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Bringing play back into the biology classroom with the use of gamified virtual lab simulations

Bina Rai[A]

Tan Hui Shin[B]

Leo Chen Huei[C]

A *Senior Lecturer, Science and Math Cluster, Singapore University of Technology and Design*

B *Undergraduate Student, Singapore University of Technology & Design*

C *Faculty Fellow, Singapore Teaching and Academic Research Talent Scheme, Singapore University of Technology & Design*

** Corresponding author: bina_rai@sutd.edu.sg*

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Abstract

Our study evaluated the integration of gamified laboratory (game-lab) simulations and virtual reality (VR) technologies into the biology curriculum in order to provide an engaging and interactive way for Gen Z (born after 1995) students to learn and understand key biology concepts in a simulated environment. We hypothesised that the students will have fun, learning through play and exploration of lab skills that may not be possible in standard educational settings. Our research question was, "Do VR game-lab simulations lead to an increase in a) student knowledge of DNA-based technology, b) intrinsic motivation to study key biological concepts, and c) self-efficacy in an introductory biology course?" In our study conducted at the Singapore University of Technology and Design, the freshmore (ages between 19-22) cohorts were randomly divided into three groups, control (n = 180 students), VR game-lab simulations experienced on a laptop (desktop VR, n = 180 students) and experienced using a headset (immersive VR, n = 90 students). The classes assigned to the control group were taught using the prior method (PowerPoint slides/chalk and talk). The biological concept covered was consistent in all groups and was the polymerase chain reaction taught using a crime scene investigation scenario. Data collected showed that the desktop VR group of students achieved the greatest improvement in quiz scores after the simulation as compared to controls and immersive VR. This correlated with the significantly reduced response times taken for quizzes too for the desktop VR group. This may be attributed to the fact that the desktop VR was a longer simulation, with in depth theoretical wikis and descriptions of relevant theory. The survey results revealed that the majority of students perceived that the simulations improved their learning of DNA-based technologies, were motivated to complete the simulation and felt more confident at the end.

Introduction

Higher education is transforming to remain relevant to the next generation. The newest students are changing the way schools serve and educate them (Global Research & Insights, 2018). A generation that rarely reads books or emails, breathes through social media, feels isolated and stressed but is crazily driven and wants to solve the world's problems (Du Plessis, 2011). Students from Singapore, which is a developed country, express these traits and hence, there is an urgent and unmet need for novel educational tools and teaching resources to improve students' engagement and learning outcomes. The Generation (Gen) Z (born after 1995) students at the tertiary level learn in a unique dynamic way and it is crucial for teachers at all levels to re-invent online learning resources to suit their style of learning. This will enable educators to continue to engage, motivate and re-instill the joy in learning.

The Gen Z in developed countries grew up playing computer games. They do not engage with textbooks that are static, text-based and rote. Based on the recent statistics of Pokémon Go players, the digital preferences of Gen Z is substantiated, with the greatest number of players (46%) aged between 19 and 29 years old (Forbes, 2016). Pokémon Go was a local phenomenon. To keep up with this digital revolution, teachers need to find online resources such as blogs and wikis that get them beyond the plain vanilla curriculum in the textbooks and come up with creative classroom set-ups (Cilliers, 2017). The development of educational games have disrupted the education sector and changed how students learned (Dichev, 2017). The Gen Z needs fast delivery of content with complex graphics. They are kinesthetic, experiential, hands-on learners who prefer to learn by doing rather than being told what to do or by reading text. Learning is no longer a spectator sport for them anymore (Rothman, 2016; Dauksevicuite, 2016).

Sibley, Nikula, and Dinwoodle (2017), reported about a group of graduate students who tried out a computer-based simulation based on an International Market course. This simulation aimed to transfer skills from classroom to workplace. The simulation succeeded in arousing greater behavioral and emotional engagement among students. It has also helped students develop cognitive understanding of the topic and boosted theoretical ability to apply theoretical knowledge to real life situations. In a separate study by Cózar-Gutiérrez and Sáez-López (2016), a group of graduate students pursuing a degree in primary education participated in a computer-based simulation activity called MinecraftEdu. This is the educational version of the virtual world game Minecraft. Most of the students agreed that gamified simulations made the subject more interesting and that the activity promoted active participation and better engagement with content.

Research regarding the effectiveness of games for science education is only beginning to emerge (Fleischmann & Ariel, 2016; Lynch & Ghergulescu, 2017). Sadler, Sonnet, Coyle, Cook-Smith, and Miller (2013) reported the implementation of a 3D biotech educational game (Mission Biotech), wherein gaming features were highlighted. A higher learning outcome, particularly with lower-level students, was observed. Notably, researchers from Denmark (Bonde, Makransky, Wandall, Larsen, Morsing, Jarmer, & Sommer, 2014) showed a 76% increase in learning outcomes by using a gamified laboratory (game-lab) simulation compared to traditional teaching, and a 101% increase when used in combination, suggesting an untapped potential for increasing the skills of science students and graduates. This study was tested on university students who were biology majors and the simulations were used in class as part of curriculum time. To the best of our knowledge, there is no evidence if a similar level of improvement to learning outcomes can be achieved for non-biology major students, whose motivation for studying biology may be lacking.

The gold standard approach towards teaching introductory biology to undergraduate students in the majority of higher education institutions adopts a combination of lectures, tutorials and laboratory (lab) sessions (de Jong, Linn, & Zacharia, 2019). Lectures and tutorials offer an effective means of transferring key biological concepts to students in a classroom setting. Lab sessions, on the other hand, provide crucial hands-on training of biological techniques designed to reinforce and apply concepts learnt in the classroom. Due to the limited lab time, cost of conducting lab class and facilities, students have to often work in groups and share research equipment and data. This compromises students' learning. It was shown that a better method of teaching is to stimulate the real experience in order to achieve the highest level of knowledge retention (>90%) (Dale, 1969). The idea of virtual labs is gaining traction (Makransky, Terkildsen, & Mayer, 2016; Jones, 2018) and virtual labs were voted as one of the top 10 emerging technologies in 2014 (Homes, 2014).

The primary aim of our study was to integrate game-lab simulations and virtual technologies into our biology curriculum in order to provide an engaging and interactive way for Gen Z, biology non-major students to learn and understand key biology concepts in a simulated environment. The specified game-lab simulations in this study were chosen because of its comprehensive, well-thought lesson plan that includes concepts in biology embedded in real world scenarios. It provides students all of the support needed to complete the lesson themselves in the form of immediate information via hints, feedback, theoretical wiki pages and test yourself questions at every stage. We hypothesised that the students will have fun, learning through play and exploration of lab skills that may not be possible in standard educational settings. In particular, students will find the gamification component and VR character of the simulations engaging. Our research questions were, "Do game-lab VR simulations lead to an increase in a) student knowledge of DNA-based technology, b) intrinsic motivation to study key biological concepts, and c) self-efficacy in an introductory biology course?"

Materials and Methods:

Approval from Institutional Review Board (IRB)

The study was approved by the IRB at the Singapore

University Technology and Design (SUTD) (Approval No: 18-172).

Experimental Design

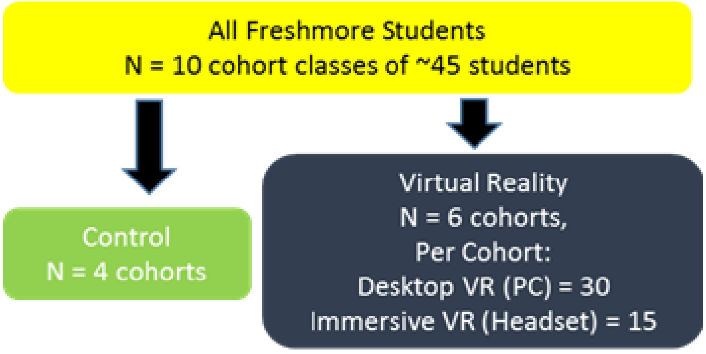

Figure 1: Diagram of the experimental design for the study.

In line with SUTD's unique pedagogy, our students were divided equally into cohort classrooms (~45/class), where all the lessons were carried out in their freshmore year (ages between 19-22). Unlike teaching in lecture theatres, the cohort classroom set-up at SUTD created a unique environment for carrying out research in pedagogy. The game-lab simulations were a part of the compulsory teaching curriculum for the 10.006 Natural World (Integrated Chemistry and Biology) module, and they were evaluated during week 10 of Term 1 of the freshmore year. In our study, the cohorts were randomly divided equally into three groups, control (n = 180 students), virtual reality game-lab simulation (desktop VR, n = 180 students) and immersive virtual reality game-lab simulation (immersive VR, n = 90 students) (Figures 1 and 2). The teaching team of instructors for 10.006 were experienced and had taught this lesson previously.

Figure 2: Photographs of students engaged in the (A-B) desktop and (C-D) immersive VR.

The game-lab simulation (Polymerase Chain Reaction Lab) that was evaluated in this study was developed by Labster (2016; Figure 3). In this simulation, students were thrown right into a crime scene where a murder had taken place. To investigate the crime scene, students' first task was to collect blood samples in the hope that the murderer had left traces of their DNA. Students will then proceed to the lab to analyse the DNA collected using a PCR kit and gel electrophoresis to see if they can identify the murderer. The classes assigned to the control group were taught using the prior method (PowerPoint slides/chalk and talk). The classes assigned to the desktop VR groups were taught using the gamified simulations integrated into the lesson material. For the classes assigned to the immersive VR groups, the students were taught using the game-lab simulations with VR goggles, again integrated into the lesson material. Hence, students in the immersive VR groups experienced the full 3D gamified virtual lab.

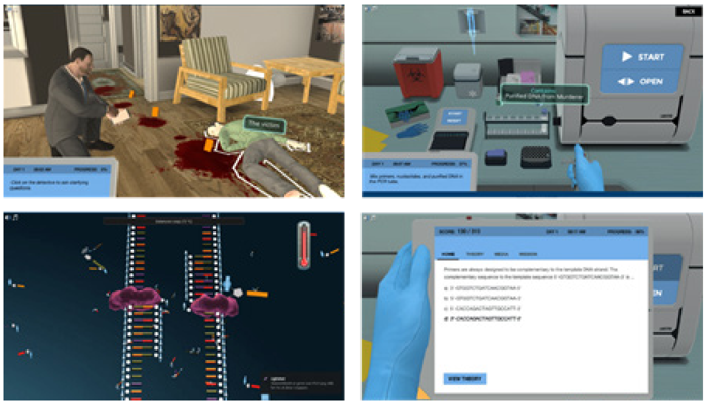

Figure 3: Screenshots of the polymerase chain reaction virtual lab simulation from Labster. https://www.labster.com/simulations/polymerase-chain-reaction/

Lesson Plan

The lesson plan for the two-hour cohort class, including the breakdown of the duration is illustrated in the following Figure 4.

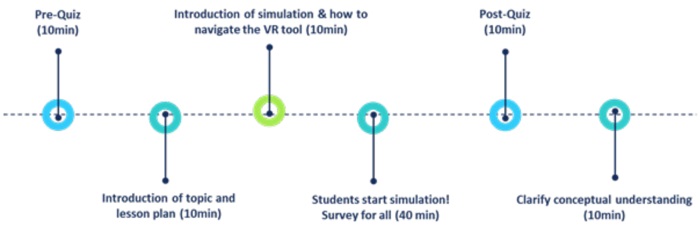

Figure 4: The lesson plan for the 2h cohort class for desktop and immersive-VR groups.

Measurement of Student Learning Outcomes – Quizzes and Response Times

Pre- and post- quizzes (with ten multiple choice questions that help students develop conceptual understanding) were used to compare the differences in acquired understanding and knowledge of the topic between the controls and experimental groups. This method was an adaption of the ConcepTests developed by Crouch and Mazur (2001). Students were required to individually complete a pre-quiz before attempting the activity and the post-quiz immediately after they had completed the simulation. Both quizzes were delivered via our university's learning management system, Blackboard, and we extracted data (scores and response times) directly from the grade center. Response times to the quizzes were automatically captured via Blackboard as the total time taken by the student from the moment he/she clicks start until clicking submit.

Student Feedback Surveys

All surveys were conducted anonymously and on a voluntary basis. Student feedback surveys were collected from experimental VR groups at the end of the simulations via three ways.

Survey 1: At the end of the simulation program, Labster has an embedded set of five questions as follows: 1. I gained relevant knowledge by using the simulation. 2. I found the simulation motivating. 3. I feel more confident about my lab skills after the simulation. 4. I feel that I can apply what I have learned in the simulation to real world cases. 5. In general, I was pleased with the simulation. Students are provided with four options – completely agree, agree, disagree or completely disagree, and took a minute to complete the questions. Labster refers to the compiled results of the survey as "Course Impact". There was a total of 131 students who responded to this survey.

Survey 2: We created our own student feedback survey within Blackboard to collect more data on the students' perceptions of the game-lab simulations, and if students perceived that it supported their learning. It consisted of seven multiple-choice questions (MCQ), adapted from Makransky et al. (2016). The MCQs were designed to assess any perceived improvements in self-efficacy, intrinsic motivation, knowledge gained and interest in biology. The MCQs were attempted according to the following scheme; 5 points for strongly agree, 4 points for agree, 3 points for neutral, 2 points for disagree, 1 point for strongly disagree. The questions asked were as follows; 1. Performing the simulation of the laboratory techniques added to my understanding of concepts of DNA technologies. 2. I would like gamified laboratory simulations to be used more in teaching. 3. Game-lab simulations can be a good supplement to regular teaching. 4. It is motivating to learn the concepts of DNA technologies through a scenario that resembles the real working situation of a forensic scientist. 5. It makes course content more interesting to work with real world examples. 6. It was interesting to use gamified laboratory simulations. 7. It is a good idea to use gamified laboratory simulations before trying out a real biology laboratory. Students were given five minutes in class to answer the survey MCQ questions, immediately after completing the simulation. There was a total of 109 students who responded to this survey.

Survey 3: We included two open-ended questions into the survey within Blackboard. This was to gather student opinions outside of what was collected in the second survey. The questions were as follows: 1. Do you have any general comments about the game-lab simulations (e.g. advantages/ disadvantages)? 2. Do you have suggestions on how to improve your experience using game-lab simulations for learning biology? Students were given five minutes in class to answer the survey open-ended questions, immediately after completing the MCQs. There was a total of 74 and 67 students who responded to questions 1 and 2 respectively.

Statistical Analysis

All data is presented as mean +/- standard error of mean. A Student's t test or one-way ANOVA with Tukey's post-hoc test was performed as appropriate to determine the statistical significance between control and experimental groups. A p value of > 0.5 was considered to be significant.

Special Note

We provided students from control groups a chance to attempt the simulations after the classes for the experimental groups were completed. The VR gear was set up for any student from the control group who wanted to try it out on one of the afternoons during term time.

Results

Student Learning Outcomes – Quizzes and Response Times

The mean pre- and post-quiz scores from the control, desktop and immersive VR groups are shown in Figure 5. The average scores of the pre-quiz were comparable between the groups (control: 74.7%, desktop VR: 69.3%, immersive VR: 70.0%), suggesting that the students had a similar background knowledge of the topic before the introduction of the game-lab simulation (Figure 5A). After teaching the topic to the students, the average scores of the post-quiz were significantly (P< 0.0001) higher for students in the desktop VR group (91.6%) compared to the students in control (82.2%) or immersive VR group (79.1%) (Figure 5B). The average scores of the post-quiz for students in the control and immersive VR group were comparable and not statistically different. Based on the cohort class, control teaching using the traditional (prior) method or immersive VR resulted in a modest 10-13% improvement between the pre- and post-quizzes (Figure 5C). However, students in the desktop VR group achieved a significantly increased score improvement (range: 10.7-56.5%, mean: 32.2%) as compared to either control or immersive VR groups.

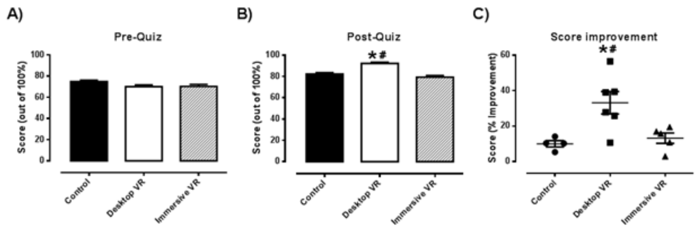

Figure 5: Mean quiz score achieved by students (A) pre- and (B) post-treatments. (C) The percent improvement in quiz scores demonstrated by class from the three treatment groups. Data shown as mean ± SEM. N = 141 (Control), N = 113 (Desktop VR), N = 64 (Immersive VR). * Significantly different to control; # Significantly different to immersive VR.

The average time taken for the students to complete the pre-quiz was found to be different between the groups. Specifically, students from the desktop (range: 3.67-5.36, mean: 4.12 min) and immersive VR (range: 3.41-4.26, mean: 3.76 min) groups completed the pre-quiz with significantly less time compared to the students from the control group (range: 4.54-6.37, mean: 5.08 min) (Figure 6A). However, after teaching the topic to the students in class, the average time taken for the students to complete the post-quiz was significantly reduced for students in the desktop VR group (mean: 3.09 min) as compared to the students from control (mean: 4.95 min) and immersive VR group (mean: 5.64 min) (P< 0.0001). The average time taken for the students to complete the post-quiz for students from the control and VR groups were comparable (p> 0.05) (Figure 6B). Overall, the students from desktop VR group took significantly less time to complete the quizzes in comparison to the control group. Interestingly, students from the immersive VR group took more time to complete the quizzes in comparison to students in the control or VL group (Figure 6C).

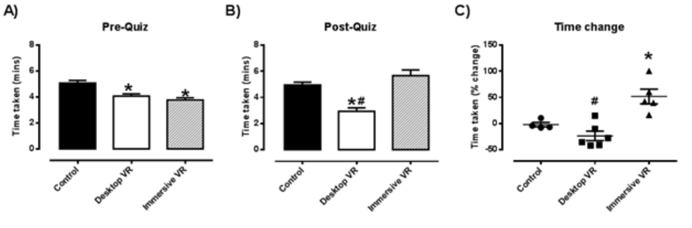

Figure 6: Mean response times (min) taken by students (A) pre- and (B) post-treatments. (C) The percent improvement in response times demonstrated by class from the three treatment groups. Data shown as mean ± SEM. N = 141 (Control), N = 113 (Desktop VR), N = 64 (Immersive VR). * Significantly different to control; # Significantly different to immersive VR.

We further divided the students into three groups based on their pre-quiz scores to determine if the game-lab simulation was more effective in improving learning outcome for students with or without prior biology background. Students with pre-quiz scores of less than 40% was classified as low (little to no prior biology knowledge), pre-quiz scores between 50-70% was classified as medium (some prior biology knowledge) and pre-quiz scores of more than 80% was classified as high (strong prior biology knowledge). Within the control group, students exposed to traditional teaching resulted in significantly increased post-quiz scores for the low student group (~33%). The magnitude of this increase was much lower (~13%) for the medium score student, and there was no observable effect for high score students (Figure 7A). The post-quiz scores were significantly increased for both the low and medium scores for students in the desktop VR group, in contrast to the control group. Notably, there was also a slight but significant increase in post-quiz scores (~10%) for the high score student (Figure 7B). Similar to the control group, there was a significant improvement in post-quiz scores for students from immersive VR groups in the low score students. It was noticed that there was a progressive loss of this improvement for the medium and high score students (Figure 7C).

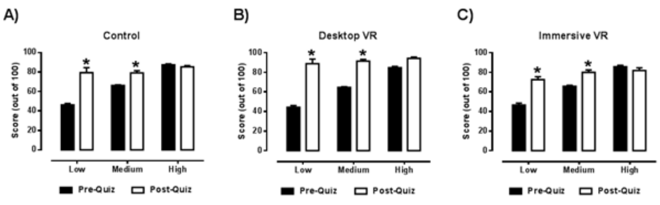

Figure 7: Mean quiz scores achieved by students from the three treatment groups, (A) Control, (B) Desktop VR and (C) Immersive VR. Students were divided into three bands, low (n<50), medium (50>n <70) and high (n>80) based on their pre-quiz scores. Data shown as mean ± SEM. N = 141 (Control), N = 113 (Desktop VR), N = 64 (Immersive VR). * Significantly different to pre-quiz.

To gather students' learning experiences of using the game-lab simulations, five survey questions within the Labster simulation were immediately posted after their session (Figure 8A). More than 90% of the students responded positively to the survey questions and agreed that the desktop VR simulations were effective for them to gain knowledge, found the simulation motivating and perceived self-efficacy (Figure 8B).

Survey Questions
1. I gained relevant knowledge by using the simulation.
2. I found the simulation motivating.
3. I feel more confident about my lab skills after the simulation.
4. I feel that I can apply what I have learned in the simulation to real world cases.
5. In general, I was pleased with the simulation.

Figure 8A: List of five survey questions that were asked within the game-lab simulation (desktop VR, via Labster).

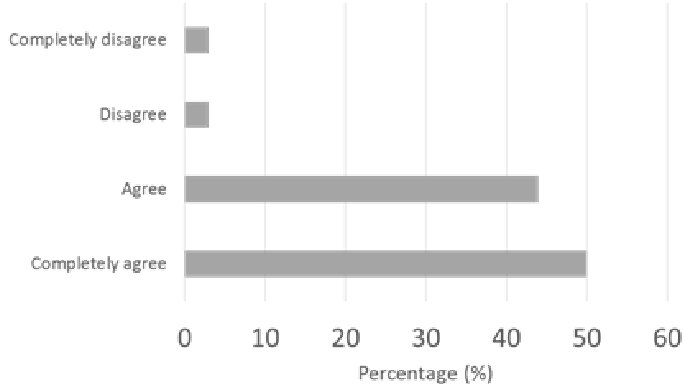

Figure 8B: Course impact based on student survey responses to the questions in (A). Students were provided with four options, completely agree, agree, disagree and completely disagree (number of respondents = 131).

Survey 2

The second survey consisted of seven multiple-choice questions assessed via Blackboard to capture students' learning experiences of using both the desktop and immersive VR. It was noted that about 90% of the students agreed that the game-lab simulations were a good way to learn concepts in biology and found them interesting and motivating. While the majority of students agreed that they would like to see more simulations used in the teaching course, there were 27.4% who strongly disagreed. In general, an average of 8% of the students remained neutral to the use of the simulations for learning in class (Table 1).

Survey Questions	Strongly Disagree (%)	Disagree (%)	Neutral	Agree (%)	Strongly Agree (%)
1. Performing the simulation of the laboratory techniques added to my understanding of concepts of DNA technologies.	0.86	1.71	9.40	41.9	45.3
2. I would like gamified laboratory simulations to be used more in teaching.	27.4	6.84	11.1	23.9	29.1
3. Gamified laboratory simulations can be a good supplement to regular teaching.	0.86	1.71	8.55	37.6	49.6
4. It is motivating to learn the concepts of DNA technologies through a scenario that resembles the real working situation of a forensic scientist.	0.86	0.86	5.13	38.5	54.7
5. It makes course content more interesting to work with real world examples.	0.86	0	5.98	27.35	64.1
6. It was interesting to use gamified laboratory simulations.	0.86	0	7.69	37.6	53.9
7. It is a good idea to use gamified laboratory simulations before trying out a real biology laboratory.	0.86	1.71	6.84	32.5	57.3

Table 1: Student survey responses to multiple-choice questions posed immediately after desktop and immersive VR treatments (via Blackboard). Students were provided with five options: completely disagree, disagree, neutral, agree and completely agree (number of respondents = 109).

Survey 3

Students were encouraged to pen down their general comments, including advantages or disadvantages that they envision based on their experience with both the desktop and immersive VR as a learning tool. Representative examples of students' comments for both simulations are grouped together in Table 2. It was noted that more advantages were highlighted by the students for the desktop VR as opposed to the immersive VR simulations. Similarly, there were minimal disadvantages listed for the desktop VR. We also collected feedback on how we could improve the students' experience with the use of VR simulations as end-users and have placed representative comments into Table 3. There were some very useful suggestions on how to design the simulations to be even more engaging and interactive, for e.g. including real-world consequences of the players' actions, including a voice-over, subtitles and possibly a Sandbox VR.

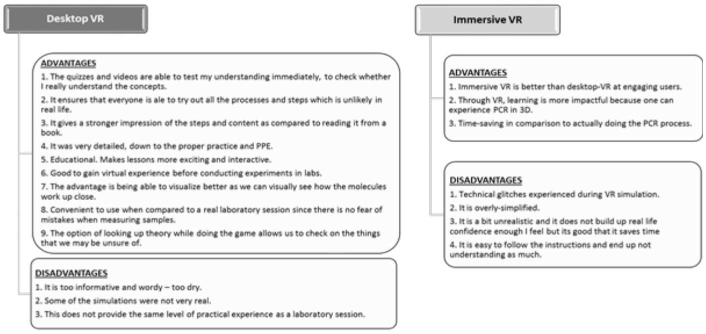

Table 2: Representative student survey responses to a short question posed immediately after desktop VR and immersive VR treatments (via Blackboard). Question: Do you have any general comments about the game-lab simulations (e.g. advantages/disadvantages)?

Students' Responses
1. It'll be good to show the consequences of the player's actions (e.g.: cross contamination) that affects the results and judgment of the player.
2. There wasn't enough time to look through all the videos and complete the stimulation within the time given.
3. Perhaps more of the molecules and processes could be gamified for better understanding of the mechanisms
4. More explanation in some areas would be nice, like how the gel works
5. Have a playback button. For VR after they speak, there is no chance for you to repeat what they say.
6. More obvious instructions on how to start.
7. Had to restart the game as I didn't know what to do at the start, ended up messing around and the game bugged out and didn't allow me to proceed.
8. More interactions can be added into the game such as when collecting pipette samples.
9. Maybe can do a voice over or have more engaging music.
10. I cannot finish reading on the LabPad sometimes because the instructions were going on, and I'm brought to another scene before I'm done looking at the LabPad.
11. Perhaps it will be better if the VR can have more mandatory quizzes and questions.
12. It will be better if we are able to use VR so we can see the movements of cells, the molecules and systems in 3D. Which helps us to visualize and understand what is going on
13. Maybe we could input some subtitles and sub headings for the names of (enzymes, processes) for better learning stimulation.
14. Would be great to have a sandbox lab game to mess around with experiments.
15. With or without real-life examples, I think looking at how molecules interact, it will be beneficial for our understanding.
16. More well-thought plot with better animations.

Table 3: Representative student survey responses to a short question posed immediately after desktop and immersive-VR treatments (via Blackboard). Question: Do you have suggestions on how to improve your experience using game-lab simulations for learning biology?

Discussion

In accordance to SUTD's unique curriculum, it is compulsory for all of our first year students to complete foundation science subjects, including introductory biology. Being an engineering and design-centric university, the undergraduate students have limited background and are possibly less inspired to study biology. It is sometimes challenging for the educators to keep the students engaged and motivated in a biology class. In addition, the traditional methods of teaching do not seem to appeal to our kinesthetic Gen Z learners in Singapore. It was also not possible for our students to have multiple lab training sessions like their counterparts enrolled in a life science degree program due to time and budget constraints in the biology curriculum. This created an urgent and unmet need for novel educational tools and/or teaching practices to improve students' engagement and learning outcomes for non-major subjects, in particular biology at SUTD.

We evaluated a possible learning solution where students could discover DNA-based technologies using a gamified virtual reality lab simulation. We hypothesised that learning via this approach would be well-aligned to Gen Z's inherent characteristics and our students in Singapore who are tech savvy and love computer games. Our rationale for this approach was based on the following advantages that we identified for using a simulation as a learning tool: 1. The gamification aspect included an interesting story line with fantastic visuals and virtual reality effects that made the simulations fun and engaging for the students. 2. The simulation was carefully chosen to match the key concepts of the lesson for the specified week. 3. The simulation was comprehensive and included test-yourself-MCQs and relevant theoretical information in the form of Wikipages. Students could only progress through the activity if they could answer the questions correctly. This provided them with immediate and useful feedback of their learning. 4. The simulation was a real-world problem that the students could relate to because they would have watched or heard of criminal science investigation on the television or social media. 5. The simulation was easily accessible via the SUTD's learning management system and available 24/7. 6. Students could work at their own pace and made mistakes in a safe environment.

In our study, the cohorts were randomly divided equally into three groups, control, desktop and immersive VR (Figures 1 and 2). For the classes selected for VR, 30 students (desktop VR group) were instructed to remain in class to experience the game-lab simulations on their own laptops. The students took about 30 to 40 minutes to complete the simulation. There were a couple of students in every class who experienced technical difficulties such as not being able to load the simulation (mainly Mac users) or not being able to progress, even though they had completed what was required and had to restart from the beginning. We had requested for our university educational technology specialist to be present in class to resolve these issues and had emailed the students prior to class a list of Labster system requirements as well. It was also noted that because our students were non-majors in biology, they struggled a little and spent some time following the sequence of certain lab techniques such as pipetting. Feedback from instructors were gathered real-time and they found that their classes which were usually very distracted and noisy became atypically quiet as the students were fully immersed in the simulations. The students appeared self-motivated and adequately challenged to complete the activity and find the murderer!

The remaining 15 students from each class were randomly selected to step outside into the attached think tank room to experience the immersive VR using the Samsung Gear headsets. There was one instructor and one research assistant present to assist the students. We first confirmed that none of them had any adverse health issues with regards to the use of the VR gear. Then, the students were debriefed on what to expect, how to progress throughout the simulation and how to operate the controls on the headset. We assisted the students in putting on the headsets. In the first class, students were provided chairs to sit on but we soon realised that they were crashing into one another. We removed the chairs from the subsequent classes and they experienced the simulation standing up, which worked out better. The students from the immersive VR group took about 20-30 min to complete the simulations. A couple of students had trouble progressing along the simulations and they were assisted by the instructors. In most of these cases, we had to restart the simulation for them. Instructors shared that it was evident that the students were excited to have been selected to do this activity and were completely engaged throughout the simulation. There was a concern raised that a couple of students may have rushed through the simulations, which may have limited their learning outcome.

Our results indicated that there was a clear positive learning outcome with the use of VR game-lab simulations as part of a lesson in an introductory biology course for undergraduates who were pre-dominantly non-majors. It was not surprising that the majority of the students agreed that the simulation was a good way to learn concepts in biology and found it interesting and motivating. This finding was similar to other studies, for example the one by Cózar-Gutiérrez and Sáez-López (2016), where a group of graduate students pursuing a degree in primary education participated in a computer-based simulation activity called MinecraftEdu. Most of the students agreed that game-lab simulations made the subject more interesting and that the activity promoted active participation and better engagement with content. If we made reference to the Self-Determination Theory (SDT) (Ryan & Deci, 2000), it takes into account our innate psychological needs for competence, relatedness and autonomy. It was evident that all of these three elements were embedded in the design of the PCR Lab simulation. The students satisfied their need for competence with optimal challenge and progress feedback throughout the simulation. Students were in control of and could determine the outcomes of their actions (autonomy) as a result of the storyline and different possible scenarios. The need for relatedness was satisfied as the students were playing the game together in a classroom setting. Students completed the simulations at different times and were actively interacting with one another throughout the process. We evaluated the desktop VR students' perceived self-efficacy via several questions in the survey, such as "I gained relevant knowledge by using the simulation." I feel more confident about my lab skills after the simulation." "I feel that I can apply what I have learned in the simulation to real world cases." Students agreed or completely agreed to the above statements, which indicated that using VR game-lab simulations for learning biology had resulted in an efficacious outcome.

The improved learning outcomes, as compared to control groups, were clearly seen with the students who experienced the simulations using their laptops. The students who experienced the simulations using the headset, on the other hand, achieved learning outcomes similar to control. This indicated that there was learning as expected, however not as significant as the desktop VR group of students. There could be several reasons for this observation. Firstly, the PCR Lab simulation on the headset was shorter in duration than the desktop version. This meant that there was less information available in the form of wiki pages describing the processes of DNA-based technologies. There were also fewer conceptual questions throughout the simulation. Secondly, there were several students who were excited and eager to complete the simulation on the headset and subconsciously rushed through it. We aim to manage this better in the next run. Thirdly, because students had the headsets on, it was challenging for us to monitor their progress to ensure that they did not miss out on anything. Learning biology in this manner could have also overloaded and distracted the learner, resulting in less opportunity to achieve learning outcomes as recently reported by Makransky et al. (2019). Having said this, students from the immersive VR enjoyed the experience and would like more of such simulations in the future as indicated by the survey results.

In conclusion, we report that undergraduate students from SUTD found the gamification component and VR character of the game-lab simulations engaging. These VR game-lab simulations lead to an increase in student knowledge of DNA-based technologies, specifically PCR and gel electrophoresis. Students were intrinsically motivated to study key biological concepts and perceived self-efficacy in achieving the learning objectives. It must be noted that this study was carried out in Singapore, where the majority of students at the tertiary level are digitally-oriented as they had access to digital devices from a young age. Hence, our approach may work well in developed countries with a similar demographic. In the future, we would like to consider the use of stand-alone VR headsets, instead of the ones used in this study that required Samsung mobile phones. This may, in the long run, result in cost savings and will streamline the process. It will also be interesting to conduct a longitudinal study to determine if the learning outcomes achieved from the simulations translate into better laboratory performance in an actual laboratory environment after a week and possibly result in deep learning and better application of the knowledge acquired after one term.

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References:

Bonde, M. T., Makransky, G., Wandall, J., Larsen, M. V., Morsing, M., Jarmer, H. Ø, & Sommer, M. (2014). Improving biotech education through gamified laboratory simulations. *Nature Biotechnology, 32*, 694-697.

Cilliers, E. J. (2017). The challenge of teaching generation Z. *International Journal of Social Sciences, 3*(1), 188-198.

Cózar-Gutiérrez, R., & Sáez-López, J. M. (2016). Game-based learning and gamification in initial teacher training in the social sciences: An experiment with MinecraftEdu. *International Journal of Educational Technology in Higher*

Education, 13(1), 1-11.

Crouch, C. H., & Mazur, E. (2001). Peer instruction: Ten years of experience and results. *American Journal of Physics, 69*, 970-977.

Dale, E. (1969). *Audio-visual methods in teaching* (3rd Ed.). New York, NY: Holt, Rinehart & Winston.

Dauksevicuite, I. (2016). *Unlocking the full potential of digital native learners*. Henley Business School, McGraw-Hill Education Handouts.

De Jong, T., Linn, M.C., & Zacharia, Z.C. (2013). Physical and virtual laboratories in science and engineering education. *Science, 340*, 305-308.

Dichev, C., & Dicheva, D. (2017). Gamifying education: What is known, what is believed and what remains uncertain: A critical review. *International Journal of Educational Technology in Higher Education, 14*, 1-36.

Du Plessis, N. (2011). *Social media in higher education: The case of Facebook*. Vaal University of Technology, North-West University: Vaal Campus, September 2011. Retrieved from http://utlo.ukzn.ac.za/Libraries/November_2011_Conferences/SOCIAL_MEDIA_IN _HIGHER_ EDUCATION_by_Plessis.sflb.ashx

Eastwood, J. L., & Sadler, T. D. (2013). Teachers' implementation of a game-based biotechnology curriculum. C*omputers & Education, 66*(1), 11-24.

Fleischmann, K., & Ariel, E. (2016). Gamification in science education: Gamifying learning of microscopic processes in the laboratory. *Contemporary Educational Technology, 7*(2), 138-159.

Forbes. (2016). *More women than men are playing Pokémon Go*. Retrieved from https://www.forbes.com/sites/ryanmac/2016/07/26/more-women-than-men-are-playing-pokemon -go-by-a-lot/#52b2556413dc

Global Research and Insights. (2018). *Beyond millennials: The next generation of learners*. Retrieved from https://www.pearson.com/content/dam/one-dot-com/one-dot-com/global/Files/ news/news-annoucements/2018/The-Next-Generation-of-Learners_final.pdf

Homes, J. *(2014). Ten emerging technologies and how will they impact education in 2015?* Tech 2.0 Education and knowledge resources. Retrieved from https://www.ibm.com/developerworks/ community/blogs/82288880-044e-425b-8c33-eff85a81d066/entry/10-emerging-technologies?lang=en

Jones, N. (2018). The virtual lab. Can a simulated laboratory experience provide the same benefits for students as access to a real-world lab? *Nature, 562*, S5-S7.
Labster. (2016). *What is Labster?* Retrieved from https://www.labster.com/what-islabster/

Lynch, T., & Ghergulescu, I. (2017). *Review of virtual labs as the emerging technologies for teaching stem subjects*. 6082-6091.10.21125/inted.2017.1422.

Makransky, G., Terkildsen, T.S., & Mayer, R.E. (2019). Adding immersive virtual reality to a science lab simulation causes more presence but less learning. *Learning and Instruction, 60*, 225-236.

Makransky, G., Thisgaard, M. W., & Gadegaard, H. (2016). Virtual simulations as preparation for lab exercises: Assessing learning of key laboratory skills in microbiology and improvement of essential non-cognitive skills. *PLoS One, 11*, e0155895.

Rothman, D. (2016). *A tsunami of learners called generation Z.* Retrieved from https://mdle.net/Journal/A_Tsunami_of_Learners_Called_Generation_Z.pdf

Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development and well-being. *American Psychologist, 55*(1), 68-78.

Sadler, P. M., Sonnert, G., Coyle, H. P., Cook-Smith, N., & Miller, J. L. (2013). The influence of teachers' knowledge on student learning in middle school physical science classrooms. *American Educational Research Journal, 50*(5), 1020-1049.

Sibley, J., Nikula, P. T., & Dinwoodle, R. (2017). Accelerating academic acculturation and the development of self-directed learning capability through online simulation. In E. Erturk, K. MacCallum, & D. Skelton (Eds.), *Proceedings of the 8th Annual Conference of Computing and Information Technology Education and Research in New Zealand*, 2nd-4th October, pp. 44-49.