters to terrain features such as cliffs, overhangs and caves, that will be common in a SR game.

IV. Using PMC for STEM Game

As mentioned, we have developed our STEM sandbox game, HelloPlanet, using PMC. The architecture of PMC is utilized to support HelloPlanet's realistic simulation.

The first and most important aspect PMC has brought is the ability to create a data structure that is homogenous for the entire planet, or sphere. This greatly helps with creating a planet model that does not have artifacts in the "corners" of the planet. PMC also allows the data that describe a planet, for example, the content of air in a specific area, to be homogeneous.

As shown in Fig. 4, with a spherical marching cubes, it is also possible for the player to create terrain dynamically using a brush. Letting the player be able to edit the terrain is crucial for a sandbox.

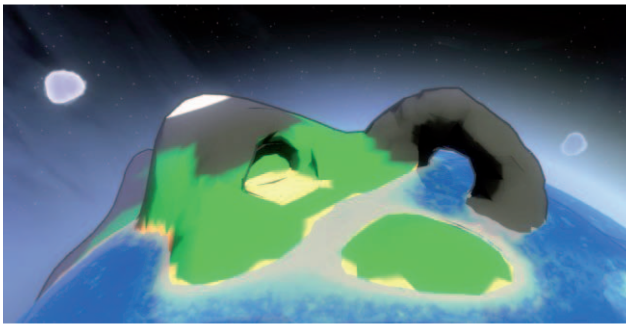

Fig. 4. A player editing the terrain in HelloPlanet. The mesh generation for arch and cave terrain features is not possible without PMC.

Another example of the advantage of PMC is that it allows ease of use to procedurally generate natural looking terrain, an important element in all sandbox games. Without it, the player will be greeted with a featureless sphere. By using fractal 3D or higher dimensions perlin noise [5], various terrain features could be generated. The simplest example is using 3D perlin noise to generate the height map for the planet.

Lastly, as mentioned, PMC also allows an easy extension for a navigational feature. A simulation game will no doubt require this to move its various characters or agents (In the case of HelloPlanet, organisms).

V. Evaluation

A. Data Subjects

The PMC-developed HelloPlanet is tested at Hong Kong schools severing primary school children and secondary school children. The schools of choice represent different socioeconomic status. Data subjects, in the end, is a total of 41 students across three classes. The composition was 19 boys and 22 girls; or 32 form 5 primary school children (Age 10-11) and 9 form 2 secondary school children (Age 13-14). 4 teachers have also observed the test and their feedbacks are collected.

B. The Game

HelloPlanet is the game given to the students. It is a planet simulation game where the students are presented with a world where basic scientific knowledge are embedded and could be taught to the students. Examples of that knowledge are altitude, tectonic plates and habitable zone. The game is played in VR with HTC Vive.

To better enhance the game-based learning benefit of HelloPlanet, various "knowledge tips" has been added for each of the game's features. The purpose of the tip is to link more clearly what the student is doing in-game with a more formal educational context. For example, when the student is exploring the terrain editing module, relevant "knowledge tip" on how this is happening in reality, which is by tectonic shift, will be provided to the student in the game. Hence, the student will be able to understand some formal concepts in a game-based learning manner. The students could be able to grasp some analytical concepts as well. For example, the questions of "Is it good to have no greenhouse gas like CO2?" could be understood by the students when trees start dying when the planet have no CO2 left.

C. Survey

For this study, two sets of survey have been prepared for the students, and one set of survey prepared for the teacher. In the two sets of survey, there are three classes of questions. I-class questions derive from a survey shown in Fig. 5. The origin of the original survey is [37] and it consists of many 7-point Likert scale questions. Those questions are used to measure the students' interest in the four disciplines of STEM. For this study, we have additionally added a measure of interest in game engineering. K-class questions consist of 9 questions that act as a benchmark for the students' science knowledge. Most of the questions are asked in a multiple-choice fashion. Only one question is an open-end question. The questions asked are related to the knowledge that could be learned in the game. One such question is "What does higher altitude means, higher temperature or lower temperature?". The last class of questions, G-class, aims to retrieve student feedback on the game. It asks questions like "Do you enjoy the game?" with a 5-point Likert scale along with some semi-open ended, and multiple-choice questions. The pre-test (or pre-game) student survey contains I-class and K-class questions, while the post-test (or post-game) student survey contains all three class. Hence, the two set of surveys combined could be used to evaluate the change in interest and knowledge gain. For the teacher's survey, their feedback on the game is collected.

D. Procedure

The students are firstly given the pre-test survey. Then, the students will play HelloPlanet (see Fig. 6) with the guidance of an observer. The observers are volunteers who are university students. Within a time of around 4 minutes, the students are given a tutorial on how to play the game and some free time to try the game on their own. During their gameplay, the observers will mark down their level of engagement in sentences with keywords [e.g. fun, concentration, (de)motivation, enthusiasm, boredom, effort], similar to [16]. They will also evaluate their motivation and estimate their gaming experience with a 5-point Likert scale. Once the game has finished, the students will be given the post-test survey. After all the students have finished, teachers are invited to give feedback on a survey.

E. Data Collecting

In the end, 41 data have been successfully collected. Those 41 students have successfully completed the entirety of the procedure. It was later discovered, however, that 2 students have neglected to complete the survey in post-test I-class and K-class questions while a student has obviously filled the post-test I-class questions insincerely as she has circled all 4s, unlike in the pre-test survey. Ergo, those 3 students' data have been declared void.

VI. Results

The test has been conducted mostly as planned. Due to the short time the students have to play the game, students may have varying free time in-game. In the following, the results found in this study are presented.

A. STEM Interest

As mentioned, I-class questions are used to evaluate student interest in the four disciplines of STEM, plus game engineering.

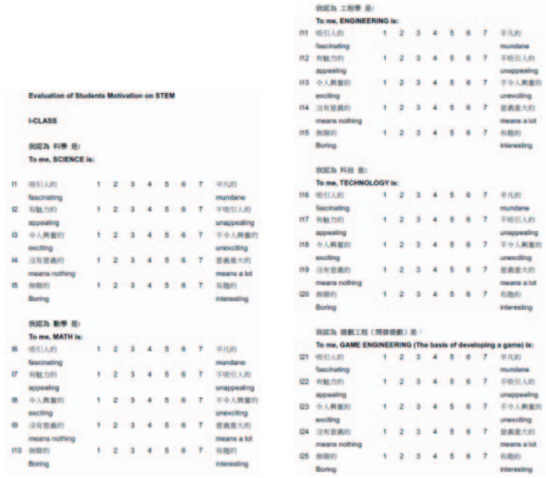

Fig. 5. The STEM interest survey, as shown above, is similar to the one in [37]. But the last item in [37] regarding career is removed and replaced with a game engineering discipline that measures students interest of it.

Fig. 6. A student playing HelloPlanet with HTC Vive

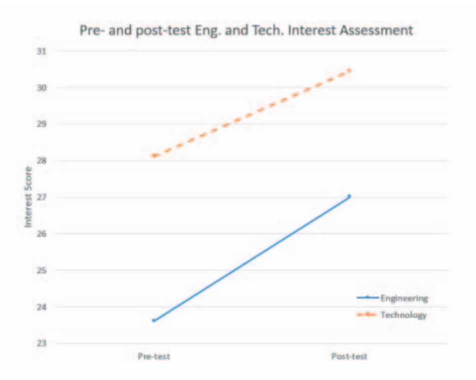

Fig. 7. Pre-/post-test changes in students' interest in engineering and technology.

TABLE I. I-CLASS SURVEY PAIRED SAMPLES STATISTICS AND TEST

Samples	*Paired Samples Statistics*				*Paired Samples Test*							
	Mean	*N*	*Std. Deviation*	*Std. Error Mean*	*Mean*	*Std. Deviation*	*Std. Error Mean*	*95% Confidence Interval of Difference*		*t*	*df*	*Sig. (2-tailed)*
								Lower	*Upper*			
Pre-test Science	29.18	38	5.270	0.855	1.447	6.237	1.012	-0.603	3.497	1.430	37	0.161
Post-test Science	30.63	38	5.567	0.903								
Pre-test Maths.	23.24	38	10.714	1.738	1.342	7.889	1.280	-1.251	3.935	1.049	37	0.301
Post-test Maths.	24.58	38	10.859	1.768								
Pre-test Eng.	23.61	38	7.123	1.155	3.395	5.415	0.878	1.615	5.175	3.864	37	0.000
Post-test Eng.	27.00	38	8.893	1.443								
Pre-test Tech.	28.11	38	7.210	1.170	2.342	5.454	0.885	0.549	4.135	2.647	37	0.012
Post-test Tech.	30.45	38	5.764	0.925								
Pre-test G. Eng.	30.74	38	6.587	1.069	0.526	5.853	0.949	-1.397	2.450	0.554	37	0.583
Post-test G. Eng	31.26	38	4.930	0.800								

TABLE II. I-CLASS SURVEY WITH PROBLEMATIC DATA SMOOTHED PAIRED SAMPLES STATISTICS AND TEST

Samples	*Paired Samples Statistics*				*Paired Samples Test*							
	Mean	*N*	*Std. Deviation*	*Std. Error Mean*	*Mean*	*Std. Deviation*	*Std. Error Mean*	*95% Confidence Interval of Difference*		*t*	*df*	*Sig. (2-tailed)*
								Lower	*Upper*			
Pre-test Science	29.00	38	5.351	0.868	2.002	5.672	0.920	0.138	3.867	2.176	37	0.036
Post-test Science	31.00	38	5.390	0.874								
Pre-test Maths.	23.11	38	10.639	1.726	1.711	7.150	1.160	0.640	4.061	1.475	37	0.149
Post-test Maths.	24.82	38	10.767	1.747								
Pre-test Eng.	23.29	38	7.689	1.244	3.711	4.809	0.780	2.130	5.291	4.756	37	0.000
Post-test Eng.	27.00	38	8.893	1.443								
Pre-test Tech.	28.08	38	7.201	1.168	2.684	5.251	0.852	0.958	4.410	3.151	37	0.003
Post-test Tech.	30.76	38	5.842	0.948								
Pre-test G. Eng.	30.57	37	6.664	1.096	1.500	4.766	0.784	0.089	3.089	1.914	37	0.064
Post-test G. Eng	32.07	37	4.415	0.726								

From the result, we have seen an increase in interest in all five disciplines as shown in Table I. By using t-test on pre-test interest score and post-test interest score, we have found that only the increase in interest in engineering and technology is statistically significant ($p < 0.001$, $p < 0.05$ respectively). The change in the two discipline is demonstrated in Fig. 7.

We are quite puzzled as the increase in interest in science from the data seems quite promising. For one question that evaluates the interest in science, there are about 20% more students who have picked the option that indicates the highest two levels of interest. After examining the data, we have found that some students seem to have confused the 7-point Likert scale questions with the thinking that 7 always refer to a highest level of interest as a small minority of students have suddenly changed their answer from a pre-test of 1 to a post-test of 4 in questions where 1 indicate the highest level of interest. The confusion with the survey is to be expected as many of our data subjects are primary school students around the age of 10. To cater to this students' confusion, we have devised a method in which such unintuitive, illogical change in answer has been dropped from the evaluation of students' interest. This new method of evaluation does not change the number of data sampled. It has remained the same (n=38) except in the evaluation of one discipline in which a students' answer seems to be completely illogical (n=37). This problem indicates that when applying the survey introduced in [37] on younger data subjects, researchers should take the initiative to carefully explain to them the meaning of the options. During our test, quite a few students have raised their confusion, but then, we only expected only those few students have this confusion.

After taken into account the answers that are illogical, the increase in interest in science is statistically significant ($p < 0.05$) as shown in Table II. We can see that our method is valid as the increase in interest in mathematics is statistically insignificant before and after ($p > 0.1$). The insignificance for mathematics is expected as the game presented to the students is unrelated to mathematics. There is no educational content related to mathematics in the game. We are, however, slightly confused with the statistically significant increase in interest for technology. Like mathematics, technology is not mentioned in the game. It is believed that the increase in interest could be contributed by the fact that most students has never tried VR devices before and therefore is intrigued by it. We advocate the interest increase in engineering could be attributed to the fact that students enjoyed the terrain editing and they understood that that is the product of engineering. For game engineering, the

TABLE III. K-CLASS SURVEY PAIRED SAMPLES STATISTICS AND TEST

Samples	*Paired Samples Statistics*				*Paired Samples Test*							
	Mean	*N*	*Std. Deviation*	*Std. Error Mean*	*Mean*	*Std. Deviation*	*Std. Error Mean*	*95% Confidence Interval of Difference*		*t*	*df*	*Sig. (2-tailed)*
								Lower	*Upper*			
Pre-test Score	3.76	38	1.497	0.243	0.316	0.842	0.137	0.039	0.592	2.313	37	0.026
Post-test Score	4.08	38	1.302	0.211								

increase in interest is considered to have a weak evidence against the null hypothesis ($p < 0.1$). Its change in interest is shown in Fig. 8 along with science. Game engineering is also not mentioned in the game. We are interested to see that by presenting a student a game-based learning experience, will their interest in game engineering increase. The ending result is that the student seems to be quite confused with what game engineering is despite a short description in the survey (the description is “the development of HelloPlanet requires game engineering”). In fact, an observer has reported that a student has raised the question of what engineering is when taking the survey. This could indicate that game engineering is not a concept that younger children might understand and should be given a more detail description if related research is done in the future. We hypothesize that if more students have a clearer understanding of what game engineering is, the increase in interest would be more evident.

B. Knowledge Gain

A science knowledge gain among students has been discovered. As demonstrated in Table III and Fig. 9, students are able to answer more questions correctly after playing the game. A paired t-test has been used and is shown to be statistically significant ($p < 0.05$). Although the improvement in answering questions in K-class is not dramatic (a student get a third question more correct than pre-test), this is reasonable as the students are only given 4 minutes to play the game. The students did not spend the entirety of 4 minutes to play the game freely to “learn and play”. Instead, in most of the time, they need to follow the guidance of the observer to play the game. It can, therefore, be expected that if the students are given more time to play, the effect of game-based learning will be much stronger.

We have also seen that for the question that has the largest improvement in student performance is one that is closely related to PMC. That question is “Higher altitude means…?” with an answer of “Higher temperature” or “Lower temperature” for the student to choose from. The ratio of students correctly answering this question hops from 68.3% to 78%. This implies that linking education with creative components such as PMC is beneficial for game-based learning.

C. Sex Difference

Independent t-test shown in Table IV shows that in the majority of times, males and females shows no differences. But that is not true in terms of an increase in interest in technology and game engineering. To discover the differences, male student and female student data have been separately processed by paired t-test.

Interestingly, it has been found that when separating male and female data, the male side shows that there is no change

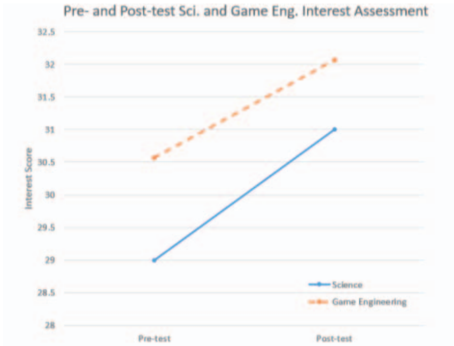

Fig. 8. Pre-/post-test changes in students’ interest in science and game-engineering with problematic data smoothed.

Fig. 9. Pre-/post-test changes in the correct answers students get in K-class questions.

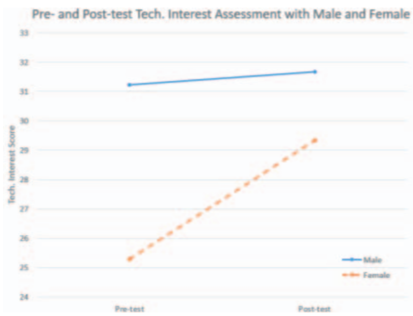

Fig. 10. Pre-/post-test male and female changes in interest in technology with problematic data smoothed.

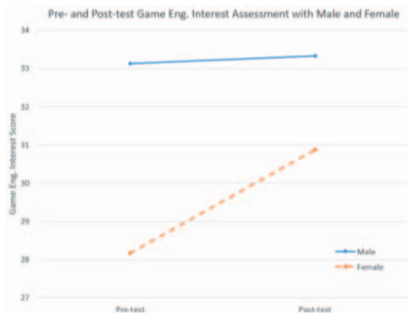

Fig. 11. Pre-/post-test male and female changes in interest in game engineering with problematic data smoothed.

TABLE IV. SEX DIFFERENCE IN TERMS OF CHANGE IN INTEREST AND PERFORMANCE

Samples	Group Statistics					Independent Sample Test									
	Sex	N	Mean	Std. Deviation	Std. Error Mean	Is Equal Variance Assumed	F	Sig.	t	df	Sig. (2-tailed)	t-test for Equality of Means		95% Confidence Interval of Difference	
												Mean Difference	Std. Error Difference	Lower	Upper
Pre-test, post-test Sci. Diff.	M	18	1.89	6.342	1.495	Yes	0.211	0.641	0.409	36	0.685	0.839	2.050	-3.318	4.996
	F	20	1.05	6.278	1.404	No			0.409	35.502	0.685	0.839	2.051	-3.322	5.000
Pre-test, post-test Eng. Diff.	M	18	3.28	4.909	1.157	Yes	1.375	0.249	-0.125	36	0.902	-0.222	1.783	-3.839	3.394
	F	20	3.50	5.960	1.333	No			-0.126	35.741	0.901	-0.222	1.765	-3.803	3.358
Pre-test, post-test Tech. Diff.	M	18	0.4444	2.727	0.643	Yes	9.352	0.004	-2.130	36	0.040	-3.606	1.693	-7.039	-0.172
	F	20	4.0500	6.692	1.496	No			-2.214	25.682	0.036	-3.606	1.629	-6.955	-0.256
Pre-test, post-test Game. Eng. Diff.	M	18	-0.39	3.071	0.724	Yes	10.721	0.002	-0.912	36	-0.368	-1.739	1.906	-5.604	2.126
	F	20	1.35	7.534	1.685	No			-0.948	25.682	-0.352	-1.739	1.834	-5.510	2.032
Pre-test, post-test K-Class Score Diff.	M	18	0.39	0.916	0.216	Yes	1.333	0.256	0.503	36	0.618	0.139	0.276	-0.421	0.699
	F	20	0.25	0.786	0.176	No			0.499	33.740	0.621	0.139	0.279	-0.427	0.705

TABLE V. I-CLASS SURVEY WITH PROBLEMATIC DATA SMOOTHED PAIRED SAMPLES STATISTICS AND TEST OBSERVING GENDER DIFFERENCE

Sex	Samples	Paired Samples Statistics				Paired Samples Test							
		Mean	N	Std. Deviation	Std. Error Mean	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of Difference		t	df	Sig. (2-tailed)
									Lower	Upper			
Male	Pre-test Tech.	31.222	18	5.560	1.320	0.444	2.727	0.642	-0.912	1.801	0.691	17	0.499
	Post-test Tech.	31.667	18	5.594	1.319								
	Pre-test G. Eng.	33.13	18	3.973	0.936	0.208	2.324	0.548	-0.947	1.364	0.380	17	0.708
	Post-test G. Eng	33.33	18	3.106	0.732								
Female	Pre-test Tech.	25.30	20	7.463	1.669	4.050	6.692	1.496	0.918	7.182	2.706	19	0.014
	Post-test Tech.	29.35	20	5.833	1.304								
	Pre-test G. Eng.	28.16	19	7.826	1.795	2.724	6.090	1.397	-0.212	5.659	1.949	18	0.067
	Post-test G. Eng	30.88	19	5.176	1.188								

between pre-test and post-test ($p >> 0.1$) in both disciplines. For male side game engineering, the stable data could be explained by the fact that the male students have already had a very higher interest in game engineering pre-test (M=33.13). The maximum interest score is 35. Their increase in interest simply cannot be measured with the current 7-point Likert scale. The female side, on the other hand, shows that the increase in technology is statistically significant ($p < 0.01$) while game engineering, similar to using a combined dataset, only held a weak evidence ($p < 0.1$). As there is a lack of female game engineers in the game industry, it is worth mentioning that this result implies that a method of motivating female students' interest in game engineering could be introducing STEM game-based learning games to them. The results are shown in Table V, Fig. 10 and Fig. 11.

D. Student Feedback

Students are showing very positive feedback from the surveys. Although the game is only played by the student for 4 minutes, students seem to enjoy the game and its terrain editing very much. With PMC, only a low development involvement is required to develop HelloPlanet. Yet, the result is extremely optimistic as >95% of students said they enjoyed the game and >85% of students said they think that terrain editing, therefore PMC, is important to the game. When asked about what they think is the most interesting aspect of the game, >40% answered "terrain editing" while > 45% answered that the "terrain editing" evoked their interest in game engineering. >75% answered that the game has raised their interest in science. SR is also introduced to the students and when asked about whether they think it is important for a game-based learning game, >80% agreed. When asked about whether the SR brought by the terrain editing, and therefore PMC, is an important SR because it enables the planet to have various terrain landscapes, >70% students agree. This shows that students could understand the concept of SR and bringing it to game-based learning by providing them with a fun experimentation platform is likely to be beneficial to their learning. Some students have commented on-spot similarly to "The game is very fun. It is like that I am actually changing an actual planet.".

Our PMC-based game is also compared with planets from other sources. Without mentioning the pros and cons of the planets and their generation methods, most students have chosen the PMC-based planet when asked about which one do they think is the most appealing and is most suited for simulation games. Given 4 choices, around 40% and >35% students choose our PMC-based planet to answer the questions respectively. This is a very encouraging result as, aside from empowered by PMC, HelloPlanet has only been developed in a relatively short period of time, yet our planet is the first choice for most students, with other three choices picked by students less than ours.

E. Teacher Feedback

Similar to students, teachers have also reacted favourably to HelloPlanet and subsequently PMC. All 4 teachers have commented that they believe their students are interested in the game and the game has or could motivate their interest in science. All of them also believe that the terrain editing is an important module for the game and it has attracted student interest in playing our game-based learning game. When asked about what is the most interesting part of the game, all of them have answered “terrain editing”. After being introduced to the idea of SR, all teachers agree that the SR achieved by PMC is important and all but one teacher believe that SR in an education game is very important as it provides a good experimentation platform for students. This again shows that SR is an understandable concept to the education sector and that there is a need for a fun, experimental platform for students.

VII. Discussion

A. Learning Gain

According to the data, students have made a statistically significant learning gain. Yet, on average, the improvement is less than one correct answer per student. We believe that naturally this is related to the study limit of students only having a very short period to play. If the play time is longer, the improvement should be greater. We also suggest that future study could consider asking more complicated questions that require students to reflect on the knowledge they learned. In this way, whether sandbox game-based learning could provoke deeper learning could be investigated.

B. Girls and Game Engineering

A very interesting and unexpected finding in this study is that sandbox game-based learning seems to have an effect on girls but not boys in their interest in game engineering. Despite changes in both sexes could not be considered to hold a strong evidence against the null hypothesis, the great difference in p-value undoubtedly represents a difference between the sexes. Of course, this could be related to the fact that boys are in general, originally more interested in games already, and already have a very high rating in interest in game engineering; while girls are less passionate about the subject, and therefore has more space to have an increase in interest. We further hypothesize that if the meaning of game engineering and its difference with games are better explained to the students, the data returned may behave differently and could better reflect students’ interest. We hold to the view that if the meaning of game engineering is understood better by the students, the change is possible to be more evident.

This surprising finding has two implications. Firstly, it gives hints on what games could attract female players. These results suggest that another type of games that could be appealing to females is education games that have a strong emphasis to teach players new knowledge. This finding echoes with the conclusion in [38], which states that females are interested in games that have real world application. Secondly, it provides an interesting proposition on how to attract more females to the game industry. It is believed that future research on the relationships between females’ interest in game engineering and STEM sandbox game-based learning would be fruitful. But female interest in game engineering could be more intricately linked with games that appeal to female as stated in [39].

C. Student Feedback

The very positive feedback from students could be attributed to the success of our PMC-based HelloPlanet. When asking to choose one of the planets from four planets, our PMC-based planet receives the most support from the students. We believe that the importance of SR, creativity and interactivity could be reflected from the students’ responses. Also, because the students are satisfied with the game, it could be deducted that they are comfortable with the VR environment as well. Hence, it implies that PMC is compatible with VR.

D. Teacher Feedback

Understandably, teachers have suggested that the period of time the student learn to play the game is too short. But this is a limit in our study as there are a limited amount of VR devices for the students. We are, however, surprised that the students have some difficulty understanding the HTC Vive controller since their generation should be familiar with gaming controllers. They have difficulty using the controller despite very clear guidance like “Press the trigger button on the back”. We advise future VR research studies with students should invest more time on teaching the fundamentals of the controller to the students first.

VIII. Conclusion

This study, via a game that uses a novel SR algorithm, has found that SR sandbox game-based learning seems to be able to stimulate young students interest in STEM. There are also implications that students have made knowledge gain. These results are satisfactory considering that the game is played in a very short period of time but clear change in students’ interest and knowledge is observable. Students and teachers feedback are very positive. An interesting possible implication on using game-based learning to promote interest in game engineering among girls is also presented. Lastly, the results show that a development direction for game-based learning game should consider three important components, SR, creativity and interactivity. Combining with the above finding, this paper has proposed a clear direction on how STEM game-based learning should move forward. It is suggested an interesting research topic could be which game design elements are best to consolidate those three components. Additionally, from the results of the data collected, other possible research topics could be how to enhance the student survey for evaluating their STEM interest and on the relationships between STEM game-based learning and interest gain in game engineering among female students.

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