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Learning Science via a science-in-the-making process: The design of a game-based learning curriculum

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Abstract. We present the design of the *Legends of Alkhimia* game and game-based learning curriculum as a model of 21st century science education. The 21st century knowledge economy demands knowledge producers and innovators. However, current public educational systems are generally designed for content mastery instead of knowledge production. Science is often learned as a product, failing to incorporate the process that makes science and helps students think scientifically. In this paper, we present the theoretical constructs underlying the design of the *Legends of Alkhimia* game and learning program. We frame science learning as a science-in-the-making process similar to that of the ancient Alchemists. We also depict the products of our design: a 6-level computer game and an 8-session role-playing curriculum.

Key words: Scientific inquiry, role-playing, design research, chemistry game, game-based learning

Introduction

Learning in the 21st Century

It remains a fact that learning science in school is often framed as mastering a body of expert-generated factual information, though alternative approaches of science learning have been advocated decades ago (e.g., Driver et al., 1994). This belief about science learning is manifested in how instructional materials are designed and used in the mainstream educational settings. The use of textbooks is an important barometer that unfolds how teaching and learning sciences is conceptualized by the mainstream educational system. Most textbooks are "designed" as well-structured packages of expert-generated contents. For the efficiency of content delivery, they are written in a "prescribed and encyclopedic style of presentation" (Bierman et al., 2006). In other words, science is repackaged as an anthology of important scientific findings reported with texts, diagrams, and tables in textbooks. What, then, have students learned of/about science when they learn science with science textbooks? It is common that students describe science as an unbiased body of knowledge discovered only by great scientists (Kelley & Crawford, 1997). Students are positioned as followers of science authorities while the major responsibility of teachers is to facilitate content mastery. Students' experience of science in schools seldom goes beyond comprehending and memorizing expert-generated factual information.

The content mastery model of science learning was an effective and sufficient educational

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model when being able to read and write is a social and economic advantage. Mastering scientific facts was seen as a higher-level skill that would bring job security and economic success. However, as the world economy shifts to knowledge economy (Drucker, 1993; Friedman, 2005), knowledge production and innovation become the new motto for social and economic success. Being able to read, write, and apply scientific facts for work - traditionally defined literacy skills - is no longer sufficient. The upheaval in social and economic life in the information age pushes back onto the public educational systems, challenging policy makers, researchers, administrators and educators to redefine success and education in the new, ever-changing global village.

How might we, then, reform science education that address the 21st century knowledge demand? In this paper, we propose a model of science learning suitable for the 21st century global economy. To this end, we examine (1) the nature of innovation and knowledge production in science, (2) instructional tools that may be designed to facilitate knowledge production and innovation, and (3) curricular activities built around our discussion of 21st century science learning and tool-mediate learning environment. As a closure to our argument about design, we articulate the role and functions of design in educational reform and situate this design in the ecology of education.

Theoretical Framework/Design Framework

Rethinking science education for the 21st century

What is the nature of scientific study? While ethnographic studies of school science identify that most students believe that scientific knowledge is "discovered" by great scientists such as Newton and Einstein, science researchers (e.g., Driver et al., 1994; Taylor, 1996; Sandoval & Millwood, 2005) argue that scientific knowledge is "constructed." In the process of knowledge construction, scientific theories are validated via explanation, dispute and arguments among the science communities before they are legitimized as scientific facts. Sandoval and Millwood (2005) succinctly synthesize the nature of scientific study. They argue that there is no inherent value of truth in scientific theories. Scientific knowledge is a human construction. Since scientific knowledge is constructed, the validity of science lies in the degree of persuasion.

The mainstream science curricula are mainly built upon the assumption that scientific knowledge is discovered and can be transmitted to students via didactic instruction and content delivery. Viewing scientific knowledge as constructed knowledge not only suggests a different view about science, but also points to a potentially productive path to revamp science education for the 21st century knowledge demand. The approaches and methods scientists are trained to construct scientific knowledge show them to be knowledge producers and innovators. Since scientists develop their skills, knowledge, identity, values and epistemology (Shaffer, 2006) through scientific inquiries, teaching students to inquire science may be a productive way to enculturate students as intelligent novices (Brown et al., 1993) who learn to be knowledge producers and innovators.

Scientific inquiry as a 21st century knowledge production skill

In constructing scientific knowledge, scientists develop specific cognitive tools as well as physical instruments to facilitate knowledge construction process. In terms of the cognitive tools, inquiry skill is essential and shared by scientists. Facing problematic situations,

scientists take actions to "convert the elements of the original situation into a unified whole" (Dewey, 1938 p. 108). The actions taken by scientists to solve problems share common characteristics—asking questions regarding unsettled situations, proposing hypotheses based on existed knowledge, conducting investigation, collecting and interpreting data, and developing theories about the questions they raised. Though there are different ways to characterize this knowledge construction process, it is typically identified as scientific inquiry (Chinn & Malhorta, 2002; White & Frederiksen, 1998). As a central tool for constructing scientific knowledge, scientific inquiry is not only a tool that scientists utilize to construct scientific theories, but also a tool that may help young people to become a knowledge producer demanded by the 21st century economy.

Challenges of fostering scientific inquiry in the classroom

Though educational researchers (e.g., Driver et al 1994, White & Frederiksen, 1998; Kuhn, 2005) commonly agree that learning scientific inquiry is essential for science education, conducting scientific inquiry in the classroom is challenging, especially in terms of keeping scientific inquiry authentic. Authentic scientific inquiry, defined as inquiry carried out by practicing scientists (Schwartz & Crawford, 2007), emerges in the communities of practicing scientists in which domain-specific skills, knowledge, identity, values and epistemology all contribute to its authenticity (Shaffer, 2006). Therefore, the authenticity relies on a community of science practitioners to take place.

To implement authentic scientific inquiry, schools face various challenges. Public educations are generally not conceptualized to foster science practices. Therefore they may not sustain such a heterogeneous infrastructure and culture that science practitioners experience in their everyday work experience. Teachers, the ones in charge of steering classroom practices, are usually not trained as scientists. Seldom do they have experience working with science practitioners. When some teachers do have the experience to foster authentic science practices in the classroom, they may find science textbooks not fully compatible with their experience working as science practitioners. Textbooks guide its practitioners to trust whatever printed in black and white while scientific journals invite critique and re-evaluation from their viewers. Therefore, Chinn and Malhorta (2002) maintain that most scientific inquiry tasks in schools are simple inquiry tasks, inquires adapted to fit in school's science curricula.

Since it is impractical to implement authentic scientific inquiry within current educational setting, simplified inquiry tasks offer a feasible solution in helping students learn inquiry. The simplified inquiries are often designed to capture core components of scientific inquiry, such as experiments, observations and illustrations. However, it is questionable if the simplified version of inquiry really helps student capture the essence of inquiry. Chinn and Malhorta (2002) argue that most simple inquiry tasks are called into question with two major drawbacks.

The first setback originates from failing to engage students in asking inquiry questions, a hallmark for inquiries. To engage a student in an inquiry, it requires the student herself to perceive a situation as unsettled or disturbed to initiate an inquiry process (Dewey, 1938; Postman & Weingartner, 1969). It is the inquiry question that motivates a person, making her an inquirer. A situation that is viewed as problematic for a chemist, such as the increase of carbon dioxide on earth, may not be viewed as problematic for a teenager student whose goals for learning about green house effect is to get good grades in chemistry tests. For the

chemist, his inquiry question may lead him into tracing Carbone dioxide footprint inside the ice at the North Pole. He may have some ideas, or even hypotheses, about what the increase of carbon dioxide might lead to. And these ideas or hypotheses are just the very beginning of an inquiry process. For most simple inquiry tasks conducted in schools, teachers often post the inquiry questions. And the answers can be Googled, if not found directly from their textbooks. Students then will conduct experiments and collect data to prove the theories they should have developed themselves. To engage students in a simplified, and yet authentic inquiry, the design of inquiry must somehow situate students in problematic situations that motivate them to be inquirers, those who ask questions and are motivated to answer them.

Another major setback for many simplified inquiries is the failure to engage students as evaluators, which is also a hallmark for practicing scientists. Once an inquiry question is raised, a practicing scientist is in constant interrogation of existing theories, data, research questions and interpretations of data. The inquiry, with or without answers already defined by others, is an open-ended challenge that demands constant evaluation in the entire inquiry process. In other words, the underlying epistemology of an inquirer is an evaluative epistemology (Kuhn et al., 2000; Chinn & Malhorta, 2002). An evaluative epistemology is deeply rooted in the belief that human knowledge is value-laden, socio-culturally relevant and constructed. Simplified inquiries not only did not facilitate evaluative epistemology; it actually facilitates false epistemology (Chinn & Malhorta, 2002). Therefore, how simplified inquiries can be designed to facilitate evaluative epistemology is a major concern for implementing inquiry tasks in schools.

Designing scientific inquiry with computer games

In the past decade video games have been proposed as a medium with rich potential to realize situated learning (Gee, 2003; Squire, 2006). Game researchers (e.g., Prensky, 2001; Gee 2003; Squire, 2006) maintain that computer and video games provide great examples of how learning experience may be designed using game designs principles. Squire (2006) points out that good video games design players' experience by situating players in contexts where learning is more contextualized and embodied than many traditional learning media. These arguments suggest that video games afford design of learning experiences coherent to the situated perspective of learning (Brown et al., 1989; Gee, 2004) and may have the potential to foster scientific inquiries that engage students in asking genuine inquiry questions as well as in fostering evaluative epistemology.

In *Mad City Mystery*, a handheld role-playing game designed to foster argument skills, Squire and Jan (2007) maintain that two major game design features, role-playing and open-ended challenges, engage players in collaborating dialogically in order to develop evidence-based arguments, a critical skill that practicing scientists employ in conducting scientific inquiry. In the *Saving Lake Wingra* game-based learning curriculum, Jan (2009) utilizes role-playing, non-player characters, and game challenges to facilitate question-asking and evaluative epistemology in middle schools. In our design, we leverage role-playing in the design of a 6-level computer game and an eight 2-hour sessions curriculum to compensate the two major disadvantages in employing simplified scientific inquiry in schools.

Design of the *Legends of Alkhimia* Learning Program

In the first part of the paper, we articulate how we may reform school science curricula to help young people innovate and produce knowledge via conducting scientific inquiries. Drawing from research literature, we also highlight two major challenges in helping students learn scientific inquiry in schools via simplified inquiries. Game-based learning approaches afford unique opportunities to engage learning styles that differ from the content mastery paradigm of learning.

In the following discussion, we present the design of the *Legends of Alkhimia* game and curriculum. The *Legends of Alkhimia* curriculum is an eight-session chemistry curriculum designed to engage students in scientific inquiry. The *Legends of Alkhimia* game replaces chemistry textbook as the major learning material in the classroom. Drawing on the theoretical discussions, we orient and align our design based on the following design guidelines:

1. Situating science learning in science-in-the-making
2. Situating science learning in scientific inquiry
3. Situating learners in problematic situations
4. Fostering evaluative epistemology in the process of learning

Situating science learning in science-in-the-making

Since the goal of our curricular design is to situate students in a science-in-the-making process, it requires a major revamp in the design and use of educational media and activities, which are designed to teach ready-made scientific conclusions. Our effort in transforming the ready-made-science curricula into a science-in-the-making curriculum is inspired by the inquiry process of ancient alchemists. Many of them posted an open-ended inquiry question—how base metals might be turned into gold—and it initiated inquiry processes still inspiring to science practitioners today. To investigate how base metals may turn into gold, alchemists proposed hypotheses, designed and conducted experiments to test their hypotheses, interpret their data and constructed knowledge regarding the properties of substances and the relationship between different substances. Though the major assumptions underlying the Alchemy concept are misleading based on today's perspective, Alchemy is a science-in-the-making process that became a precursor of modern chemistry.

Alchemy provides a model through which a simplified, and yet epistemologically authentic science-in-the-making process may be replicated in the classroom. To replicate the science-in-the-making process, we leverage the affordances of 3D role-playing computer games to engage students in similar challenges and inquiry processes. We design The *Legends of Alkhimia* game and curriculum to structure students' scientific inquiry experience. The following delineates how we design science-in-the-making in the classroom with The *Legends of Alkhimia* game and curriculum.

Designed for secondary (middle school) science education in Singapore, the *Legends of Alkhimia* curriculum is an eight-session chemistry curriculum (See Table 1) composed of the following activities: briefing, gaming, small group discussion, whole class discussion and debriefing. The *Legends of Alkhimia* game is the cornerstone based on which all curricular activities are structured. The game consists of six levels of game challenges and inquiry cycles. Each level will be played in a session for about thirty minutes. Typically, students will discuss their prior knowledge and experience at the beginning of a session, followed by playing a level of the *Legends of Alkhimia* game as a team of four players, and then

collaborate to interpret their findings in the game in order to propose and evaluate their theories about the nature and relationship of substances that emerge in the game world.

Table 1. The *Legends of Alkhimia* game-based learning curriculum

Session (Time)	Topic/ Learning Outcome/ Activity	Game Play
0 (120 min)	• Intro to project and admin matters • Pre-Survey • Overview of learning scenario and final project • Prepare personal profile (e.g. in the form of curriculum vitae, draw how they see themselves as a chemist) and group profile to be uploaded on wiki:	NA
1 (120min)	*In-session:* • Scientific inquiry *Out-of-session online discussion/ research:* • Classes of substances (elements, mixtures, compounds, metals and non-metals) • Classes of behaviours of substances (chemical reactions and non-chemical changes) • Separation of mixture (solid-liquid)	*Level 1* • Separate solid-liquid mixtures • Destroy metal monsters
2 (120min)	*In-session:* • Scientific inquiry *Out-of-session online discussion/ research:* • Classes of substances (solute, solvent and solution) • Common reactions of metals • Factors of rate of reaction (particle size, concentration)	*Level 2* • Separate mixtures (solid-liquid, solutions) • Destroy acid monsters
3 (120min)	*In-session:* • Scientific inquiry *Out-of-session online discussion/ research:* • Common reactions of acids • Limiting and excess reagents • Properties of gases (hydrogen and carbon dioxide)	*Level 3* • Neutralize samples of acids and bases in the lab • Neutralize contaminated cabbages in the farm
4 (120min)	*In-session:* • Scientific inquiry *Out-of-session online discussion/ research:* • Classes of metals (according to reactivity) • Factors of rate of reactions (reactivity of metal, temperature)	*Level 4* • Test effect of temperature on rate of reactions in lab • Destroy acid monsters in both cold (mountain-top) and hot (underground) conditions
5 (60min)	• Re-visit self and group profile • Re-visit and getting started on final assignment	

6 (120min)	*In-session:* • Scientific inquiry *Out-of-session online discussion/ research:* • Mixtures of liquids (solutions, miscible, immiscible liquids) • Separation of substances based on different densities	*Level 5* • Separate solutions, miscible and immiscible liquids • Use liquids to destroy door made of metal of very low reactivity
7 (120min)	*In-session:* • Inquiry into self and identity *Out-of-session online discussion/ research:* • Consolidation of previous sessions' discussion topics	*Level 6* • Synthesize notes taken of substances and reactions from previous levels • Select best metals for ammunition and armour • Decorate armour • Destroy super monster
8 (120min)	• Group presentation of final project task (a proposal) • Evaluation of proposals • Update CV and group profile • Post-survey	NA

The Legends of Alkhimia game

In the game, students role-play as apprentices of a master chemist to tackle six levels of game challenges (see Table 2). Typically, a player will tackle a challenge in cycles of three steps. First, a player encounters a problematic situation that can be overcome only by conducting appropriate experiments. He must identify the sources of the problems and hypothesize how the issues may be solved through experiments. Second, the player conducts virtual experiments in the in-game virtual lab in order to produce substances that may solve the problems. Third, the player uses the lab-generated substances to test how they work. The last step is where players test their hypotheses. These three steps are designed to be an in-game inquiry cycle—raising questions, proposing hypotheses, conducting studies, testing their hypotheses and developing theories. In the game, players are designed to fail in their initial trial. They then gain critical information and experience out of the failure. A successful player must learn from his failure in game and modify his hypotheses accordingly in order to tackle the game challenges.

Table 2. Six levels of game challenges in the *Legends of Alkhimia* game

Level		In-Game Challenges	Related ideas/concepts in the design
1	Lab	Separate mixtures (solid-liquid, solutions)	• Strong and weak acids dissociate in water to different extents • Separation of substances can be based on size of particles and boiling points • Kinetic Theory
	Field	Destroy metallic monsters	
2	Lab	Separate mixtures (solid-liquid, solutions)	• Depending on the substances to be recovered and the properties of the substances, different separating techniques are used • Collision theory
	Field	Destroy acid monsters	
3	Lab	Neutralize samples of acids and bases in the lab	• Metals can be classified according to their reactivity • Reactivity of metals affect the rate of reaction of metals with acids • Properties of material affect uses of the material: Insoluble bases are used instead of soluble bases to neutralize acids.
	Field	Neutralize contaminated cabbages in the farm	
4	Lab	Test effect of temperature on rate of reactions in lab	• Substances may or may not react with other substances depending on whether heat is applied • Properties of material affect uses of the material: Carbon dioxide is used in fire extinguishers; hydrogen is used in airships and as rocket fuel
	Field	Destroy acid monsters in both cold (mountain-top) and hot (underground) conditions	
5	Lab	Separate solutions, miscible and immiscible liquids	• Depending on the substances to be recovered and the properties of the substances, different separating techniques are used • Big ideas/ concepts as level 1 and 2
	Field	Use liquids to destroy door made of metal of very low reactivity	
6	Lab	Synthesize notes taken of substances and reactions from previous levels	• Big ideas/ concepts as level 1-6
	Field	Select best metals for ammunition and armour Destroy super monster	

For example, in level one of the *Legends of Alkhimia* game, the players were attacked by three moderately reactive metallic monsters, which can be destroyed using acid in the battlefield. Facing this problematic situation, players have a gun and two cartridges, A and B, which could be used as weapons against the metallic monsters. Cartridge A, a mixture of sand and strong acid (which is unknown to the players), is more effective against the monster, but is also a rare substance and in a smaller amount. Cartridge B, composed of sand and weak acid, is less effective against the monsters but in a greater amount. The players may use both cartridges to defeat the monsters, but their weapons will jam initially because of the sand in the cartridges. Defeated by the monsters, players manage to retreat to

the virtual lab where several lab functional units and apparatus are available for conducting certain experiments. If a player hypothesizes that their cartridges were jammed because of impurity in the cartridges, he may conduct experiments that may enhance the purity of the cartridges, such as using coarse and fine filters, separating funnels, or the combination of a few lab functional units, to purify the cartridges. The player can then bring the produced cartridges back to the battlefield to see if his hypothesis and experiments work as predicted.

A key design decision across all levels is that the substances being used to create the monsters and cartridges are concealed to the players. It situates players in a world similar to that of the ancient alchemists. Like ancient alchemists, players may not know what these substances are and are unclear about their relationship with other substances, such as the substances in their weapons. They must construct knowledge about these substances by collecting and identifying suitable data from multiple resources. For example, they may examine the procedure through which a specific substance was produced using specific lab equipments and its effectiveness against the monsters to interpret and construct knowledge about the substances in game. The design of this scientific-knowledge-in-the-making process is coherent with John Dewey's (1993) argument about scientific induction:

Scientific induction means, in short, all the processes by which the observing and amassing of data are regulated with a view to facilitating the formation of explanatory conceptions and theories (pp. 86)

The *Legends of Alkhimia* Curriculum

While the *Legends of Alkhimia* game is designed as the backbone of this learning program, the game does not provide a complete package for scientific inquiry for a few reasons. First of all, the inquiry in the game is more of an individual quest than of a collaborative effort critical to the knowledge production in professional scientific communities. It is essential to extend their inquiry experience in the game into activities that support reflection and evaluation of their performance in game. This brings the second issue, which is also critical in shaping players' inquiry experience. Though the *Legends of Alkhimia* game aims at designing players' experience as science-in-the-making through scientific inquiry, not all players will play in the ways intended by the game designers—as a scientific inquiry experience. This is an issue common to the design of instructional media whether the chosen medium is a traditional textbook or a new digital medium. A textbook can be read and interpreted differently by readers who bring in different experiences, desire, and prior knowledge into their reading of the textbook, thus generating different meanings to the readers. Activities after game play are mainly designed to facilitate players' interpretation of the game toward scientific inquiry. The out-of-game activities are designed to support individual, group and whole class reflection and evaluation on scientific inquiry. The following describes a typical activity structure shared by six of the eight sessions of the entire learning program:

Pre-game prior knowledge sharing

Each student brings in unique experience and knowledge into the designed chemistry inquiry. Before playing each level of the *Legends of Alkhimia* game, students will share their experience of previous experience and playing session. This may not only help students reconnect to prior knowledge, but also keep the chemistry theories they are developing in check. In addition, students will also bringing to the fore their selves as agents in a shared learning experience. Through the pre-game activities, students will collectively establish a

social presence and social context based on prior experience to be over-layed or connected with the present to situate learning activities in the current session.

After-game group reflection and whole class discussion

Following game-play, students will organize themselves in their game-play groups. They will share their own in-game scientific inquiry notebook with the group members and select what and why they think is the best one to release to the class. We see that in the process, the students will have to collaboratively negotiate what counts as good scientific inquiry and bring these criteria into evaluating and selecting the best set of in-game notes. Students will also negotiate how the substances are classified and what names to be given to them like ancient Alchemists.

A whole-class discussion and reflection is designed to present, challenge or consolidate theories proposed by each small group. The whole class activity will take two forms. First, each group will take turns to report on their in-game inquiry as well as classification and naming of substances. Thereafter, the teacher will facilitate the whole-class discussion to reflect on the students' scientific inquiry. The discourse will revolve around two big questions: What are the properties of the substances? What evidences can be used to argue for or against the proposed theories of the substances? The themes of the questions are aligned to the main learning goals, and the questions are recurrent and revisited through the program. As closure to the session, students will vote, as a class, the best names for the substances and the best inquiry. The teacher will also recap the knowledge constructed by the class.

Role-playing in the Legends of Alkhimia Curriculum

In science classrooms that highlight content delivery, teachers often act as content authorities. They deliver contents and explain key ideas to students who are often considered passive receivers. As content authorities, teachers evaluate and judge if students have contributed to the intended answers when there are discussions. The underlying assumption about learning and role-playing often creates an initiate-response-evaluate (IRE) discourse structure that inhibits students from expressing their own voices and judgments (Cadzen, 2001). In many cases, it eventually mystifies the nature of scientific knowledge and affects students' confidence to perform like scientists (Lemke, 1990). We aim to change this widely accepted notion about role-playing in the classroom through design. In the *Legends of Alkhimia* curriculum, the teacher recedes from being a content authority to be a process director in order to help students to take a more central stage in learning. Role-playing as science apprentices, students are seen by the teacher as leading actors and actresses in the *Legends of Alkhimia* role-playing curriculum.

As a process director, the teacher envisions the inquiry process her students needs. The students are the leading actors and actresses who take the central stage in performing inquiry. The teacher director guides them, but he or she does not perform for them. For example, the teacher-facilitated discussion during the group reflection and whole class discussion are designed and facilitated by the teacher, but it is the students who are making arguments and interpretations about properties of different in-game substances. The teacher interprets (and invites other students to interpret) students' performance (e.g. classification and naming of substances) and speech acts in order to understand what guidance might be needed. He or she will also mediate students' discussions as a more or less equal voice. At

times, the teacher questions students as a curious co-participant. At times, he or she assumes more control in order to carry the discussions in depth. A useful strategy is to "re-voice" (O'Connor & Michaels, 1996) students to frame discourse towards learning goals and position students as members of a community of practice.

There are two major goals for designing the teacher-facilitated discussions. On the one hand, guided by the more experienced teacher, students will construct evidence-based knowledge with respect to the two over-arching questions and learn to see themselves as sources of scientific knowledge. On the other hand, through participating in teacher modelled scientific discourse in the earlier sessions, students will be acculturated into initiating and engaging in scientific discourse on their own. Therefore, in the latter sessions, the teacher will distribute more control over the class discourse to the students and allow more time for student initiated discourse. In other words, the teacher director fades into the background accordingly when student actors are capable of talking and performing inquiry on their own (Vygotsky, 1978).

Conclusion: Designing for 21st Century Science Education

In this paper, we initiate our argument by maintaining that literacy is dynamic, contingent upon the status of the world. The literacy skills defined by the industrial society are no longer sufficient in a globalized knowledge economy. One of the essential new literacy skills for the emerging new global society is the ability to produce knowledge and innovate. In science education, learning to inquire scientifically is a skill that may helps one to be a knowledge producer.

Though the world that we live today has advanced technologically and economically, schools lag behind in social transformation (Tyack & Cuban, 1995). Transforming science learning from the current content mastery paradigm to incorporate inquiry-oriented learning model has been proposed and conducted by many science education researchers (e.g., White & Frederiksen, 1998; Chinn & Malhorta, 2002). Since authentic scientific inquiries are hard to reproduce in schools, scientific inquires are usually simplified. As a result, many scientific inquiries are not only epistemologically inauthentic, but also fail to engage students in asking inquiry questions on their own. To tackle the challenge, we design a learning program, The *Legends of Alkhimia* game and curriculum, to help students inquire with epistemological authenticity. The science-in-the-making processes and practices from ancient Alchemists inspire our design of the Chemistry learning program for secondary school students in Singapore.

The Centrality of Design in Developing Educational Theories

We highlight the centrality of theory-informed design not only as a way to advance the design aspect of theory development in education, but also as a productive approach to transform educational practices. Today's school system is conceptualized and designed mainly on common sense rather than on science (Tyack, 1974; Sawyer, 2006). Hence the learning practices in schools often lack of theoretical clarity. Designs of learning programs drawing on rigorous educational research may help to transform schools toward a more research-based practice.

In this conceptual paper, we articulate how we may transform current educational practices. We draw on past studies to understand typical classroom practices and the design

philosophy underlying these practices. Without tackling the major design assumptions, our re-conceptualization may be scratching the surface only. To transform the educational practices scientifically, the design should be informed by the knowledge base available to researchers. In other words, the researchers present a design framework that is guided by theoretical constructs (diSessa & Cobb, 2004). In our case, we present a design case informed by social constructivism, scientific inquiry, game-based learning and classroom discourse. Furthermore, when a design leverages specific technologies to engineer a learning environment, it is essential to consider the affordances and constraints of the technologies (Norman, 1993; Pea, 1993) and how the affordances may be leveraged to align with the intended pedagogy in design. In this regard, we believe that a book might be written in a style or genre that supports scientific inquiry similar to our design with a 3D role-playing game.

Limitation of Design

As schools are stabilized communities that practice learning, they have established certain cultural models over years of practices. The curricula, assessments, pedagogies and school logistics are all aligned to formulate a stable structure that not only enhances the efficiency of the system, but also keeps the system in check. This creates a catch-22 situation for educational reform. On the one hand, we wish to create a steady system in order for it to perform consistently and effectively. On the other hand, we wish to transform the system accordingly so it can better adapt to global changes that are often hard to predict. Our design is situated in this larger educational ecology. Mainly focusing on designing for local classroom change, this design does not reflect on the ecological issues arising at the level of educational administration and policy. However, as a basic functional unit of the entire educational system, classroom practices will bring out both local and ecological issues. We believe that the enactment of this design-based research (Brown, 1992; Collins, 1992; Barab & Squire, 2004) study will inform us not only students' inquiry experience in the *Legends of Alkhimia* learning program, but also insights into how their learning experiences are structured by the current classroom culture, schools or even the educational system.

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