THE GEOTHERMAL WORLD VIDEOGAME:

AN AUTHENTIC, IMMERSIVE VIDEOGAME USED TO TEACH OBSERVATION SKILLS NEEDED FOR EXPLORATION

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ABSTRACT

Interviews with geothermal professionals have identified geothermal concepts (i.e. knowledge) and skill sets that entry-level geologists commonly lack when beginning a career in the geothermal energy sector. To help address these issues, an authentic and immersive 3D free-roaming videogame called ‘The GeoThermal World’ was designed and piloted in 2012 at the University of Canterbury to teach undergraduate students about geothermal fieldwork and resource exploration.

An experiment was carried out to compare students’ learning experiences in a real fieldwork activity at Orakei Korako to learning experiences in the virtual setting of the videogame. Both settings were designed with the same outcomes in mind: to provide the students with a level of background knowledge and operating procedures to do basic geothermal fieldwork. Several datasets were collected to characterize the students learning and to allow us to compare their overall experiences and perceptions of the tasks in different settings.

In both activities, we aimed to teach the students how to observe, characterize and record geologic information at a hot spring. Preliminary results indicate that both settings are successful at teaching geothermal concepts with some strengths and weaknesses identified in both. However, the settings seem to be complementary to one another. Hence, ideally, field teaching experiences as a part of the undergraduate geology curriculum could be supplemented by digital or virtual experiences. This may cut down on the time required to ‘skill-up’ new entry-level geologists who may be lacking geothermal-specific field knowledge and skills. Further development of ‘The GeoThermal World’ will allow us to refine the authenticity and create more complex virtual geothermal settings and challenges.

1. INTRODUCTION

“Fieldwork gives opportunities for learning which cannot be duplicated in the classroom. It greatly enhances students’ understanding of geographical features and concepts, and allows students to develop specific, as well as general skills” (H.M.I. (Her Majesty’s Inspectors) 1993). Many geologists may think that field trips are the best (and possibly only) way to teach certain concepts and skills in geology but “… effective learning cannot be expected to follow just because we take students into the field” (Lonergan and Andresen 1988). Field trips have been shown to offer many valuable opportunities to learn theoretical concepts taught within the Geosciences (e.g. Elkins and Elkins 2007; Kern and Carpenter 1986) however there is a paucity of rigorous education research on practical skill development (such as observations, taking measurements, and note-taking), particularly in higher education.

Skills are thought to be acquired best through participation (active learning), hence activities are needed through which skills can be learned, and practiced in the field setting (Lonergan and Andresen 1988). Observing, measuring and recording data from outcrops and natural phenomena are regarded as part of the primary skills that a field geologist should have (noted amoung other commonly taught field skills in Nicholas, 2000). A main educational research question then becomes: How can we effectively teach field-based geology skills? Can we utilize videogames to achieve the same learning outcomes?

In recent years, virtual environments have emerged as a popular means of teaching geology and other science disciplines. There are different forms of technology (or media) that has been developed to supplement or even replace field trips and have been thus far aimed at secondary and introductory levels of the geosciences. These include: virtual laboratories (Clary and Wandersee 2010), virtual field trips (Browne 2005), and two-dimensional videogames (Schwert, Slator, and Saini-Eidukat 1999). ‘GeoThermal World’ is the one of the first 3D, fully immersive videogames designed to teach upper-level students authentic geological skills.

Videogames can enable learners to see and interact with natural geologic phenomena that may be difficult or expensive to access. Interactive technology (like videogames) can present learners with explicit challenges, that provides instant, individualized feedback customized to the needs of each student (Honey and Hilton 2011). This level of one-on-one feedback is difficult to replicate in real life with students in the field.

Aside from general skills, geothermal geology is not typically required or the main focus of current curricula within undergraduate programmes in New Zealand. Exposing students to academic and applied geothermal topics, as well as possible career options for geothermal geologists (a growth industry in New Zealand) have been a secondary aim of this project.

Figure 1: (Top) A photograph of the Hochstetter Pool (foreground) at Orakei Korako which the students were asked to describe in the field (Photo taken by Daniel Hill). (Bottom) A screenshot of one of the three, fictitious Sapphire Pools which were described by the students in the GeoThermal World videogame.

We discuss here the learning gains (i.e. knowledge acquired) achieved from a virtual field locality (the Sapphire Pools) within the videogame, compared to an actual field locality (the Hochstetter Pool) at Orakei Korako. Images of both settings are included in Figure 1.

Overall we aimed to help students develop and apply a systematic and conscientious approach to geothermal geology and exploration. Both activities were designed with the same task-specific learning goals, which include transferable skills (i.e. skills that can be applied to any geologic field or scientific activity):

After participating in the videogame or field trip activity, students will be able to:
1. Make and record visual observations at a geothermal hot spring.
2. Know how to take quantitative measurements (e.g. conductivity) at a geothermal hot spring.
3. Perform goals 1, and 2 in order to fully characterize a geothermal hot spring in a geologic notebook.

The following section describes the methodology used to carry out a comparative experiment which was designed to measure the knowledge acquired (i.e. learning gains) from both activities.

2. METHODOLOGY

Educational researchers utilise quantitative and qualitative methods and instruments to characterize and measure students' learning experiences. In order to understand whether a student learned something from the two activities, we designed a short three question skills test which could be given before the activities (pre-test) and after the activities (post-test).

Qualitative data (such as interviews, and student notebooks) were also collected from both studies, and will be the focus of future research that helps us to probe deeper into both learning experiences. The following subsections briefly describe the student population, the details of each activity, and the design and marking of the skills test.

2.1 The Student Populations

Our two study populations (field, and videogame) were made up of mostly 3rd and 4th year (Masters) Geology students, with a subset of Non-geology science majors (e.g. Environmental Science, or Biology). 40 students participated in the field study, and 25 students participated in the videogame study. 13 of the students from the field study also played the videogame. This allowed us to compare their individual test results and overall experience with both activities.

2.2 The Field Study

The field study consisted of a roughly 1-hour activity at the beginning of a typical field trip day at the Hochstetter Pool at Orakei Korako on Feb 2nd, and 3rd 2012. The class was split up into two groups with ~25 students and 3 different instructors. The three instructors were briefed with a specific set of tasks and 'rules' to allow us to control the content (i.e. how much and what kind of information was given) and context (i.e. how much reasoning and relationships are explored) under which the tasks were taught at the hot spring.

The field activity began by asking the students to describe the overall/surrounding geology and then leading them to describe the water, sinter, and vegetation properties of the locality. Many of the observations (such as colour, clarity, and activity of the water) were 'new' types of observations to make at a field site for many of the students. After location sketches and observations were made, one of the instructors illustrated how to measure the conductivity, temperature, pH, and take a sample of the water to send to a laboratory for chemical analysis. The activity concluded with a 'summary log' (on the back of their 'notebooks) of each observation type where the professors ask aloud to the entire class: "What is the 'right answer here?' for this particular field site.

During the activity, the instructors encouraged the students to ask questions and they were allowed to engage in normal field trip discussions. The education researchers were present to observe and record the tasks as well as the instructor-student interactions. It should be acknowledged that this style of teaching for some instructors is not ideal. However, these barriers were set in place in order to allow us a more confident direct comparison with the tasks that have been statically engineered into the videogame. This was intended to decrease the unknown variables that could impact the overall learning experience.

2.3 The GeoThermal World Videogame Study

The videogame study consisted of many 1-1.5 hour lab-style sessions where 1-6 students played individually and in pairs over several days in June 7th, 8th, and 12th 2012. The computers were set-up adjacent to one another like a typical computer room/lab setting. Video observations were recorded to follow the behaviour, and student language use

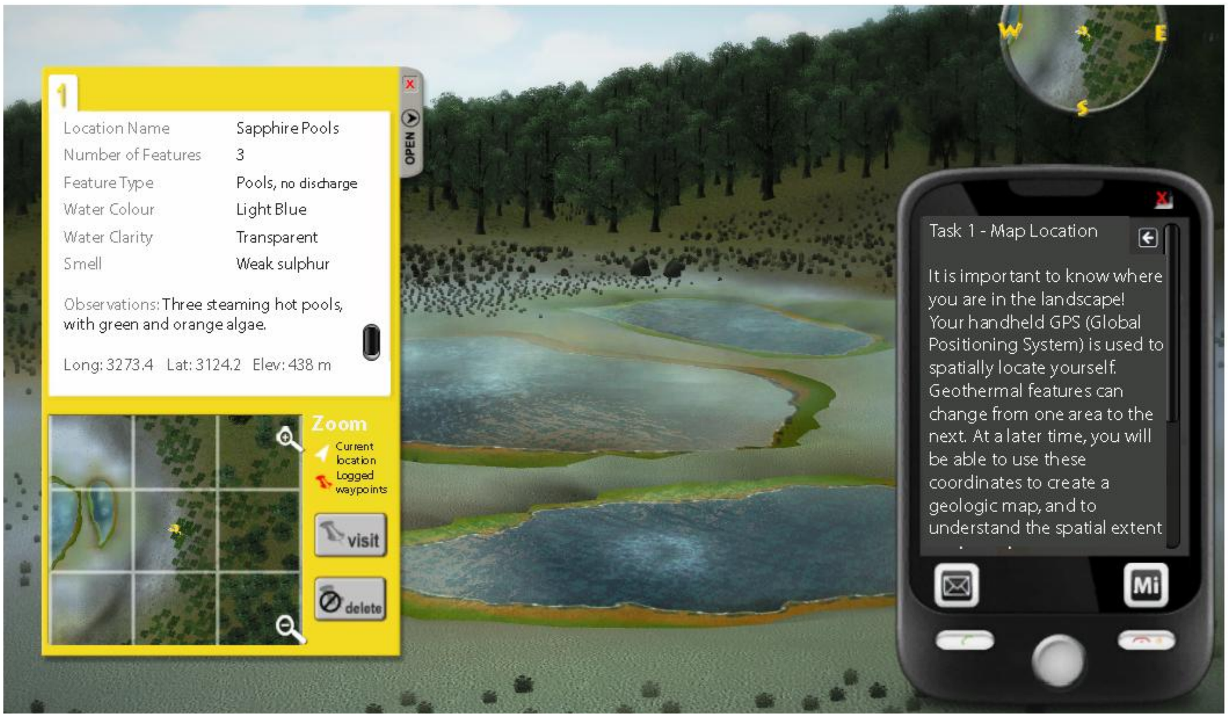

Figure 2: A screenshot of the Sapphire Pools, with two important tools which were developed for the videogame. (Left) A digital geologic notebook which has drop-down options (e.g. Number of features, etc.) and a section for written observations. (Right) The students' Smartphone, which contains hints and contextual information to guide the student through the observations of the hot pools.

during their experience with the game. The game is designed to be self-run, but students were instructed that they could ask us (the researchers) and the other students in the room questions if they wanted to.

The videogame begins with a fly-through of the 'World' around an active volcano and into a field site adjacent to a small town. The student geologist is told that their 'Mission' is to explore the geothermal features, and balance environmental concerns with economic/industry concerns of the company for which they are now employed. With little intervention, the students are guided to make their own observations of the Sapphire Pools: a. Take photographs and b. measure quantitative data just as in the field study. Familiar tools were created for the videogame such as: a gps, geologic notebook, camera, temperature probe, pH and conductivity probe and 'hands' that will safely take a water sample for chemistry. These tools were designed to be as they are in real life, with some modifications to make playing the game more intuitive (Refer to Figure 2).

The students' progress is guided by several design items such as drop-down options within the digital geologic notebook; 'hover hints' (where a tool is further described by hovering your mouse over the item); a Smartphone tool (where the company manager can email the student) to provide context for why they are taking the measurements; and a field assistant (Hamish) who is located nearby to provide some guidance if the students are stuck. The game concludes when the student has successfully written geologic notes, selected the right observations, measured the highest readings, and taken several representative photographs of the field site. Due to time constraints we were unable to include the 'summary log' mission (as performed in the field activity).

2.4 The Skills Test:

The pre-post skills test was a paper-based test which was designed and administered in order to assess the student's knowledge of observation and measuring skills that are needed at a geothermal hot spring before and after the activities. Each question is linked to the learning goals that are set out for the activities. It should be mentioned that we are not assessing their ability to make observations, but rather their knowledge of 'what they should do'.

Question 1 consisted of an open-ended, short-answer style question: "Question 1. (a) List as many types of visual observation data as you can, that can be collected at a geothermal hot spring. (b) For each type of data, write the reasoning for why you collect it (what is the purpose for collecting it?)". Question 1 made up the majority of the marks on the test with twelve correct observation types that should be noted (e.g. the colour of the water, the textures of sinter near the springs, and the surrounding geological features, etc.) when thoroughly describing a hot spring. Each observation was awarded 0-1 mark for listing each type (Question 1a.), and 0-3 marks for the reasoning provided (Question 1b.) for a total of 48 marks. This style of question (open-ended; short answer) was chosen purposely and allows us to probe specific student responses for not only awareness of items, but the depth of their responses - which is not possible with multiple-choice style questions.

Question 2 was made up of three multiple-choice questions (worth 2 marks each), which asked the student to locate places on a diagram of a hot spring to safely and accurately take temperature and conductivity readings, as well as identifying what white-coloured material may be surrounding a high temperature pool.

Question 3 asked: "Of the following, which is NOT an effective method when sampling &/or visiting geothermal hot springs?" Of the nine options, the incorrect responses were: 1. Tasting a small amount of the water; 2. Digging in the ground adjacent to the hot spring; and 3. Taking 10 pH readings.

Testing 'conditions' at Orakei Korako were not entirely controlled as it was given 'in the field', with some noise and visual distractions that come from being at a tourist location. However, in both studies all of the students were given as much time as needed to fill out the tests (most students completed them in approximately 15 minutes), and were not allowed to share their responses with others.

2.5 Marking the Skills Test:

Question 1 is an open-ended question and in order to mark it objectively, a 'rubric' was designed to award students for (a.) listing the correct items and for (b.) showing a high/or low level of understanding of why we take this sort of data. A rubric refers to a set of guidelines/criteria which is used to grade students uniformly, in what is considered a qualitative assessment (with more inherent subjectivity) (Arter and McTighe 2001). Different marks were awarded based on the level of sophistication reached for each category (e.g. poor, adequate, good, and excellent). The well-designed rubric helped the marker to be unbiased, and consistent when considering all the responses.

For example, two students are asked to explain why we observe water clarity at hot springs: Student A (low-level) simply wrote: "composition". They received 0.5 out of 3 marks. While Student B (high-level) wrote: "[transparency] of fluids, how clear is the water? [It] can indicate [the] amount of material in solution and this [can] be a proxy for temp[erature] (higher T = more dissolved, less cloudy)". This response received 2.5 out of 3 marks.

Marking of the multiple choice questions (Questions 2, 3) was straightforward with either correct (2 marks) or incorrect (0 marks) responses noted.

3. RESULTS & IMPLICATIONS

Hake (1998) published a seminal work that provided education researchers with a sound metric that normalizes each student's individualized learning 'change'. 'Learning gains' (commonly shortened to 'gains') are calculated by:

$$\text{Learning gains} = \frac{(\text{Post-test \% - Pre-test \%})}{(100\% - \text{Pre-test \%})}$$

Positive gains indicate that the student in question scored higher on the post-test than on the pre-test. Negative gains indicate the opposite. For example: Student A receives a pre-test score of 30%, and a post-test score of 44%. This results in a 0.2 gain. Student B receives 80% on the pre-test and 84% on the post-test resulting in same gain (of 0.2). The change in learning is dependent on each student's individualized 'starting point'. Normalizing the change in test scores allows us to compare them to one another and assess whether or how much they 'learned'. Averaging an entire population will show whether the majority of students acquired positive learning gains, or negative ones. Comparing learning gains with pre-test or post-test scores will also allow you to differentiate between the impact that the experience had on specific demographic groups within your study population; or between two differing teaching methods.

3.2 Results: Overall Learning Gains

We set out to test whether a videogame could effectively teach field-based skills when compared to a real world field activity. Overall, the skills test results indicated that both learning activities are capable of generating positive learning experiences. The change in scores from the skills test among students in the field was marginally greater than for students in the videogame. Learning gains with the field activity (0.12 ± 0.09) reaching slightly higher totals (Figure 3) than the videogame (0.06 ± 0.07). Elkins and Elkins (2007) note that the field teaching typically results in higher learning gains of concepts when compared to traditional lecturing techniques. This data suggests that students can also acquire positive skill sets from field learning, which are equivalent to the videogame we have designed.

3.3 Student Demographics

Aside from overall (average) learning gains, it is helpful to plot specific demographic groups within each population to determine if they were affected by the activities in different ways. We categorized the skills test data into: 1. Age; 2. Gender; 3. Academic background; 4. Field experience; and 5. Videogame experience.

No significant correlations were found, which indicates that learning gains (and the students' learning experiences) were not affected differentially by the above parameters. Two plots are worth noting however. Figure 4A shows a plot of the field results, sorted by the students major, and experience (e.g. Geology Major, 3rd yr). Figure 4B shows a plot of the videogame results, sorted by whether the student had been at Orakei Korako ("Yes") or not ("No"). On average for both of these plots, the students learning gains are similar, but the pre-test values are not.

This implies that regardless of the discipline of the student, their predisposed skill set, or their previous experiences that equivalent learning gains occurred. Videogames can be commonly regarded and research has shown that men can perform better than females, or that possibly 'gamers' may succeed while 'non-gamers' may not (Brown et al. 1997). Several of our participants stated that they "Never" or "Sometimes" played videogames and achieved some of the highest gains from the study group. Based on these preliminary findings, we are confident that our game design appears to be successful at teaching people from all backgrounds about geothermal hot springs.

3.4 Item Analysis of Question 1 (Observations)

A breakdown of the student's responses to Question 1 further support the idea that both learning activities were successful at increasing the students' knowledge to observe hot springs. There are two elements that we can derive from the student's responses of Question 1: (a.) Whether particular categories/items of observation were known to them, or became known to them (i.e. awareness) after the activity (e.g. did they list 'colour' in the post-test, but not in the pre-test?) and (b.) Did the student's reasoning become more sophisticated between the pre-test and post-tests? [i.e. inferring a change in the depth of their understanding; represented by a spectrum of marks between 0 (low) to 3 (high)].

The responses from both study populations were collated (for each student) and it appears that both were effective in creating awareness of the types of observations that scientists record at hot springs (Table 1). The overall positive change in the number of students' awareness of observations was almost identical [averages of 13% (field), and 12% change (game)]. This again showed that the game was equally successful at teaching students to know what to look for when making observations at geothermal areas. The videogame showed improvement across more categories than the field activity, although the field activity showed bigger improvements in some categories.

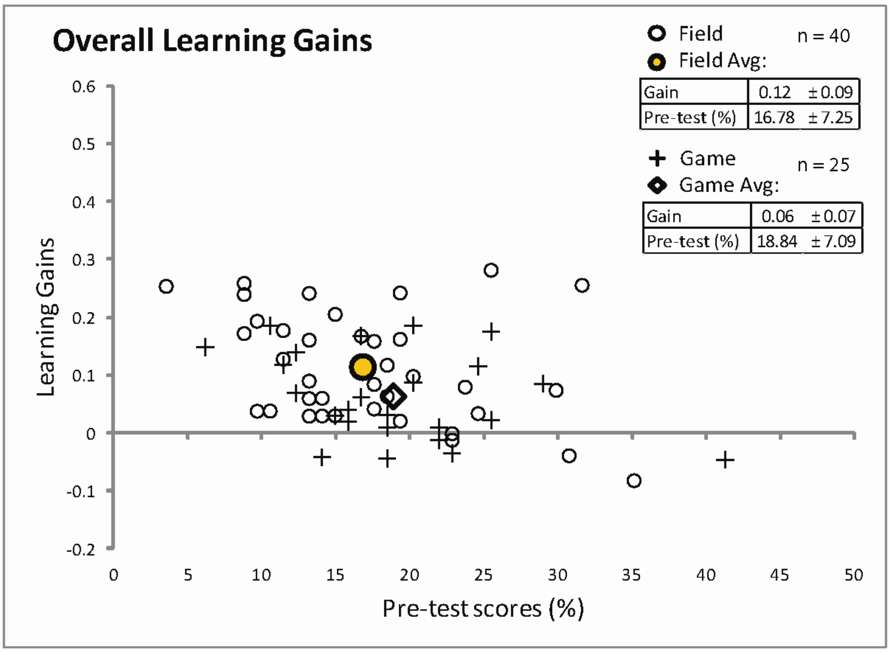

Figure 3: A learning gains versus pre-test score plot of the skills tests. The two study populations are shown (Field, circles; and Videogame, crosses) as well as their averages. Overall, both learning activities resulted in positive learning gains implying that the students 'learned something'. The Field activity resulted in marginally higher learning gains (on average).

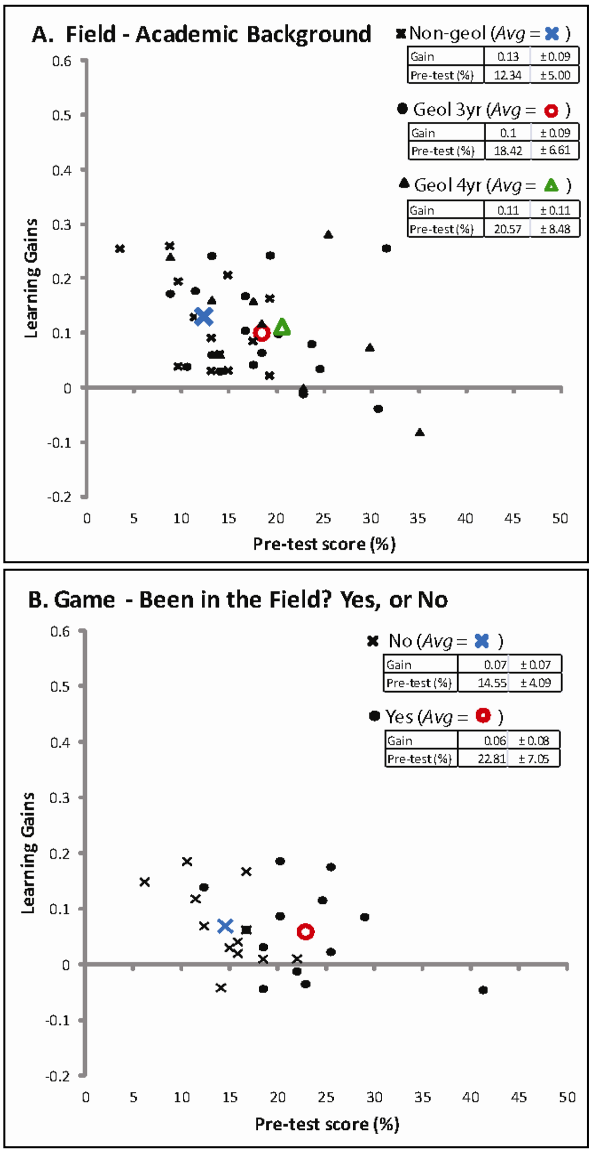

Figure 4: (A) A gains versus pre-test plot of the field study data which has been sorted based on the students' academic background. Note that the non-geology majors had a smaller pre-test score, but (on average) had equivalent gains. (B) A gains versus pre-test plot of the videogame study data. Here, the students have been sorted between the students who have been in the field study (Answered: "Yes") and those who had not (" No"). Again, this is illustrating that they came into the study with less knowledge (lower pre-test score) but achieved equivalent gains.

The field was highly successful at bringing awareness to the water properties, notably the activity of the hot springs (change of 65%!) which is likely due to a sensory effect (seeing the boiling water, hearing it, smelling it), it being a novel (or new) observation to be taken; or that the instructors may have focused (spent more time) on this observation. While, the videogame showed more successful changes with the close-up surrounding features (e.g. sinter textures, algae, and vegetation). This is likely due to the explicit nature of the game (in addressing each observation in turn; allowing students to derive what they feel is important) while field teaching tends towards being more holistic, and less explicit in nature.

Generally, both activities were less successful (i.e. had negative or negligible values) at bringing awareness to the other geological information and classification of the features. Negative values could indicate that students thought these types of observations were less important to focus on, or note. Alternatively, it may be that the students shifted their focus onto the most immediate/important observations (what are the properties of the water?). This result is surprising, as usually field activities are better at teaching contextual information. Classification in particular was not the focus (or one of the major learning goals) of the activities – but will be the focus of future field research and videogame levels.

Change in Awareness of Items to Observe

	Items:	Field (n = 40) Pre (%)	Post (%)	Change	Game (n = 20) Pre (%)	Post (%)	Change
Water properties	Colour	30	58	**28**	39	70	**30**
	Clarity	5	70	**65**	29	52	**24**
	Smell	3	25	**23**	21	43	**22**
	Activity of the feature	68	83	**15**	68	83	**15**
Close-up	Mineralogy	55	58	2	32	4	***-28***
	Sinter	18	18	0	29	52	**24**
	Algae	18	25	8	14	39	**25**
	Vegetation	25	60	**35**	36	48	**12**
Other	Number of springs	8	15	8	21	26	5
	Size of springs	35	20	***-15***	18	17	0
	Other geological info	68	53	***-15***	43	52	9
	Classification	23	20	-3	14	22	7
			Total Avg	13		Total Avg	12

Table 1: The values above represent the changes in 'awareness' that were recorded in categories of observations that the students exhibited, from Question 1 of the skills test. Orange values represent >10% (positive) changes of awareness, and blue values represent >-10% (negative) changes of awareness.

Table 2 lists the changes in 'sophistication' or depth of student responses after participating in the learning activities. Categories with higher averages had more 'high level responses' (e.g. marks of 2.5 or 3). Overall, the field activity was slightly more effective at students developing a deeper understanding of why they collect particular observations (with an average of 0.14 for the field, and 0.1 for the videogame).

Both activities were successful at 'deepening' the students' knowledge around water properties (e.g. colour, clarity, and smell). The field was more successful at deepening students' understanding in most categories; The game showed more improvement than the field at smell, algae, and other geological information. Based on our current understanding of field learning, it is not surprising that most categories were better/deeper understood from the field activity. Classification was better understood in the field, and this shows the strengths behind following the highly contextualised nature of field learning. While, the videogame was not designed to delve into chemistries and classification of hot springs it is reasonable that values for this category are not significant.

		Change in Sophistication of Response					
		Field (n = 40)			Game (n = 20)		
	Items:	Pre (Avg)	Post (Avg)	Change	Pre (Avg)	Post (Avg)	Change
Water properties	Colour	0.13	0.46	**0.34**	0.41	0.57	**0.15**
	Clarity	0.04	0.51	**0.48**	0.21	0.50	**0.29**
	Smell	0.03	0.26	**0.24**	0.11	0.43	**0.33**
	Activity of the feature	0.46	0.65	**0.19**	0.36	0.39	0.03
Close-up	Mineralogy	0.36	0.35	-0.01	0.23	0.00	***-0.23***
	Sinter	0.13	0.19	0.06	0.18	0.24	0.06
	Algae	0.08	0.20	**0.13**	0.07	0.26	**0.19**
	Vegetation	0.18	0.48	**0.30**	0.29	0.28	0.00
Other	Number of springs	0.04	0.09	0.05	0.11	0.20	0.09
	Size of springs	0.16	0.14	-0.03	0.00	0.09	0.09
	Other geological info	0.69	0.48	***-0.21***	0.29	0.41	**0.13**
	Classification	0.11	0.24	**0.13**	0.07	0.13	0.06
			Total Avg	**0.14**		Total Avg	**0.10**

Table 2: The values above represent the changes in 'depth' or sophistication that were recorded in categories of observations that the students exhibited, from Question 1 of the skills test. Orange values represent >0.1 (positive) changes, and blue values represent >-0.1 (negative) changes in the depth of reasoning that the students used in that category.

It is interesting to note that a videogame (virtually-constructed) was actually more successful in teaching students about why smell is relevant to observe at hot springs. In order to create 'smell', we put 'word clouds' that would pop-up over the steaming water with the words: 'Eggy'. Text within their Smartphone would help explain why egg smell is related to H_2S emissions; and generally why we observe smell at hot springs. Regardless of the limitations of technology, the students appeared to pick this information up, and develop an understanding of this method.

The depth of their understanding is also likely to be directly related to how much context was provided as to why they are collecting particular observations. Although we provided a script to the instructors in the field, it was common for some student questions/ and instructor responses to become more in depth than was comparably provided in the videogame. This shows the strength of field teaching in that a student may want to know why they are doing something, and a lecturer can immediately respond with contextual reasoning. While a videogame is limited to what information can be embedded and the style is of discovery (i.e. inquiry-based learning) where a student interacts and comes to conclusions on their own. This may leave some contextual information hidden, and not picked up by students who are not looking for it.

3.5 Limitations

Rigorous quantitative research typically requires larger study populations (or n values) to be more confident of the validity and reliability of the overall results. Also, validating the skills test would provide more confidence in the results from this study. These factors will be explored in the near future.

Another issue that we noticed is a phenomena called 'testing fatigue" or "test sensitization" (Cohen, Manion, and Morrison 2007; pg 214). When we looked at a plot of the results from the group of students who participated in both studies, we observed an obvious lack of effort in several of the students' responses. This resulted in less sophistication in responses and therefore smaller post-test scores. This was noted among 2 participants in the field study (post-tests) and 6 students among the videogame study (some pre- and post-tests). Therefore, the average learning gains achieved can be considered a minimum for both activities. Further testing with new participants should allow us to better constrain the overall learning gains in both settings, but particularly the videogame.

4. CONCLUSIONS & FUTURE WORK

Our comparative study of The GeoThermal World videogame versus the Orakei Korako field activity has shown that a videogame can be just as successful at increasing students' knowledge and depth of understanding of observation skills in geothermal geology.

Although the field achieved higher overall learning gains, it appears that some aspects of the videogame were more successful such as teaching awareness of ALL the observations that are useful at geothermal hot springs (e.g. sinter, algae and vegetation). It may be that being the field presents additional distractions that you don't have 'in' a videogame. The sensory 'overload' may actually inhibit students from focusing on each observation. Further research into the students' attitudes and geologic notebooks should illuminate many other aspects which impact learning in the field.

The major drawbacks or limitations to the videogame may be in achieving 'depth' to students understanding of some topics. Inherently, a student may only learn about – what is included in the videogame. This is especially true for visual and contextual information. The Sapphire pools were located at the base of an active volcano. Some students observed this important fact, while others were so focused on the tasks that they missed the context entirely. The solution is to make explicit sub-tasks (or missions) to pay attention to 'the bigger picture'.

As of yet, we have only designed the 'first level' (or slice) of the GeoThermal World Videogame. We have planned and mapped out several other virtual field sites (acid sulphate; and bicarbonate) within the World. Theoretically, the more time spent inside the context of the videogame, and the more diversity that the student experiences - the deeper the students understanding of geothermal geology may become.

For the best possible results, we recommend using The GeoThermal World to teach students the basics of geothermal hot spring observations prior to going out into the field. Allowing them to 'play' with these ideas prior to implementing them in real life (with all its distractions and complications) may encourage students to get to higher levels of sophistication in the field.

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