Playing games, learning science: promise and challenges

Kim Chwee Daniel Tan & Yam San Chee

National Institute of Education Nanyang Technological University, Singapore, daniel.tan@nie.edu.sg

Abstract

Computer games can provide an immersive environment for players (learners) to experience scientific phenomena, reactions and properties according to related theories and laws, and provide a relevant context to assist learners to make sense of scientific concepts involved. Inquiry-based learning is also facilitated as players have to explore, discover, form hypotheses, experiment and make decisions based on outcomes generated in the game in the pursuit of an overall goal. Thus, science-based computer games can allow the player to learn to be a scientist, by thinking and acting as one in the game, instead of merely learning about science. This paper describes the development of a multi-player game, *Legends of Alkhimia*, and its associated instructional material to facilitate scientific inquiry and the learning of chemistry by lower secondary (Grades 7 and 8) students in Singapore. Challenges faced and lessons learnt in the implementation of game-based learning in the classroom are also discussed.

Introduction

Constructivist theories of knowledge are based on the assumption that knowledge is constructed by the learner rather than being transferred from the teacher to the learner (Bodner et al., 2001). As learners have to personally make sense of what they are taught, teachers need to provide them with the appropriate experiences of the relevant phenomena, introduce the concepts, theories, procedures and language necessary for the understanding of the phenomena, and allow them to discuss their understanding with their peers and teachers (Driver, 1995; Driver et al., 1994). However, learners may not be provided the opportunities to meaningfully explore, negotiate and construct their understanding in school as much focus can be placed on the knowledge and skills that will be assessed (Rop, 1999). Learning is limited if they are required "to learn and think in terms of words and abstractions that they cannot connect in any useful way to images or situations in their embodied experiences in the world" (Gee, 2007, p. 73); they may not be able to understand and apply what is taught in a decontextualized manner. Computer games can be valuable tools to facilitate meaningful science learning if they encourage students to learn science and actively apply their knowledge during gameplay to solve problems, reflect on what they did, and discuss their actions and the consequences of these actions with their classmates and teachers (Squire & Jenkins, 2003).

Games for learning science

Dempsey et al. (2002) define games as "a set of activities, involving one or more players…(with) goals, constraints, payoffs, and consequences…is rule-guided…(and) involves some aspect of competition, even if that competition is with oneself" (p. 159). Good games are motivating, fun, engaging and capture the attention of the players. These qualities of games, as well as their popularity, have attracted the attention of educators keen to explore the use of games to facilitate learning in schools (Dempsey et al., 2002; Oblinger, 2006; Sandford & Williamson, 2005). The types of games that have been used in educational settings include puzzles, bingo, word games, board games, card games and computer games (Crute, 2000; Dempsey et al., 2002; Gee, 2007; Rogers, Huddle, & White, 2000; Squire & Jenkins, 2003).

Computer or video games are "digital applications that can be controlled by individuals or groups of players using a PC or a console such as a Playstation or Xbox machine" (Sandford & Williamson, 2005, p. 1). They allow inputs from one or more players and generate outcomes using the rules programmed into the applications (Oblinger, 2006). Many are "narratively driven, experientially immersive, and multi-media rich" (Barab & Dede, 2007, p. 1), allow players to take on the identity of characters in the game and experience new worlds and roles that would otherwise be inaccessible to them (Oblinger, 2006). For example, a computer game can allow a student to role-play a chemist, and this requires the student to act, think, use tools and solve problems like a chemist; they 'learn to be' a chemist instead of merely 'learning about' chemistry (Brown & Adler, 2008). These processes may not be emphasized in normal science lessons; the use of algorithms and memorization without clearly understanding the processes involved is quite common (Barrow, 1991). Computer games and simulations that have been developed for learning science include *Racing Academy* which requires players to apply physics, mathematics and design principles to build cars to race against each other (Sandford & Williamson, 2005), *Environmental Detectives* in which students play the roles of different parties involved in addressing a chemical spill on a college campus (Klopfer & Squire, 2008; Squire & Jenkins, 2003), and *Supercharged* in which players learn and apply electromagnetism principles to navigate mazes (Squire et al., 2004). In general, the studies showed that participants who played the games found the contexts fascinating and enjoyed interacting with the virtual worlds (e.g., Klopfer & Squire, 2008), and reported that the students who primarily engaged in gameplay had better understanding of the relevant science concepts than those who did not (e.g., Squire, Barnett, Grant & Higginbotham, 2004). Shaffer (2006) argues that computer games can help make learning relevant, authentic and motivating. Immersive environments allow learners to experience scientific phenomena and their behaviour according to related theories and laws, as well as help learners to think and talk about the phenomena "using their intuitive understandings developed in simulated worlds" (Squire et al., 2004, p. 1); these simulations and immersive experiences may not be possible with other types of games such as word, board and card games. Inquiry-based learning is facilitated in computer games as players have to explore, discover, form hypotheses, experiment and make decisions based on the simulated outcomes in the goal-driven contexts of the games (Gee, 2007; Mayo, 2007; Sandford & Williamson, 2005; Squire & Jenkins, 2003). Players learn by doing, trying alternative means, making mistakes, and then reflecting on the outcomes and consequences (Squire & Jenkins, 2003; Sandford & Williamson, 2005; Shaffer 2006).

Learning with *Legends of Alkhimia*

This paper describes the development of a multi-player game, *Legends of Alkhimia*, and its associated instructional strategies to facilitate scientific inquiry and the learning of basic concepts involved in separation techniques, reactions of acids, bases and salts, and rates of reactions in lower secondary chemistry (Grades 7 and 8). The affordances and challenges faced in the implementation of game-based learning in the classroom are also discussed.

Legends of Alkhimia is a game that supports up to four players simultaneously, to be played over a local area network, typically in a computer laboratory in school. In the game, the students role-play as apprentices of a master chemist to tackle a series of challenges encountered at various game levels. The design of the game is based on the Performance–Play–Dialog (PPD) model (Chee, 2011, Chee & Tan, 2012; Chee, Tan, Jan, & Tan, 2012) where students construct their knowledge and gain competence in chemistry by performing as chemists. This performance is manifested in playing the game and dialoguing, facilitated by the teacher, to make sense of the chemistry phenomena experienced in the game world and in-game virtual laboratory. In general, a player will encounter a problem in the game world and needs to travel back to the in-game virtual laboratory to hypothesize the source of the problem and conduct experiments to generate possible solutions to the problem. He/She then goes back to the game world to determine if the proposed solutions will work. If the proposed measures fail, the player has to go back to the in-game laboratory to conduct further experiments to explore other possibilities and test them out again in the game world. Thus, students learn chemistry by playing the game, reflecting on their actions and the consequences of their actions, and deliberating on their experiences related to chemistry in the game, as part of a process of Deweyan inquiry. The game provides the context and motivation to learn, and students enact their developing competence in the way they play in successive levels of the game and dialogue on what they did and why in those levels. This approach is different from a traditional, didactic chemistry lesson where students passively receive knowledge from their teachers.

Legends of Alkhimia and its associated instructional material aim to facilitate lower secondary students' (Years 7 and 8) understanding of scientific inquiry, separation techniques, and reactions of acids and bases as listed in the lower secondary science syllabus (Ministry of Education, 2007). The related learning outcomes are given in Figure 1. A few additional learning outcomes from the upper secondary chemistry syllabus (University of Cambridge Local Examinations Syndicate, 2008) are also included in the game. For example, the use of a separating funnel was included to give students some experience of its use in the in-game laboratory as actual practical work involving separating funnels is rare in Years 7 to 10, as well as to complete all the separation techniques that they have to learn in secondary chemistry; the researchers judged that Years 7 and 8 students are able to understand the critical concepts involved in the separation technique, that is, density and miscibility. The learning objective for acids, "investigate the properties of acidic and alkaline solutions", is rather vague in the lower secondary science syllabus so details are taken from the upper secondary chemistry syllabus to clarify this learning objective. As chemical reactions are involved in the gameplay, that is, when the students try to defeat the different monsters they encounter, the effects of concentration, particle size and temperature on the rate of reactions from the upper secondary chemistry syllabus are also included to provide more options for the students to produce cartridges containing different types of reagents and use them on the monsters under different conditions to see the effects of these different cartridges. This will provide the context for the discussion on the factors affecting rate of reaction but not in detail as this topic is not assessed in Years 7 and 8.

The challenges in the six game levels developed are given in Table 1. The gameplay in Level 1 will be described in detail to illustrate the tasks, and the chemistry and inquiry processes involved in *Legends of Alkhimia*. In Level 1, players encounter silver-coloured monsters that they have to destroy (see Figure 2). However, they find that their weapons keep on malfunctioning when they shoot, and will wonder why this happens. They have to retreat to the in-game virtual laboratory where the master chemist suggests that their cartridges may have been contaminated. When they examine the original cartridges, they will notice that the cartridges contain a mixture of a dark-coloured solid in a blue liquid. They need to hypothesize that one component of the mixture could have caused the malfunction in their weapon, so they need to separate the mixture and then test out in the game world which component is responsible for the malfunction; the students will perform the separation processes with a purpose in mind. A flow diagram to illustrate the processes involved and the results obtained is given in Figure 3.

Scientific inquiry

- recognise that the study and practice of science involve three major elements: attitudes, processes or methods, and products
- recognise that the products of science are the tested data collected by scientists for centuries and explain with examples of how people working with science have formulated concepts, principles and theories
- show an awareness that science is not confined to the laboratory, but is manifested in all aspects of the world
- use scientific inquiry skills such as posing questions, designing investigations, evaluating experimental results and communicating learning
- show an appreciation that scientific inquiry requires attitudes such as curiosity, creativity, integrity, open-mindedness and perseverance
- value individual effort and working in a team as part of scientific inquiry

Separation techniques

- show an awareness of basic principles involved in some separation techniques such as filtration, distillation, paper chromatography and *the use of a separating funnel**
- explain how the properties of constituents are used to separate them from a mixture:
  - magnetic attraction
  - filtration
  - evaporation
  - distillation
  - paper chromatography
  - *using a separating funnel**
- show an awareness of the applications of the various separation techniques in everyday life and industries

Properties of acids and alkaline solutions

- investigate the effect of a variety of acidic, alkaline and neutral solutions on Universal Indicator paper and natural indicators (i.e. obtained from plants)
- investigate the effect on Universal Indicator paper when acidic and alkaline solutions are mixed
- investigate the properties of acidic and alkaline solutions (action of alkalis on ammonium salts NOT required)
  - *describe the characteristic properties of acids as in reactions with metals, bases and carbonates**

Speed of reaction*

- *describe the effect of concentration, particle size and temperature on the speeds of reactions**

Note: * the learning objectives are taken from the upper secondary chemistry (Years 9 and 10) syllabus (University of Cambridge Local Examinations Syndicate, 2008)

Figure 1 Learning outcomes emphasized in the Legends of Alkhimia (Ministry of Education, 2007; University of Cambridge Local Examinations Syndicate, 2008)

Figure 2 Players fending off a monster attack in Level 1 of the game

The equipment available in the laboratory bench (see Figure 4) comprises two types of filter paper, a filter funnel and beaker combination, a separating funnel and beaker combination, and a beaker-tripod stand-bunsen burner combination. The students are encouraged to use of all of the equipment to separate the mixture to produce as many different types of cartridges as possible for use in the game. When the mixture is heated to dryness, the student will obtain a cartridge containing only a brown solid. If the student uses a separating funnel, a cartridge containing the original mixture would be obtained. Two cartridges, one containing the blue liquid and one containing the brown solid, are obtained when filtration is carried out with a fine filter paper, whereas a cartridge with blue liquid with some brown solid and a cartridge with a brown solid are obtained when a coarse filter paper is used.

The in-game laboratory allows students to try out various means to separate the mixtures and discover the outcomes of their attempts, something which rarely happens in a normal science laboratory class because of time constraints and because the students are required to do the 'correct' experiments with little or no mistakes and seek the 'right' answers (Crawford 2000). In addition, doing 'wrong' experiments will incur additional cost in terms of equipment and reagents, and may have safety consequences. Thus, students usually learn only the 'correct' procedures in school; they are not asked to consider alternative procedures and compare them with the 'correct' procedure. The game encourages players to explore 'wrong' procedures and experience the outcomes with minimal real-world consequences (Gee 2007; Sandford & Williamson 2005). Mistakes made in the game are not considered as something to be avoided but as "opportunities for reflection and learning" (Gee 2007, p. 36); in order to really understand why a procedure is 'correct', one needs to realise or experience why it is better than the other procedures which are 'wrong' or unsuitable for a particular purpose.

Table 1. Game challenges in the six levels of the Legends of Alkhimia

Level		Challenges	Chemistry concepts involved
1	Game world Virtual lab	• Weapons jammed when fighting metallic monsters • Destroy metallic monsters • Separate/purify substances in the given cartridges	• Separating substances based on their properties, e.g. particle size vs. pore size in filtration • Reaction of acid with metal
2	Game world Virtual lab	• Weapons have no effect acidic monsters as cartridges contain acid • Destroy acidic monsters • Separate/purify substances in the new cartridges provided	• Separating substances based on their properties, e.g. differences in boiling points in simple distillation • Reactions of acid with metals and bases • Factors affecting rate of reaction e.g. surface area and concentration
3	Game world Virtual lab	• Clean up contamination arising from the waste of the monsters and cartridges • Neutralise acids and bases	• Acid-base reactions • Use of indicators • Effect of soluble and insoluble base/carbonates in neutralization reactions
4	Game world Virtual lab	• Destroy acid monsters in two different environments (hot and cold) • Determine the effect of temperature on the rate of reaction • Determine the effect of different substances on the rate of reaction	• Reactions of acid with metals and bases • Factors affecting the rate of reactions, e.g. temperature and nature of the substances
5	Game world Virtual lab	• Destroy door to escape from room • Separate liquids to obtain fuel to destroy door	• Separating substances based on their properties, e.g. differences in boiling points in simple and fractional distillation; differences in miscibility and density of liquids using a separating funnel • Combustion of fuel
6	Game world	• Destroy different types of monsters encountered in the previous levels	• Reactions of acid with metal and bases • Factors affecting the rate of reactions, e.g. temperature and nature of the substances

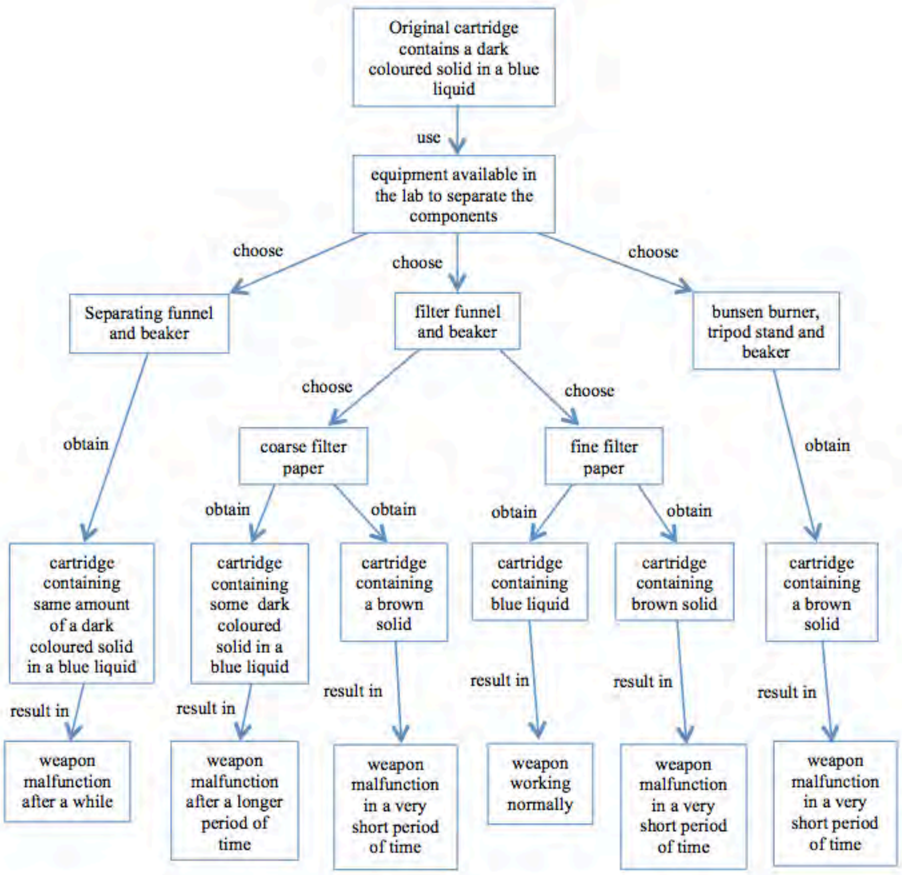

Figure 3 Flowchart illustrating the processes involved in the in-game laboratory in Level 1

Figure 4 A player performing an experiment at the laboratory bench in Level 1

When the students have finished their experimentation in the in-game laboratory, they re-enter the game world to encounter the silver-coloured monsters again with the different cartridges that they produced (see Figure 3). They will soon learn that the cartridge obtained containing the original mixture (obtained using a separating funnel) and the brown solid cartridge cause their weapons to malfunction. The cartridge with the blue liquid and lesser amount of brown solid (obtained using the coarse filter paper) will also cause the weapons to malfunction, albeit after a longer period of time. However, the blue liquid cartridge allows the weapons to be fired repeatedly and inflicts great damage on the monsters; eventually, the monsters are vanquished. The students will not know why the blue liquid is effective against the monsters, so this will be dealt with after the gameplay session where the students will describe and discuss what they did during gameplay; the blue liquid is supposed to be an acid which reacts with the silver-coloured monsters which are supposed to be metallic in nature and destroys them. Students are invited to speculate on what is going on, propose specific hypotheses, and cite any available evidence they can to support their hypotheses. Student peers are encouraged to interrogate and critique the work-in-progress hypotheses. The teacher facilitates this process as a classroom dialogue and introduces the relevant chemistry concepts at the appropriate junctures.

Implementation of the *Legends of Alkhimia* program

The test of an early version of the Legends of Alkhimia program was conducted in November 2009 in School A, a typical government secondary school with a group of eight students, four boys and four girls, with two teachers, a male and a female, observing the session. This test was to assess the usability of the functions in the game and the learning activities which were integrated with the gameplay, as well as the playability of the game. A survey was administered to the students to collect their feedback. Six students found the game challenging and seven students indicated that they enjoyed the learning experience with *Legends of Alkhimia*. Six stated that the group discussion helped them better understand the game. Technical problems which arose were noted by the game development team and were addressed in the following version of the game.

The first trial of the almost complete (beta) version of the Legends of Alkhimia program was conducted in July 2010, again in School A with the same two teachers, this time involving two Year 7 classes, an experimental and a control. A detailed account of this trial has been reported in another paper (Chee & Tan, 2012). The researchers found that the students who played the game had a better understanding of separation techniques and scientific inquiry than those who did not.

In January to March 2011, another trial of the Legends of Alkhimia program was conducted in School B, involving a class of 31 Year 8 students and one female teacher, Teacher C, who had no experience with game-based learning. This third trial, a continuation of the Legends of Alkhimia research, is the subject of this paper, and it focuses on teacher enactment and perception of game-based learning. The trial was conducted as an after-school enrichment program over seven 2-hour sessions and 1 one-hour session as the school could not accommodate the implementation of the Legends of Alkhimia program during curriculum hours. The students were in a science talent class (chosen from their performance in the school's selection tests), and since the class would have additional hours of chemistry instruction, the Legends of Alkhimia program being an enrichment program, no comparable class was available as a control group in terms of additional instructional time as well as ability of students. Teacher C was interviewed on six occasions throughout the trial and her experiences and challenges faced when she implemented the Legends of Alkhimia program are discussed in the following section.

Challenges in game-based learning

Are students learning?

During interviews in all three trials, the students stated that they enjoyed playing *Legends of Alkhimia* and valued the opportunities to explore and experiment with the different apparatus and substances in the in-game laboratory. However, it was observed in the trials at Schools A and B that, while the students were engrossed in gameplay, they were not engaging deeply with the chemistry concepts. Teacher C was concerned that her students were focussed mainly on the playing of the game and getting the better of the monsters; she commented in an early session that many students "don't really think very carefully about a lot of things…so they just do it", relying much on trial-and-error. When the students were experimenting in the in-game laboratory, they did not seem to take the nature of the mixtures and equipment into much consideration. They also did not spend much time analysing and interpreting the results of their separation and thinking how the results could inform further experimentation; several students did not understand the relevance of what they were doing in the game, so they had difficulty explaining what they were doing apart from saying that they were trying out the available equipment. When they left the in-game laboratory and entered the game world, the students were so engaged with battling the monsters with the cartridges at their disposal that they did not seem to consider the outcomes of using different cartridges other than which was the most effective cartridge to use against the monsters. Klopfer and Squires (2008) also found that the students were very enthusiastic and excited participating in their augmented reality simulation, *Environmental Detectives*, but the students, too, did not seem to interact deeply with the content during the simulation sessions.

However, this is to be expected as the students are unaccustomed to this mode of learning and may have not developed the capacity to engage in inquiry. Lessons in School C do not normally encourage "situated and embodied thinking and doing" (Gee, 2007), so students are used to passively receiving knowledge re-presentation from their teachers rather than actively thinking and constructing knowledge for themselves. The Legends of Alkhimia program is designed to facilitate students' inquiry, thinking and talking in ways that are relevant to the discipline (Shaffer, 2006), and develop the relevant process skills, dispositions and habits of mind in lower secondary science (Ministry of Education, 2007). The initial period of a new way of learning is difficult for students (and teachers), so they need time to be accustomed to the required thinking, talking and doing, and to value these processes. Thus, additional time within the two-hour session had to be allocated after the gameplay for students to review and make sense of what happened in the in-game laboratory and game world in order for them to discuss and reflect on what they had done (Chee et al., 2012; Sandford & Williamson, 2005). Squire et al. (2004) emphasize the need for structures to help reduce student difficulties and help them to see how they are learning science through the game, so log sheets were designed for this purpose (see Appendix 1). These log sheets were distributed before gameplay session started and required students to note down the equipment that they used in the in-game laboratory and the results of each experiment using specific equipment. With the log sheets, discussions can be centred on whether a particular experiment is successful, and if unsuccessful, the reasons why and how to address the shortcomings. Squire et al. (2004) also found that log sheets were required to reinforce the purpose of the activities as students were not critically reflecting on what they were doing in the game. In addition, they also suggest that the teacher project relevant game scenarios during the reflection part of the session to facilitate more focussed thinking. For example, the teacher can carry out experiments in the in-game laboratory and lead the students in the discussion of the results obtained, the concepts involved and possible alternative separation routes. Through these discussions, the students should gain a better understanding of the inquiry process, and the procedures and reactions involved in the various levels that they had played, and be able to apply this understanding when playing later levels of the game, in the classroom or in the laboratory.

Understandably, some students complained about the need to reflect on their gameplay and discuss issues, especially in the first few sessions when they were still not used to the Legends of Alkhimia program. Playing the game was fun for the students but the thinking and reflection after the playing was tedious to some of them so they did not take this part seriously. To motivate these students, assessment of their performance in the Legends of Alkhimia program was required as Teacher C commented that students expect to be rewarded with good grades for putting in time and effort into thinking. However, she agreed that the majority of the students enjoyed exploring and thinking about what they did during the game, and discussing these with their classmates. She also mentioned that she had to be very familiar with the game in order to help students make connections between gameplay and chemistry concepts at the various game levels.

One very important observation that Teacher C made was that students could not see the impact of the cartridges on the monsters as chemical reactions, so the learning of the reactions involved was not impactful. Some students viewed the cartridges as projectiles, causing 'physical' damage to the monsters (making holes in them) rather than the contents of the cartridge reacting with the material of the monsters, which was the intention of the researchers. Thus, the instructional material was revised to make the links between the game and real chemistry more explicit. For example, demonstrations of acid reactions (and separation processes) were included in the lesson plans (an example is given in Figure 5) to help students experience the real-life equivalent of the phenomena that they encountered in the game world (and in-game laboratory). In Level 1, the teacher can demonstrate to students, using a visualizer, the reaction between an acid (the content of the cartridge) and a metal (the material of the monster). As an extension, the teacher can also demonstrate the testing of hydrogen and/or the reaction of different metals with acid and complete the demonstrations with equations of the reactions. Students may be able to make more sense of the demonstrations and equations as they have played the game and experience the situations where the reactions are involved (Gee, 2007). It was unfortunate that none of the researchers realised that close-up animations showing the effect of the content of the cartridges on the monsters were necessary, and so, were not considered during the developmental phase of the game. Virtual effects showing the contents of the cartridge splashing or scattering onto the monsters and reacting with the substance of the monsters could have parallel real-life reactions and create greater impact on the students' experience of the relevant reactions during gameplay.

	Activity	Time/min	Resources	Remarks/ Rationale
5	Teacher demonstration of real chemistry (Whole-class) The teacher demonstrates separation of soil and water using filters of different pore sizes.	30		
5.1	Questions: • How does the apparatus work? • What is the principle behind the separation techniques? What can be successfully recovered? Why? Are there alternative methods to separate soil and water – distillation – can compare pros and cons. Learning points: • The size of the pores in the filter paper and the size of the particles in the mixture determine what passes through the filter paper.	(15)	Material: Muddy water Apparatus: Filter paper, filter funnel, conical flask, sock/cloth	Possible alternative conception: • Solute particles will be filtered off, especially in the filtration of a mixture consisting of a solution and an insoluble substance
5.2	The teacher demonstrates reaction of acids with metals (HCl with magnesium, zinc and copper). Learning points: • Different metals react differently with the acid • Metals react with acid to produce hydrogen and salt • Hydrogen extinguishes a lighted splinter with a ‘pop’ sound (explosion)	(15)	Acid: 0.1M HCl Metals: magnesium, zinc, copper Apparatus: (Experiment) test-tubes, splinter, matches/lighters; (Demo) petri dish, visualiser or overhead projector.	

Figure 5. Abridged version of the lesson plan for Level 1 focusing on teacher demonstrations

Teachers' struggles with game-based pedagogies

Expository teaching is the general mode of teaching in secondary chemistry focussing on students' mastery of content (Chee et al., 2012) and Teacher C agreed with this assertion; when she taught in the classroom, she would present the concepts explicitly, clearly and linearly with students taking notes. Thus, teachers face challenges and tensions when they implement game-based learning because students are expected to learn by doing in the game instead of receiving the knowledge from them. Teacher C mentioned that she seemed to be “a bit lost” at what to do during gameplay as it is not easy for her to refrain from telling students the right answers when she sees students struggling during the in-game laboratory or the reflection sessions, or taking what she considers to be a long time to come up with a solution. She was anxious that her students might not learn what they were supposed to learn and tended to believe that leaving students to work out the answers for themselves might not be effective; neither was it an efficient use of (precious) time. In addition, there was the worry that students would not know how to play the game successfully if they were not first taught the content involved (Chee et al., 2012). Teacher C stated that her students felt confused as the way of doing things was new, there were so many thing happening at the same time and so many possibilities, as well as no clear way of doing things; the students had to try many things out and make sense of what was happening, so she believed that learning was more difficult and confusing for them. Teachers need to be convinced that students are able to perform and gain competency through gameplay as they are supported by the design of the game and the facilitation of the teacher (Gee 2007). Towards the end of the Legends of Alkhimia trial in School B, Teacher C mentioned that she had learned to trust the students more, and that the students were able to learn the required concepts with the appropriate scaffolding and take charge of their own learning; she saw more students being able to explain what they were doing in the game using the appropriate chemistry concepts.

The additional time required to enact the Legends of Alkhimia program compared to the normal frontal teaching of the required concepts could be a potential concern for teachers. Thus, when the Legends of Alkhimia program is introduced to more schools, teachers will be given the option to choose the levels that they think are more important for their students' learning. This was in line with Teacher C's feedback that she would only use certain levels if she were to use the Legends of Alkhimia program during curriculum time with future classes. The researchers believed that the inquiry and learning processes would not be as effective if only certain levels were played by the students but agreed that this would be a pragmatic compromise to encourage more teachers to experiment with the Legends of Alkhimia program. The researchers would also explore implementing the Legends of Alkhimia program in informal learning environments such as in science centres to address the issues of time constraints and teachers' and students' unfamiliarity and reluctance to engage in game-based learning during curriculum time.

Support for teachers who are interested in implementing game-based learning is essential as the practices involved are different from the normal teaching and learning activities in school, and require teachers to adopt a mind-set of learning by doing science rather than teaching for content mastery (Chee et al., 2012). The support can be in the form of opportunities to observe other teachers enacting game-based learning in real classroom settings, listening to the success and 'horror' stories shared by the teachers facilitating the game sessions, discussing issues of learning and implementation, and inviting other teachers to observe and comment on their own enactment of such lessons. These will be built into the Legends of Alkhimia program when it is introduced into schools; hopefully, a community of teachers who are interested in game-based learning will be established so that they can learn from and support each other in their endeavours. Otherwise, there is a high possibility that a lone teacher who adopts innovative pedagogy such as game-based learning will not persist with it in the future (Chee et al. 2012).

Conclusion

Game-based learning has the potential to facilitate contextualized learning that is fulfilling and motivating (Shaffer 2006). The Legends of Alkhimia program is an attempt in this direction to facilitate the acquisition of inquiry skills as well as the learning of chemistry concepts. Students who were involved in the three trials of the game found it interesting and engaging, and the results from surveys and a conceptual test indicated that they gained a better understanding of the inquiry process and chemistry concepts involved. Teachers play a critical role in game-based learning as they provide support and focus for student reflection and learning during the game sessions. As the adoption of game-based pedagogies may require a drastic change in beliefs of instructional practice, how students learn and should be taught in schools, support needs to be given to teachers by game developers and researchers in the initial stages, and at a later stage, by a community of peers who were earlier adopters of game-based learning. Such support could include in-service courses on the theoretical basis of game-based learning and the skills required to facilitate such learning, observations of actual game-based learning sessions in school, colleagues sharing their experiences in using games for students to learn with, and peer observations and coaching during the teacher's own implementation of game-based learning with her/his classes.

Acknowledgments

The work reported in this paper was supported by a research grant (NRF2007–IDM005–MOE–006CYS) from the National Research Foundation, Singapore. The authors acknowledge with gratitude the contribution of the research and game development team members: Ek Ming Tan, Mingfong Jan, Rahul Nath, Yik Shan Wee, Cher Yee Ong, Won Kit Ho, Simon Yang, Andy Lim, Henry Kang, Ittirat Vayachut, and Aldinny Abdul Gapar.

References

Barab, S., & Dede, C. (2007). Games and immersive participatory simulations for science education: An emerging type of curricula. *Journal of Science Education and Technology, 16*(1), 1-3.

Barrow, G. M. (1991). Intellectural integrity or mental servility. *Journal of Chemical Education, 68*(6), 449-453.

Bodner, G., Klobuchar, M., & Geelan, D. (2001). The many forms of constructivism, *Journal of Chemical Education, 78*(8), 1107.

Brown, J. S., & Adler, R. P. (2008). Minds on fire: Open education, the long tail, and learning 2.0. *Educause Review, 43*(1), 16-32.

Chee, Y. S. (2011). Learning as *becoming* through performance, play, and dialog: A model of game-based learning with the game *Legends of Alkhimia*. *Digital Culture & Education, 3*(2), 98-122

Chee, Y. S., & Tan, K. C. D. (2012). Becoming chemists through game-based inquiry learning: The case of *Legends of Alkhimia*. *Electronic Journal of e-Learning*, 10(2), 185–198.

Chee, Y. S., Tan, K. C. D., Jan, M. F., & Tan, E. M., (2012). Learning chemistry performatively: Epistemological and pedagogical bases of design-for-learning with computer and video games. In K. C. D. Tan & M. Kim (Eds.), *Issues and challenges in science education research: Moving forward* (pp. 245–262). Dordrecht: Springer.

Crawford, B. A. (2000). Embracing the essence of inquiry: New roles for science teachers. *Journal of Research in Science Teaching, 37*(9), 916-937.

Crute, T. D. (2000). Classroom nomenclature games - BINGO. *Journal of Chemical Education, 77*(4), 481-482.

Dempsey, J. V., Haynes, L. L., Lucassen, B. A., & Casey, M. S. (2002). Forty simple computer games and what they could mean to educators. *Simulation & Gaming, 33*(2), 157-168.

Driver, R. (1995). Constructivist approaches to science teaching. In Steffe, L.P. & Gale, J. (Eds.), *Constructivism in education* (pp. 385-400). Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Driver, R., Squires, A., Rushworth, P., & Wood-Robinson, V. (1994*). Making sense of secondary science: Research into children's ideas.* London and New York: Routledge.

Gee, J. P. (2007). What video games have to teach us about learning and literacy. New York: Palgrave Macmillan.

Klopfer, E., & Squire, K. (2008). Environmental Detectives—the development of an augmented reality platform for environmental simulations. *Educational Technology Research and Development, 56*(2), 203-228.

Mayo, M. J. (2007). Games for science and engineering education, *Communications of the ACM, 50(7)*, 30-35.

Ministry of Education (2007). Science Syllabus: Lower Secondary: Express/Normal (Academic). Singapore: Author.

Oblinger, D.G. (2006). Games and learning. *Educause Quarterly*, 3, 5-7.

Rogers, F., Huddle, P. A., & White, M. D. (2000), Simulations for teaching chemical equilibrium, *Journal of Chemical Education , 77*(7), 920-926.

Rop, C. J. (1999). Student perspectives on success in high school chemistry. *Journal of Research in Science Teaching, 36*(2), 221-237.

Sandford, R., & Williamson, B. (2005). *Games and learning*. Bristol: NESTA Futurelab.

Shaffer, D. W. (2006). *How computer games help children learn*. New York: Palgrave Macmillan.

Squire, K., & Jenkins, H. (2003). Harnessing the power of games in education. *Insight, 3*, 5-33.

Squire, K., Barnett, M., Grant, J. M., & Higginbotham, T. (2004). *Electromagnetism supercharged! Learning physics with digital simulation games*. Paper presented at the International Conference of the Learning Sciences 2004 (ICLS 04), Santa Monica, CA.

University of Cambridge Local Examinations Syndicate. (2008). Chemistry: GCE Ordinary Level (Syllabus 5072). Cambridge: Author.

Appendix 1 Game log for students for Level 1

Initial Cartridge (I)	Cartridge Content
	• Part Substance A: Liquid, blue • Part Substance B: Solid particles, brown

Apparatus		Used	Effects in Lab	Used	Effects in Lab
1					
2					
3					
4					
5					
6					

		Effects in Mission		Effects in Mission
Cartridges Obtained				