Gaming in a 3D multiuser virtual environment: engaging students in Science lessons

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Abstract
Based on the exploratory study of a 3D multiuser virtual environment (3D MUVE), known as Quest Atlantis (QA), in a series of Primary Four (10- to 11-year-olds) Science lessons at Orchard Primary School in Singapore, this paper examines the issues of learning engagement and describes the socio-cultural context of QA’s implementation. The students and teacher were observed during the lessons, interviewed after, and the completed quests were analysed to determine the level of engagement achieved. A pre- and posttest on the Science concepts covered was also administered. A seven-level taxonomy of engagement was used to provide the study with a more holistic perspective of engagement, together with the attempt to concretise the element of engagement into observable traits. Although there was a significant improvement of the posttest over the pretest, the level of engagement of the students was low (between 3 and 4). The lack of engagement might be a result of the distractions in the 3D MUVE, the students’ difficulty with language used in the QA, their lack of computer competency for QA tasks, and/or their inability to complete the quests’ section on reflections. The biggest challenges to the integration of QA into the Science curriculum were the interdependent issues of time (or lack of it) and ‘buy-in’ by the school and parents.
Science education and 3D technology

Our students are constantly exposed to new technologies and have grown accustomed to their presence in their daily lives. One of the most influential effects of this technological advancement on students is their exposure to computer games. These students invest huge amounts of time to master the rules, functionalities, and strategies of these games. They are motivated to purchase costly books giving specific gaming tips and developing skills. With broadband technology, local area network (LAN) gaming is now more accessible than before. It is common to see these players gathering and gaming in LAN gaming centres until late at night. Some children even exhibit addictive behaviour towards playing computer games to the detriment of their school work (Harris, 2001). Such excitement and engagement among students playing computer games bear considerable potential for education (Prensky, 2001; Squire, 2002).

Play, as a curricular tool, has enormous potential for engaging children of all ages in deep learning. Vygotsky (1978) notes that ‘the influence of play on a child’s development is enormous (p. 96.) ... [allowing the child to function] a head taller than himself’ (p. 102). He explains that play can be thought of as a scaffolding activity that has the potential to engage children in issues and debates that are not addressed directly through participation in society and through exposure to curriculum of schools. While play is generally accepted as a key element of learning activity for young children, it seems to be undervalued in the education of older elementary students. Motivated by the potential of play for learning in academic settings, the teachers in Orchard Primary School, a neighbourhood elementary school for 7- to 12-year-olds, embarked on a small-scale exploratory study of an educational multiuser virtual environment (MUVE), known as Quest Atlantis (QA), to inquire into a range of issues that support learning engagement in Science lessons.

Tobin, Tippins and Gallard (1994) emphasize that traditional methods focus on the quantitative aspects of Science where students learn how to use procedures and the rules of thumb. Numerous examples are given by the teacher on the same topic so that students can recognize it and perform well in examinations. Often, students may obtain ‘right’ answers without necessarily understanding the topic since learning is by rote. Tobin et al (1994) also claim that motivation to learn more decreases with this lack of understanding. Thus, any improvement in the level of scientific understanding among primary school students is likely to result in increased interest in Science.

QA is a technology-rich game (without guns) that was developed by the Centre for Research on Learning and Technology (CRLT) at Indiana University. The MUVE game provides a platform for students to engage in inquiry-based learning and consists of: (1) a 3D MUVE; (2) learning quests and unit plans; (3) a storyline, presented consistently throughout QA space through video clips, novels, and comics, which involves a mythical Council and a set of social commitments; and (4) a globally-distributed community of participants from the United States of America, Australia, Singapore, Malaysia, China, and Denmark (Barab, Thomas, Dodge, Carteaux & Tuzun, 2005). Teachers can
use the teacher toolkit in QA to register their students, assign them curricular tasks from the database of quests, provide individual feedback on their completed tasks (quests), and review their chat and email participation. Students log in through networked computers and enter 3D MUVE where they can choose a virtual character, an avatar, which is free to move around in the different virtual worlds to interact with other avatars and complete quests.

Based on the exploratory study of how QA is used in a series of Science lessons to support learning engagement among Primary Four (10 to 11 years old) students in Orchard Primary School, this paper examines issues of learning engagement and describes the context of QA’s implementation by highlighting the core challenges and tensions. By so doing, it promotes dialogue among education researchers and practitioners about the design of learning environments and the reconfiguration of learning activities in schools to enhance long-term engagement of students in Science.

Studies have shown that learner engagement is paramount to learning success (Herrington, Oliver & Reeves, 2003). There is a myriad of definitions for the term engagement (Bangert-Drowns & Pyke, 2001; Kearsley & Shneiderman, 1998; Lee & Anderson, 1993). What is apparent about the definitions of engagement is that they entail some kind of mindfulness, intrinsic motivation, cognitive effort, and attention. Kearsley and Shneiderman (1998) also highlight that although engagement can occur without the use of technology, technology offers opportunities for engagement in ways that may otherwise be difficult to achieve.

**Indicators for learning engagement**

In order to examine learning engagement in QA and its activities, the study needs indicators of engagement. However, engagement is not an absolute term. In general, engaged students comply with minimal requirements of a given task and disengaged students go off-task (Bangert-Drowns & Pyke, 2001). However, there are different levels of engagement that one can attain. The engagement can either be classified as high or low. In an attempt to concretise the element of engagement into observable traits, or as Bangert-Drowns and Pyke (2001, p. 219) term them, ‘behavioural indicators’, they have constructed a useful descriptive taxonomy of engagement, which consists of seven distinct forms.

The taxonomy was developed based on Bangert-Drowns and Pyke’s (2001) observations of pre-K through sixth-grade students, working individually on assigned software at the computer, in an urban elementary school for science and technology. Immediate field notes were recorded on student–software transaction, manipulation of the software, body posture and off-task behaviour. These notes were collated and studied for emerging themes and the 7-level taxonomy of engagement was formulated. At the very highest—level 7—there is evidence of literate thinking. This is seen as intentional learning involving problem-solving and self-regulatory skills. At the very lowest—level 1—there is disengagement.
Although Bangert-Drowns and Pyke (2001) deal with electronic text, the levels of engagement and the observable elements encompassing each level are very relevant to the learning engagement that students experience in QA-mediated Science lessons, especially since QA is actually composed of text-based quests situated in a 3D MUVE. Table 1 provides a brief description of engagement and the quality of learning achieved at each of the seven levels of the taxonomy of learning engagement adopted in this study.

One must note that the seven levels of engagement are not hierarchical in nature and there may be overlaps. Furthermore, as Bangert-Drowns and Pyke (2001) have conceded, the taxonomy does not define determinants for engagement. Three students may be disengaged or frustrated, one because he cannot navigate the software, another because he does not understand the content, and the third because the software goals are inconsistent with his interests. This is a limitation of the taxonomy that will be addressed in this paper by examining the level of engagement that a student demonstrates in QA-mediated Science lessons.

The nature of Science education

‘If a single word had to be chosen to describe the goals of Science educators during the 30-year period that began in the late 1950s, it would have to be inquiry’ (DeBoer, 1991, p. 206). From a Science perspective, inquiry-oriented instruction engages students in the investigative nature of Science as it focuses on the active search for knowledge or understanding to satisfy a curiosity (Haury, 1993). From a pedagogical perspective, this is in contrast to traditional expository methods of teaching. Therefore, teachers should provide students with opportunities to explore and look for information or engage in ‘hands-on’ activities; otherwise, learning of Science may be compromised (Kober, 1993). These opportunities include scaffolding students in the design and conduct of experiments, identification and solving of problems, and discussion and reflection of their findings. In this study, QA provides a platform for inquiry-oriented learning. Students have the freedom to search for and interpret information in pursuance of the quests. That is, students have the opportunity to ‘do’ Science and, hence, are more likely to engage in the learning process (Kober, 1993).

QA and its opportunities for learning engagement in Science lessons

Immersion and interaction

QA uses 3D virtual technology to create an interactive environment to immerse children aged between 8 and 12 years in educational tasks which it calls quests. The mix of software and hardware gives users an illusion of being immersed in a 3D space with the ability to interact with the objects in that space by using input devices such as keyboard and mouse. The 3D virtual environment is then characterized by two elements that facilitate learning engagement—immersion and interaction. According to Csikszentmihalyi (1990), immersion or the illusion of immersion in a 3D virtual environment (Byrne, 1996) is when the users’ self-consciousness and time awareness begin to disappear, and the engagement level increases.
<table>
<thead>
<tr>
<th>Taxonomy level</th>
<th>Type of engagement</th>
<th>Quality of learning</th>
<th>Descriptive indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Literate thinking</td>
<td>Integrating new knowledge with personal values and beliefs</td>
<td>Students reflect on the meaning of the software’s navigational, operational, or content structure. This reflection requires the students to access their prior knowledge, experience, personal beliefs, values, and feelings. At this level, the students can entertain alternative interpretations of the content and use these understandings to reflect on personal experience.</td>
</tr>
<tr>
<td>6</td>
<td>Critical engagement</td>
<td>Self-initiated and systematic knowledge-building</td>
<td>Students create their own goals to test the limitations and possibilities of the software and their understanding of the content. The students manipulate the software features and try to alter the functionalities to better their experience and achieve their objectives. This suggests that the students are engaged in critical thinking.</td>
</tr>
<tr>
<td>5</td>
<td>Self-regulated interest</td>
<td>Developing software and content expertise in areas of interest</td>
<td>Students achieve a heightened state of personal interest and excitement. According to Csikszentmihalyi (1990) as stated in Kondradt and Sulz (2001), this is a state of flow, which is characterized as intense concentration and excitement. At this flow state, students find it enjoyable and become absorbed in their activities (Kondradt &amp; Sulz, 2001).</td>
</tr>
<tr>
<td>4</td>
<td>Structure-dependent engagement</td>
<td>Developing schema for content comprehension</td>
<td>Students exhibit competence and compliance with the software demand characteristics. They are able to orderly explore the range of software options and perform tasks in a routine and competent manner. However, students do not engage in nonroutine or exploratory tasks. Lee and Anderson (1993) termed this as cognitive engagement.</td>
</tr>
<tr>
<td>3</td>
<td>Frustrated engagement</td>
<td>Developing schema for software use</td>
<td>Students possess clear goals when working with the software but are unsuccessful in completing them. The students understand that the software enables the goals they are after. However, due to the lack of navigational and operational competence, the students are unable to use the software effectively. Lim and Chai (2004) term this the loss of task-orientation.</td>
</tr>
<tr>
<td>2</td>
<td>Unsystematic engagement</td>
<td>Acquiring disconnected facts about software and content</td>
<td>Students seem confused or ‘lost’. They possess unclear goals when working with the software. They move from one incomplete activity to another without any apparent reason.</td>
</tr>
<tr>
<td>1</td>
<td>Disengagement</td>
<td>None</td>
<td>Students stop working with the software or maintain disinterested random activity as a cover for mental and emotional withdrawal. In the most extreme case, students will avoid the computer itself.</td>
</tr>
</tbody>
</table>
The engagement is heightened when users are able to interact with the elements in the virtual environment (Winn, 1997); where interaction enables a two-way communication that is receiver-specific and provides two-way information flow. According to Byrne (1996), the control of one’s environment and interactivity are cornerstones of virtual environments that engage students by making them active participants in the 3D virtual environment rather than passive observers. Figure 1 is a screenshot of the 3D user interface of QA. The essential elements within the interface are the visual field with its avatars and quests, plus the real-time chat window through which students can interact and share their understanding of quests.

QA is different from traditional role-playing games as it allows the student to leave the virtual environment and accomplish quests in the physical world. For example, a student will look for a quest online and read the resources available. Thereafter, he/she may proceed out to the real world, carry out an experiment or conduct an interview. The data collected is then interpreted and analysed before he/she submits the completed quest to the council online.

**Inquiry-oriented learning and scaffolding**

QA allows students to travel to virtual places and carry out quests. A quest is a curricular task designed to be entertaining yet educational. In order to complete these quests,
students need to participate in real-world activities that are socially and academically meaningful. Sample quests include researching other cultures, analysing newspaper articles, interviewing members of the community, and using some software to come up with a meaningful document. The quests consist of information collection, interpretation and analysis, and personal reflection to foster critical thinking and metacognition. This inquiry-oriented learning process empowers students and enhances learning engagement in Science lessons (Bybee, 2000; Edelson, 1998; Hawkins & Pea, 1987; Linn, Bell & His, 1998). Figure 2 is an example of a quest in QA taken from the Water Village on ‘Making it rain’.

Although empowering students with more autonomy may enhance learning engagement, some studies have identified that the cognitive demands of such open learning environments may be too complex for some learners (Hedberg, Harper & Brown, 1993; Land, 2000). These demands include responding to questions asked, keeping track of concepts covered, jumping from one topic to another and making notes when necessary (lack of response strategies), the integration of new and prior knowledge (situated knowledge paradox), and the generation and refinement of questions, interpretations,
and understanding based on new information (metacognitive knowledge dilemma). The quests in QA address these demands by providing template-based response documents with guiding questions, web links, and keywords. Such scaffolding directs students' attention to key variables, concepts, and visual cues, facilitate their cognitive thinking and metacognitive skills, promote their knowledge integration, and guide them to generate questions and elaborate upon their thinking (Land, 2000).

Game-like experience and rewards
At the very outset, QA sets the stage or context for the students. The students are told that Atlantis is facing impending disaster as a result of lost values and corrupt leadership. To rebuild and restore lost wisdom, the Atlantian Council created a series of quests. The teacher plays the role of an Atlantian Council member and mentor and assigns these developmentally appropriate quests to his/her students. The completed quest is then submitted to the teachers acting as Council Members for review and feedback. Points, regalia (medals and crowns are awarded to questers as they accumulate points), and rewards such as attractive trading cards will also be awarded for advancement in the quests and these are associated with wisdom.

According to Csikszentmihalyi (1990), the point system is a form of feedback and this enhances flow, which is characterized by intense concentration and excitement. In this flow state, students experience a sense of control and intrinsic interest (Chapman, Selvarajah & Webster, 1999), and hence, become more engaged in the 3D MUVE (Konradt & Sulz, 2001). They compare and compete with their peers to demonstrate their progress in the game (Barab et al., 2005). This serves as a form of extrinsic motivation similar to when a teacher gives his/her students stickers for good work done.

Opportunities for collaboration
In pursuance of the quests, students are able to interact with the digital artefacts and participants in the MUVE. Figure 3 is a screenshot of QA showing a scene of the MUVE on the left with a chat space at the bottom and the personal homepage (email, links, bulletin board, map, friend list, information) of the quester on the right. There are two forms of communication in QA—synchronous and asynchronous. Both forms of communication have the potential of engaging students in collaborative tasks where learning is viewed as a social process that involves building connections—among what is being learned and what is important to the learner and those situations in which it is applied, and among the learner and other learners with similar goals (Barab et al., 1999). These communication tools facilitate interactions to support the shared construction of knowledge among members of a learning community in the Science classroom.

The above discussion has shown the opportunities provided by QA for learning engagement in schools. However, the extent to which these opportunities are actually taken up depends on how QA is situated in the learning environment. Participation in QA may trigger changes in the activities, curriculum and interpersonal relationships in the learning environment, and may be reciprocally affected by the very changes it causes.
(Lim, 2002). Therefore, this study intends to examine how QA is used in a series of Science lessons to support learning engagement among Primary Four students. Three research questions are generated:

- What are the issues of learning engagement in QA-mediated Science lessons?
- What are the core challenges and tensions of integrating QA in the Science lessons?
- How are these challenges and tensions addressed?

An emerging methodological framework, design-based research, is adopted in this study to address these questions. By doing so, the paper aims to refine the taxonomy of learning engagement by Bangert-Drowns and Pyke (2001) and articulate the design of engaging QA-mediated learning contexts for Science lessons that may be sustainable and scalable.

**Research setting and methods**

**Research setting**

The exploratory study was conducted between July 22 and August 4, 2003 in Orchard Primary School, a government elementary school in a lower-middle income neighbourhood in the eastern part of Singapore. At the time of the study, there were about 1200 students in the school, consisting of boys and girls between the ages of 7 and 12. The
average class size was 40. The school has a staff of 50 teachers and 6 support personnel. There were two computer rooms, and each was equipped with 40 networked computers, data projector, projector screen, and whiteboard. The school curriculum included English, Mathematics, Science, Social Studies, Art, Malay, Mandarin, Tamil, Physical Education, and Music.

The teacher, Mr Toh, in the exploratory study, volunteered to be part of the QA team in Singapore. He had been a primary school teacher for the past 10 years and had just been promoted to be the technology coordinator in the school. He was particularly intrigued by the level of interest and excitement generated by computer gaming among children and teenagers. The teacher observed that the players of computer games ‘invested huge amount of time trying to master the rules, functionalities, and strategies of the games... It is common to see these players gathering and gaming in LAN gaming centres till late in the night’. He would like to emulate this level of excitement to engage students in the learning of Science through the use of QA. He speculated that ‘this new opportunity enables us to present scientific knowledge in a way more appealing to our students than the traditional textbooks. This appeal could lead to an increased level of engagement with the content and improve the students’ grasp of abstract scientific concepts’.

QA was the learning tool for all five one-hour sessions on the Water Cycle, Water Purification, and Water Pollution. The researchers and teacher chose these topics as they involved the abstract scientific concepts of evaporation and condensation. Based on the teacher’s experience, Primary 4 students usually encountered problems with these topics and could not fully grasp the concepts. This was evident from their written work and responses in the examination. For example, when students were asked to explain the water cycle, they often regurgitated the three steps from memory—water bodies, evaporation, and rain. Students often missed out the step on cooling and condensation before rain could occur. Their lack of understanding became more apparent upon oral questioning during which they were unable to explain the link between evaporation and rain. Orion and Rosanne (2003) state that earth systems, such as the water cycle, should take central place in the Science curriculum, as society needs environmentally literate citizens.

The eight Primary 4 students in the study were required to work in pairs on one computer. Purposeful sampling was adopted where the students selected came from a class of average ability, thus making up a representative sample of the students in the school. All of these students had computers at home and had had experience with computer games. The eight students were identified based on two criteria—gender and Science results. They represented three achievement levels (high, medium, and low) based on their First Semester Science examination results ranging from a high of 89% to a low of 56%. Initially, four males and four females were selected, but one male student pulled out of the study and only a female student was available at such short notice. Each pair of students selected a password and user identification name to gain access into QA.
Research methods
To examine how QA is used in a series of Science lessons to support learning engagement among Primary Four students in Orchard Primary School, multiple methods of data collection and analysis were employed to enhance the validity and reliability of the study (Maxwell, 1998; Stake, 1994; Yin, 1994). These methods involved gathering accounts of different realities that had been constructed by various groups and individuals in the QA-mediated Science lessons. The qualitative exploration of Mr Toh’s planning and implementation of QA in his lessons, the students’ engagement in the QA space and activities, and the context of participation of the teachers and students where QA was situated were examined by observing lessons, interviewing students, and documenting the submitted quests and reflections. A quantitative exploration of students’ engagement, based on the qualitative data, and development of a repertoire of competencies in the Science topics (the Water Cycle, Water Purification, and Water Pollution) were examined by comparing scores from pre- and post-QA-mediated lesson series assessments.

Prelesson and postlesson series assessment
Students sat for a prelesson series assessment in the first session. The purpose was to establish their current level of understanding about the topics on the Water Cycle, Water Purification, and Water Pollution. These topics had been covered two weeks earlier as part of the Science syllabus using a didactic teaching approach. The prelesson assessment was open-ended and tested students’ understanding about the abstract scientific concepts of evaporation and condensation. At the end of the fifth session, the students sat for the postlesson assessment. In addition to the prelesson assessment’s questions, there was a section that asked students about their QA experiences in the learning of Science. The pretest-posttest design was used to determine the effect of QA-mediated lessons on the learning of scientific concepts.

Face-to-face interviews with students
Each student participated in two 15-minute interviews. The first interview, conducted immediately after the QA-mediated lessons, focused on the issue of engagement and attempted to determine the level of engagement that students have attained. Questions in the first interview were formulated to obtain the students’ perceptions of their own learning engagement during the lessons. The students’ responses were then analysed based on the descriptive indicator attached to each level of engagement by Bangert-Drowns and Pyke (2001) (see Table 1). Questions included, ‘What is/are your goal/s in QA?’, ‘What are some of the problems you have faced in QA?’, ‘How did you overcome the problems?’, ‘Can you recall step-by-step how you normally complete the quests?’, ‘What are the features of QA that you have used? How do you usually use them?’, and ‘Would you use QA after this series of lessons? If yes, what is the motivation? If not, why?’ The second interview elicited information about the students’ background and experience with computers. It also dealt with the students’ perceptions of QA-mediated learning of Science concepts.
Observations of QA-mediated lessons
Observations facilitated the collection of rich data in natural settings. They also helped to generate and refine questions during the interviews with both students and teacher regarding an observed behaviour or action. During the observation of all five QA-mediated Science lessons, a record of events was kept based on an observation checklist that included room layout, lesson objectives and sequences, interactions among participants, interactions between participants and QA, and the learning engagement of students in the QA-mediated lessons.

Students' submitted quests and reflections
Some of the quests required students to produce work outside the 3D space. These were submitted to the teacher by hand while the digital ones were sent to him via QA. The students' work provided the researchers with valuable evidence about the level of students' engagement with the quest and their understanding of the Science concepts. This served to triangulate against the data gathered from the face-to-face interviews, observations, and assessments.

Data analysis
Data analysis within each method and between methods (pretest-posttest, interviews, observations, and the students’ work) took place alongside data collection and processing. To deal with the task of trying to analyse while still collecting data, as more layers of the settings uncovered themselves, the data was continually subjected to a filtering system. The procedure included identifying the main ideas in the initial stage, unitising the data, categorizing the units, negotiating the categories, and identifying the emergent themes (Vaughn, Schumm & Sinagub, 1996). The ongoing analysis assisted in undoing errors or biases that might have crept in during fieldwork. The emergent themes were then triangulated to ensure the robustness of the findings.

Issues of learning engagement in QA-mediated science lessons
The highest level of engagement achieved by the students was level 4. Only three out of eight students in the study were at this level (exhibiting competence in navigating and exploring the QA space and options). They also understood what the quests required of them and were engaged in accomplishing the same. These students showed the most significant improvement in their postlesson series assessment. The rest of the students in the study were in level 3, frustrated engagement. They showed evidence of clear goals but were frustrated because they were not able to complete their task due to the lack of navigational and operational competence to complete the quests. The students who remained in this frustrated level for too long were observed to fall back to either level 2 or 1. Thus, teacher intervention was necessary to maintain a certain level of engagement. From the observations and interviews, almost every student passed through this level.

Immersion, interaction, and extrinsic motivation
From the observations and interviews, the students were clearly very excited when in the 3D space. This initial interest is crucial as it serves as an extrinsic motivation for
students to use QA—without the initial interest, students are not likely to progress on to higher levels of engagement. Byrne (1996) attributes this engagement to the fact that the 3D space is novel to the students and that they enjoy the free roaming without the fear of any repercussions. This was observed when a few students boasted to their peers that in QA, they could jump off the third floor of a building and walk through fire without getting hurt. The students were totally immersed online when they were first introduced to QA. They made remarks such as: ‘Wow, teacher, It’s so nice!’, ‘So many places to go!’, and ‘Teacher can we explore the place?’ This finding was supported by the interviews where the majority of the students stated that they enjoyed using QA because they ‘can explore a lot of things’ and ‘can explore fun areas’, and wanted more time to engage in free exploration. Some also added that ‘QA is fun and makes me want to learn more Science things’ and ‘QA makes Science not so boring’. The immersion in the 3D environment appealed to the students and served as an extrinsic motivation for them to learn Science concepts in the QA-mediated lessons.

Another aspect of QA that served as an extrinsic motivation was its interactivity. Evidence of this was seen as students were observed interacting with the elements in QA. They showed their fascination of the teleport machines that brought them from one world to the next with sound effects. One student commented in the interview that he would add more teleports in QA if he were the programmer so that he could travel from one place to another more quickly. The students quickly discovered they could change their avatars even before the function was made known to them. They felt empowered to be able to control the avatar’s movements and actions in 3D, dictating its every move. Most of the students were particularly impressed by the bird avatar that could fly around QA high up in the air at great speed. These findings support Byrne’s (1996) assertion that the element of interactivity is indeed engaging.

**Immersion, interaction, and distraction**

It was observed on numerous occasions that the students were so immersed in the 3D virtual world and the sense of freedom to explore that they lost their focus on their learning tasks. A student might engage within the 3D space but fail to engage the quests. Indicators of such disengagement with the quests included moving around aimlessly in 3D space without attempting any quest, being slow in submitting work required by the quest, and handing in shoddy and/or incomplete work. Contrasting examples comparing the quality of students’ work can be seen in Figure 4, which shows two contrasting drawings of the Water Cycle. Three groups handed in relatively detailed drawings of the water cycle within the given time frame for the activity—a sample of which is seen in the first drawing in Figure 4. However, one group lost valuable time as they were not engaged with the quest but were more interested in exploring the 3D space. As a result, they handed in an incomplete and incorrect drawing of the Water Cycle, which is seen in the second drawing in Figure 4.

There were also occasions when the students were distracted by elements in the 3D space as they were on their way to look for a quest. This slowed them down since they started free exploration of the 3D space and some eventually lost their way. Some
Figure 4: Contrasting examples comparing the quality of students’ work on the water cycle. A detailed drawing of the Water Cycle. A non-detailed and incorrect drawing of the Water Cycle.
students also had difficulty locating the quests—this might have diminished their sense of purpose. Three out of the eight students stated during the interviews that they had difficulty locating the quests and one of them suggested that QA ought to ‘provide us with a more useful map’ as the existing one had not helped them since ‘it was too small and very difficult to see.’ Although the teacher sometimes intervened and directed some teams to the quests, the 3D space might have been a distraction to some students and this would be counterproductive to their learning processes. As Lim and Chai (2004) have noted, when too much effort is put into navigating and interacting with the material presented in hypermedia, mental resources available for the task itself diminishes.

It was observed that students who remained in this frustrated level for too long would eventually fall back to either level 2 or 1. Thus, teacher intervention is necessary to maintain a certain level of engagement. From the observations and interviews, almost every student passed through this level. This was observed in two of the teams. They could not locate the quests and when they became frustrated, started asking instead for permission to surf the Internet and check their emails.

**Inquiry-oriented learning, scaffolding, and critical thinking**

Based on the comparison of the mean scores between the prelesson (3.38 out of 10) and postlesson series (7.75 out of 10) assessments, there was an improvement of 4.37. The one-tailed $t$-test showed a significant difference at $p < 0.001$. It suggests that the students have improved significantly as a result of learning in QA-mediated Science lessons. This suggests that the inquiry-oriented learning opportunities and scaffolding have enhanced students’ learning of scientific concepts such as evaporation and condensation. A more detailed analysis of the students’ responses in the two assessments indicated that the students might have developed a higher level of critical thinking after the series of QA-mediated lessons—their responses for the postlesson series assessment were better explained and elaborated. Table 2 shows the differences in the responses provided by two of the students in the pre and postlesson series assessment for question 1 that required them to explain the water cycle in their own words.

It is clear from Table 2 that the students grasped the stages of the water cycle, and could differentiate between the concepts of evaporation and condensation and explain them in some detail in the postlesson assessment. In the interviews, some students commented that ‘in QA, you must look for things and solve the quests’ and ‘we are not told what to do and are free to search’ and as a result, many of them ‘understand water cycle better in QA’. Thus, the students’ learning of scientific concepts has been enhanced in the QA-mediated lessons as they were given the opportunity to engage in the exploration and construction of knowledge by themselves at their own pace.

**Inquiry-oriented learning, scaffolding, and assumptions about students**

While QA might provide students with the opportunities to engage themselves in inquiry-oriented learning, it could not be assumed that these opportunities would be
taken up. Without the necessary scaffolding to smoothen the learning processes for the targeted students, they might suffer cognitive overload that, in turn, might then result in disengagement. This lack of engagement might be due to the students’ difficulty with the language used in QA, their lack of computer competency for QA tasks, and their inability to complete the section on reflections on the quests.

The students’ difficulty with the language used in QA was only identified during the study. Many of the students repeatedly asked for the meaning of words used in the quests. In the interview, half of the eight students stated that ‘the language is difficult to understand’. As the quests and instructions in QA were written for native speakers, many of the students had difficulty in understanding the language used in QA. Three of the students stated that they needed more help in understanding the words used in the quests. It was not until the third lesson that Mr Toh became aware of the problem. He read through some quests with the students and explained the tasks to them before letting them work through QA at their own pace.

Most of the students lacked the computer competency for some of the QA tasks. Quests such as ‘Finding the Temple’ required them to use the print screen and copy/paste functions. When the students did not know how to carry out these functions, they lost task-orientation and became disengaged. After one of the students highlighted the problem to Mr Toh, he addressed it by getting the attention of the students and demonstrating how to carry out the functions.

Besides the lack of some computer competency, the students did not know how to complete the section on reflection on the quest. However, in QA, every quest requires the students to submit a reflection of their learning based on three standard questions:
• How does your response meet all the goals of the quest?
• What did you learn about the topic and yourself from doing this quest?
• Tell the council how your response helps the mission of QA?

Most of the students experienced difficulty in answering the questions on reflection. Three of the students expressed a sense of helplessness during the lessons as they were resigned to the fact that they could not answer a crucial part of the quest. Some of these unsuccessful attempts on reflecting on the water purification quest included, ‘We have learnt to purify water by pouring muddy water into the dishpan and it evaporate and became water droplets and drip into the plastic cup’ and ‘It is helping us with purification of water evaporater we put the cup in the centre to keep it dry’. Four out of eight students indicated in the interviews that they did not understand the section on reflection and did not like that element in QA. The students simply did not know how to reflect on their learning since it was an uncommon activity in their school experience. Mr Toh was observed on many occasions to be guiding individual pairs of students through the section on reflection.

Over the course of the exploratory study, the researchers and teacher have redefined the roles of the students (independent and self-regulated) and teacher (coach and coinvestigator), and redesigned the activities in the QA-mediated learning environment. Ongoing learner analysis was undertaken to ensure that timely computer skills were taught and appropriate scaffolding built into the lesson. The latter involved the use of orienting activities, prompts, and checklists. These aided in improving and sustaining student engagement.

Core challenges and tensions of using QA in Science lessons
However, the biggest challenges to the integration of QA into the Science curriculum were not factors that stemmed from the classroom. They were the interdependent tensions of time (or lack of it) and buy-in by the school and parents. These tensions were barriers for the teacher and students to take up the opportunities for collaboration and a game-like experience.

Time
Time was a cause of tension because teachers in Singapore were expected to complete a certain number of topics in syllabus within a term. There were always numerous worksheets and examination practice papers to accomplish in the scheme of work that was determined by the heads of departments. Using QA in the learning of Science meant that more time was required for learning a given topic as compared to the chalk-and-talk method. In the exploratory study, the teacher took almost three hours to complete the Water Cycle topic in QA and there was hardly enough time for his students to adequately reflect on what they had learnt. But when the teacher taught the Water Cycle to his students in other classes using the textbook, it took him only one hour. Thus, curriculum time was a barrier imposed on QA by the environment. As a result, QA could not be fully integrated into the curriculum and many of its opportunities—such as providing a game-like experience and supporting collaboration among stu-
dents—were not taken up. However, over time, this temporal constraint upon understanding concepts might change.

Assessment and buy-in by school and parents

The prevailing mode of assessment in primary schools in Singapore does not really encourage teachers and parents to ‘buy into’ the idea of inquiry-oriented learning approaches. The mode of assessment has always been based on paper-and-pen examinations that test students on a set of competencies that could be developed by completing numerous practice papers before the final examination. This mode of assessment largely conflicts with the shift in paradigm towards more student-centred approaches. Thus, the current mode of assessment might have failed to support the effective integration of QA in the Science curriculum. As a result, students might not fully reap the learning opportunities afforded by the QA environment. This is unfortunate, especially since they are part of a learning community.

Conclusion

From the findings above, three emerging issues are identified on how a 3D MUVE may be used to engage students in the learning of Science: (1) analysis of students’ competencies; (2) role of the teacher; and (3) engagement in 3D space versus engagement in tasks.

Analysis of students’ competencies

In the study, the teacher initially overestimated some of his students’ existing set of competencies. As a result, some students could not accomplish the tasks and became disengaged. For example, the teacher was initially not aware that some students would have difficulty with the language used in QA. It was only during the study that this was identified when he observed that some of his students could not understand the language used in the quests. The students’ computer competency was another problem that was encountered. Some of the quests required students to use specific functions (like the print screen and paste functions) in order to complete the quest. Once again, some students did not know how to access or use these functions.

However, the greatest obstacle to engagement was their inability to reflect on the quest. All eight students had difficulty with this task, as they were not used to reflecting upon their learning. Such an activity was new for the students who were more skilled in traditional testing. This lack of competencies led to a low level of engagement due to a loss of task-orientation. Therefore, learner analysis to determine students’ competencies is crucial so that timely computer competencies can be taught and appropriate scaffolding can be built into the lesson. This will increase and sustain student engagement in the 3D MUVE for the learning of Science concepts.

Role of the teacher

The teacher contributed to the level of engagement students achieved in the 3D MUVE-mediated Science lessons. Orienting activities that supported learner autonomy led to better student engagement. These activities included introductory sessions to the 3D
MUVE, objectives of the lessons, and demonstration of how to complete a quest. From the findings, it is clear that the teacher was fluent with the 3D MUVE and conducted orienting activities to scaffold his students. Lim and Chai (2004) stress the importance of orienting activities in computer-mediated lessons, which include exploring the different functionalities of the software, conducting an introductory lesson, and demonstrating a task as the students watch. These activities reduce the students’ cognitive load so that they can attempt and become engaged in completing the learning tasks. In addition, handouts can be given to students listing specific QA functions for the specific quests. This minimizes the unnecessary classroom management problems when students ask similar questions at the same time—a problem in Singapore’s elementary schools where the average number of students per class is 40.

Engagement in 3D space versus engagement in task

It was apparent that engagement in the 3D MUVE space might not necessarily lead to engagement in the learning task. A student could be engaged in the 3D MUVE by exploring the different worlds, avatars, and quests but fail to engage in the learning tasks. Indicators of such disengagement with tasks included moving around in the 3D space and not exploring the quests; slowness in submitting work required by the quests; and, handing in shoddy and/or incomplete work. Once the teacher identifies such disengagement, intervention is necessary to get students back on course to engage in the learning tasks. However, the teacher may need to further investigate the reasons for the disengagement. From the study, the reasons varied from wilfully refusing to engage in a quest to not being able to understand what the quest required of them. The nature of learning tasks as 2D experiences also vividly contrasts with the 3D exploration (thus, less differences between these experiences may make future students more inclined to follow a quest).

To learn scientific concepts more effectively, students need to engage with the content and not merely learn by rote. This is especially true when the scientific concepts are more abstract. Teachers must be able to guide students through inquiry-oriented-learning approaches and facilitate learning—the focus is shifting from teachers telling students what to learn to teaching them how to learn. Though the current landscape of education, the curriculum, and the modes of assessment may pose a challenge for teachers using 3D MUVE, the technology presents them the opportunity to excite students and engage them in learning scientific concepts through the inquiry-oriented approach, which may lead to enhanced understanding (especially when the 3D/2D distinction is finally blurred or removed).

The research team is currently working with teachers on a set of quests that will be anchored on the curriculum and with a language level more appropriate for nonnative English speakers. The team is also exploring the ideas of integrating manipulable learning objects into the quests and construction of quests by students for other students to enhance student engagement in QA. Although QA is a 3D MUVE that can immerse students in a community of practice to accomplish educational tasks in the form of
quests, these quests can be presented and accomplished to better represent the opportunities afforded by technology. For example, as the presentation of the quests moves beyond a 2D text-and-audio format, the activities in the quests need to be more interactive both online and face-to-face, and students’ submission of the completed quests also needs to move beyond text and graphic files (or even text input into template boxes), towards multimodal and interactive objects. The whole move is towards a more complete virtual world without the discontinuities that break up the patterns of engagement.

References


