Designing with Stakeholders for Learning Innovations: Voyage to the Age of Dinosaurs

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This paper discusses our design approach to incorporating the diverse voices of stakeholders in developing a game for learning Earth system science, named *Voyage to the Age of Dinosaurs* (VAD). We focus on the identification of design problems (e.g., learning designs, game/graphic/intelligent designs, and design processes), the proposed solutions through and the common understandings among the voices of "experts" (e.g., learning scientists, educators, computer scientists, artists), and the process of understanding and designing with learner voices as we complete the first year of a three-year project.

The goal of VAD is to provide an immersive experience by recreating and replaying portions of Earth's history using intelligent agent technology and a 3D multi-user game environment. Much literature has documented the difficulties learners have in understanding the Earth as a complex system, with misconceptions often developing early in childhood (e.g., Barnett, Kafka, Bellegarde, & Pfitzner, 2004; Gobert, 2000; O. Lee, 1999; Sneider & Ohadi, 1998; Tsai, 2001). In this project we try to address design problems of many artifacts and rules in educational games not fostering learning and many designers only talking to the users through the final product (Norman, 2004).

In the three-year collaboration we have been working with two secondary schools in order to develop a culturally appropriate learning design, which reflects diverse voices of stakeholders using an informant design process (e.g., Druin, 2002; Scaife, Rogers, Aldrich, & Davies, 1997). One of the key intentions of the informant design workshops was to create tensional conditions in which learners' identities would shift; we wanted to provide an alternative environment for the learning of geography, to re-cast the role of geography learners, in order to enable shifting of their learner identities from being passive recipients of knowledge, to taking on the role of empowered and acknowledged experts in their own rights, who could legitimately contribute to the development of knowledge in their community of learning (be it their team, class or any other group). We also recognized how the learners, having their own rich funds of knowledge (González, Moll, & Amanti, 2005; Moll, Amanti, Neff, & Gonzalez, 2001), including cultural practices particularly, would be able to tap these resources, and we expected them to position themselves dynamically and negotiate the various tensions in working towards their personal and group goals, as implicitly and explicitly determined in the workshops. In the process of dynamic positioning and negotiations, we sought to create commonalities of experiences among the learners so as to foreground learners' voices.

Designing with Users

In the information age, the way that young users live and learn is changing with the emergence of new technologies, from Internet to multimedia. Researchers need to consider whether the new technology meets young users' need and helps their meaning-making processes. As young users' voiced likes, dislikes, wants and needs become increasingly important with regard to the development of technology, designers have started to realize that young users need to be involved in the design process in a meaningful way (Facer & Williamson, 2004). Although there have been many attempts to improve methods of design with young users (Druin, 1999; Facer & Williamson, 2004; Scaife et al., 1997; Taxen, Druin,

Fast, & Kjellin, 2001), there is still some dispute over the methods of involving young users in the design process. Recently the more popularized approaches in practices of design process are user-centered design, participatory design and informant design approaches (Facer & Williamson, 2004).

User-centered design views young users as testers for designs to assess whether their needs are met (Norman & Draper, 1986). This approach allows researchers to gain feedback from young users about the advantages and disadvantages of their design and explore further improvements. However, the limited involvement of young users cannot make any changes to basic product design, and young user's contributions cannot be input into the redesign process immediately (Scaife et al., 1997).

Compared to the user-centered approach, participatory design (PD) considers young users as partners throughout the design process by assigning them more equal and responsible roles (Druin, 1999), so young users become empowered to design/change and make decisions to develop the product (Nesset & Large, 2004). However, the strength of PD in maximizing young users' contributions in the design process has been challenged (Scaife & Rogers, 1999; Scaife et al., 1997). First, it's infeasible to make a decision in the co-design group during the design process, since young users might not see adults as equal peers. Secondly, it's not possible for young users to control the design direction in the design process and define the learning goals for themselves.

Given these shortcomings, informant design has been proposed to make up for those drawbacks from user-centered design and PD. Young users are a part of the design and play various roles in each stage, depending on when researchers believe young users can give appropriate information and ideas. During development, young users are asked to observe and evaluate existing games and are asked for input for low tech prototypes. Once the technology is ready, they are involved as testers to provide feedback. Meanwhile, the method suggests involving more kinds of informants to maximize the variety of suggestions (Scaife et al., 1997).

Researchers found informant design helpful for understanding young users' needs and preferences, and this method also helps to elicit some creative ideas. Examples can be found in Antle (2003)'s research, which involves young users as informants to design story builder software. Based on young users' feedback, the product was developed and improved to be more attractive and useable, with changes from earlier concepts and interfaces from interaction modes to button labels. Furthermore, some research (Scaife & Rogers, 1999; Xu, Mazzone, & MacFarlane, 2005) documents that young users inform technology design in terms of what behavior, features,and specific effects they enjoyed at the interface, during interactions with both low and high tech prototypes in the informant design. The most prominent case is food webs research from Scaife and Rogers (1999). After realizing that the developed software was boring to the 9-year-old users, researchers started a new low tech prototyping session to ask young users to draw what food webs software should be like (e.g. interface and behavior). Due to the minimal results from the first session, the second low tech prototyping session concentrated more on young users' interacting with props of animals instead of drawing. Young users were asked to tell researchers what could be changed in the software, through working with low tech prototypes. This session provided young users an opportunity to reveal insightful points for the structure of learning design and interface design. Designers were surprised by young users in the high tech prototyping session as well.

Working with existing high tech prototypes, young users came up with ideas about special components for developing technology, following related suggestions from designers.

As mentioned, in informant design young users' voices are elicited and promoted. They always come up with ideas that the research group did not have for enhancing the product (Scaife & Rogers, 1999). However, some challenges of informant design have been revealed: 1) researchers have to assess the feasibility of young users' ideas, since many of the ideas are completely unworkable in computational terms (Antle, 2003; Scaife & Rogers, 1999; Xu et al., 2005); 2) unfamiliar researchers may cause young users not to put forward their "voices;" 3) big problems arise when interdisciplinary teams impose their own views on the group. Therefore, negotiating the intentions, needs and interests of the stakeholders and considering how to maximize the input of diverse informants is the focus of future researche (Scaife et al., 1997).

A prominent example of one way to maximize the input from various participants is the study performed by Scaife and Rogers (1999).The researchers state it's possible to bring out more "imaginative and kid-appealing ideas" when software designers work and communicate more closely with their young users during the high tech prototyping session (p. 43). The research aims to design interactive software to teach young users basic concepts of ecology. During the low tech prototyping session, the graphic designer was asked to be involved in and observe what young users do with the low tech prototype. Thus the graphic designer understood better the "emotions" of young users that could not be transferred from the session videotapes. It also provided graphic designer an opportunity to brainstorm ideas in direct communication with young users. Meanwhile, more creative ideas were raised by young users, since young users felt that adults wanted to listen to their voices about the new software and they realized their important role in the process (Rudd, Colligan, & Naik, 2006; Scaife & Rogers, 1999).

The future developments of informant design are stated in Scaife's studies (Scaife & Rogers, 1999; Scaife et al., 1997). To maximize informants' input, future researchers should identify the various positions and contributions of the relevant informants for other domains and contexts, as they will interact with each other in different ways (Mazzone, 2008; Scaife & Rogers, 1999; Scaife et al., 1997). Scaife's research group also hopes to work further on informant design to address the questions, "How to design software that caters for the learning needs of the huge variety of kids?" and "Is informant design useful for other areas?" etc (Scaife & Rogers, 1999, p. 24).

Research Context

Singapore is a multicultural society with a British colonial legacy, and it provides an interesting context for research on designing with users. Singapore is a modern, highly-industrialized and multi-racial country. Equality among and respect for differing cultures among the different races are emphasized in the government's policy of multiracialism. The English language has been used as the medium of instruction in all government schools in Singapore since 1984 (Foley, 2001) for the purposes of promoting economic progress (Vasil, 1995). Notwithstanding rapid economic development, the culture of Singaporeans is diversity. On one hand, Western influence continues today in economic development. Singapore is greatly interconnected with the world through industry, trade, media, and the movement of people. Most Singaporeans who speak English can easily accept "Western values" as portrayed through Western media (Tay, 1996). On the other hand, the practice of "Asian values" was advocated by Asian leaders such as Lee Kuan Yew, the Minister Mentor

of Singapore, to counteract aspects of western ideologies, such as individualism. Asian values were employed to alleviate the threat of Western culture and values in Asia by building an Asian cultural identity (Chua, 1995). Lee Kuan Yew, defined Asian values in terms of respect for elders, family values, filial piety, a regard for scholarly learning and so forth (K. Y. Lee, 2000).

In schools and families, hierarchy (in terms of authority and obedience) is one of the most prominent features in "Asian values;" it still plays a role in the values system, which is established to rule and constrain relationships among people (Li, Carstensen, & Hammen, 2007). Under this value system, elders and teachers are deified, and have authority and power. Their voices are much more important than those of students. By contrast, students' voices might be restrained and ignored in this cultural context since they are trained to comply with elders and teachers. Albeit schools adopt English language as the first language in the schooling, orderly behavior and respect for seniors and authorities, as observed among students in East Asia with traditional values (e.g. China) (Cheng & Wong, 1996; Li et al., 2007), might also be reflected in the schooling in Singapore. Our research is trying to 1) hear the student voice where it is very soft and consider an appropriate and effective way for eliciting that voice in the Asian cultural context; 2) develop an understanding of cultural appropriate educational game ideas in the specific Singaporean context; 3) further explore ways to maximize the input from the various participants based on the relationships between them. This project is an extension of the research on designing with users. About twenty students from two schools in the age group of 13–15 are participating in this project as users and design partners, whose experiences with technology center around online communication activities and online games, such as *Maple Story* and *World of Warcraft*.

Overall Approach to the VAD Learning Design

Our learning design proposes to provide an engaging learning environment for Earth system science in Singapore's secondary level Geography curriculum. Our multidisciplinary team came together as we recognized that our research-based learning design needs distributed expertise from various and essential disciplines. Different research communities often come up with their own designs, focused mostly on theories and meanings of one particular discipline (Buchanan, 1996). The meanings of other disciplines are mostly assumed and interpreted by a single discipline's team. Our approach to learning design is to bring expertise from three main areas (Learning, Technology, and Art; see Figure 1), build common understanding, and make design decisions together. Our multidisciplinary team includes members of (1) the Learning Sciences Lab at the National Institute of Education; (2) Nanyang Technological University (NTU) School of Computer Engineering (SCE), Information Communication Institute, and School of EEE (ICIS/EEE); (3) NTU School of Art, Design, and Media; (4) Singapore Ministry of Education, Educational Technology Division; (5) Singapore Science Centre (SSC); (6) Chinese Academy of Sciences; (7) Tokyo National Science Museum; and (8) New York Institute of Technology. In our case, learners and teachers provide their expertise in all three areas, as they are the experts in knowing what they are excited about.

We have three main aims for this project. The first is *to design content that will support deep learning of Earth system science*. Previous research has drawn attention to the difficulties young users experience in building a concept of the Earth as a complex system: young users tend to develop naïve concepts from an early age (Barnett et al., 2004). They include belief in flat-Earth ideas (Sneider & Ohadi, 1998), supernatural forces as causes of earthquakes and volcanoes (O. Lee, 1999; Tsai, 2001), and a single causal mechanism for volcanic eruptions

(Gobert, 2000). Such concepts relate to how they perceive and feel about such phenomena according to the information available to them within the environment they live in (i.e., perceiving the Earth as flat is situated within the flat-looking ground that we live in). Earth is a very dynamic system, and people in various parts of it are constantly suffering from natural events (e.g., volcanic eruptions, earthquakes, flood, tsunami, etc.). Understanding the Earth as a constantly changing system, however, is also difficult to imagine since we can only see what happens on a day-to-day basis in our lived settings. Although the literature cited refers to young users and our learners are adolescents aged 13 -15, interviews with their teachers also show that they too have these sorts of misconceptions.

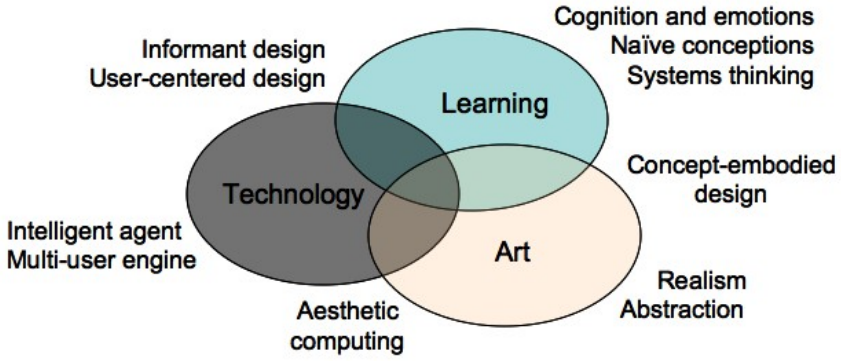

Figure 1. Design Approaches in Our Multidisciplinary Team

From the "Learning" perspective from Figure 1, we see that cognition and emotions are distributed among people (at various levels, such as classroom, community, and society), artifacts, and symbols (Salomon, 1993) and situated within the learning as well as their life contexts. Emotions can be directly associated with concepts they learn because they are results of direct or indirect life experiences, which sometimes provide more reliable information about situations than reasons, and supply the best resource to accomplish our goals (Zhu & Thagard, 2002). The distributed nature of cognition and emotions often allows us to form naïve concepts, as we perceive our world through our senses, cultural beliefs and associated emotions; at the same time, learners' concepts and emotions can become generative resources for learning when we take them seriously. We therefore proposed that fossils and the fossilization processes of dinosaurs (commonly perceived as gigantic and powerful creatures long extinct) could become powerful conceptual and motivational anchors for learning complex Earth processes, as the fossils themselves embody the Earth's dynamics and history (see Figure 2). Fossils are formed (and often exposed) because of Earth's materials, weather/climate, and structure/dynamics, and thus provide evidence not only of ancient life but also of the Earth's history and processes such as the movement of tectonic plates.

The second aim of our design is *to develop an immersive interactive media that appropriately recreates and replays parts of Earth's history*. We are using intelligent agent technology within a 3D multi-user gaming environment, which could potentially provide learners with opportunities to explore properties that are inaccessible to them through everyday experience. Learners are able to interact with the virtual environment, artifacts, tools, human characters, creatures, and their fellow learners (represented by human avatars) that may embody conceptual and emotional elements related to their Earth science learning. Three general principles govern the design of this media.

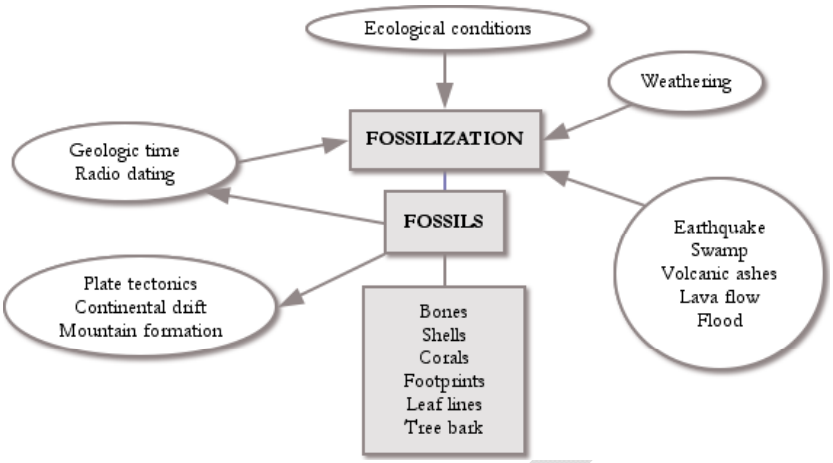

Figure 2. Fossils and Earth System Processes

First of all, the designs of the objects, landscape, and characters, regardless of their realistic or abstract representations, should implicate certain aspects of paleontological and geographical contents beyond aesthetic value or preference of an artist. For example, dinosaurs' appearance and movements reflect the research of paleontologists, as well as artists' imaginations and expressions of the creatures' skin/feather colors, textures, and so forth. Concept-embodied design on the right side of the Figure 1 refers to such art production activities, where the areas of learning and art overlap.

Second, any objects or characters placed in a computing environment can become intelligent agents, which are autonomous, able to dynamically adapt their behaviors by observing the environment, learn new things from the environment to achieve goals, and cooperate and interact with other autonomous agents and human agents (Russell & Norvig, 2003). Extending the notion of a distributed system of thinking and feeling, the participants (learners and multiple agents), artifacts, and immersive environment contribute to the accomplishment of various tasks. Emotions arise from interesting content, relational meanings around the content, and situational context (Planalp, 1999). Such emotions are represented (e.g., urgency due to volcanic eruption) and shared among characters, artifacts, and players. Group level emotions in a system of learning form and evolve as the members work together, and distributed emotions can improve or impede overall performance the system (Norman, Ortony, & Russell, 2003). One of the aims of aesthetic computing, where the art and computer engineering overlaps, is to improve the emotional and cultural level of interaction with the computer (Fishwick, 2006). We hope our design provides learners with engaging experience and shifts their role from passive recipients of knowledge to active meaning-makers by making meaningful associations through their explorations. We call this active meaning-making process, beyond mere social interactions within the immersive environment, "serious immersion," and the understanding resulting from such immersive experience, "embodied learning."

The third aim *is to accomplish a culturally appropriate design through an informant design process*. We investigated secondary geography teachers' reflections on their teaching, students, and ideas about educational innovations, and students' concepts of Earth systems and ideas about meaningful learning environments. These investigations and the continued co-design process help us establish a framework for collaborative design practices with the teachers and their students (Brown, 1992; Collins, Joseph, & Bielaczyc, 2004; Druin, 2002;

Scaife et al., 1997) and build the capacity for such educational design processes in Singapore. As we said earlier in this paper, the main design problems we would like to address through this process include: 1) many artifacts and rules in games do not foster learning; 2) different research communities and industries come up with their own educational games without conversations with others; 3) many designers only talk to the users through the final product (Norman, 2004); and 4) many designers/researchers reject broader notions of design and defend their work which only carry their own theories and meanings (Buchanan, 1996). We would like to understand learners better and explore ways to use their Earth science concepts and their cultural exposure to different games generatively in our design, by listening to their voices and involving them as co-designers.

Informant Design and Voices of Stakeholders

In this project, we intend to foreground learners' interests, their opinions, their ideas and what they value among those of various stakeholders; that is, we aim to develop a prototype for adolescent learners by soliciting their voices. As discussed earlier, we note that common approaches of developing prototypes with users such as user-centered design, informant design and participant design purport to solicit users' voices although the extent of doing so differs in each approach. In our work, we have found three compelling reasons to solicit the students' voices through the informant design approach:

(i) It creates an intertextual link with other sources of the students' knowledge.

Mikhail Bakhtin (1986) argued that "our speech… is filled with others' words, varying degrees of otherness or varying degrees of our-own-ness, varying degrees of awareness and detachment. These words of others carry with them their own expression, their own evaluative tone, which we assimilate, rework and re-accentuate" (p. 89). Through the informant design approach, we want to know which voices students tend to foreground, whose voices these are, and what students' own voices tell us about their way they have learnt and would like to learn about earth science concepts. By listening to the students, we may find intertextual links to their sources of knowledge about earth science concepts.

This is where we expect to see tension between learners' existing identity as students of rote study and a repositioned one as meaning makers. Through our informant design workshops, we have created opportunities for them to voice what they think about certain earth science phenomena and what sense they make of them, rather than what they can regurgitate from their textbook or other notes. Put differently, we deliberately stir up a tension between what Bakhtin (1981) terms the *authoritative discourse* and the *internally persuasive discourse*. The former is the official discourse or the voice of authority, while the latter is the discourse of the individuals' personal beliefs and ideas that shape the way we tell ourselves about the world and who we are (Landay, 2004).

(ii) It creates deeper meaning making for the learning of Earth science concepts

Kress (2003) puts forward a theory of constant transformation of both resources and subjectivity, whereby learning is perceived as a change in resources resulting from active transformative engagement with an aspect of the world. The learner (the sign-maker) is constantly transforming the set of resources and himself. Based on Kress's (2003) theory of learning, signs are indications of the interest of the learner, engagement with the world and his experience of the world. Signs made outwardly are the best evidence of learning as their characteristics give access to the cognition and affect of the learner. Different semiotic modes demand and produce different engagement with the world. The forms of engagement thus lead to distinct forms of thinking and interacting with ideas, resources and others. In the

way we design our informant design workshops, we find ways to give the students the resources and tools to value their own voices and represent their thoughts. Through this approach, we hope to find out what meanings these students have made about certain earth science phenomena, what they have understood as well as what misconceptions they have and what they have yet to know about these phenomena.

(iii) It taps the students' funds of knowledge as an attempt to bridge their school and out-of-school practices

Prensky (2001) remarks that digital natives use technology in a greatly taken-for-granted manner. Technology is part and parcel of their daily lives. For many of the students we have been working with, computer gaming is part of their daily literacy practices, and forms an integral part of their cultural environment. We want to tap their funds of knowledge (González et al., 2005; Moll et al., 2001) about games and learn about their gaming experience. Specifically, we want to know what engages them, and what kind of gaming experience attracts adolescents. By tapping their funds of knowledge in this way, we hope to recontextualise their gaming experience into pedagogical practices. This is our attempt to bridge their out-of-school practices with their school practices, with the purpose of motivating them to learn our dynamic earth as a system of interrelated events and entities that extends beyond the boundaries of school-based rote learning.

Traces of Learner Voices

During our project's planning stage, we envisioned that working with the teachers and students would be most essential at the beginning of the project to understand their needs and their ideas about meaningful learning environment, and to help us come up with the design. However, the way we work with the teachers and students has been evolving as we try to converge the focus of various stakeholders of the team as well as to open up a possibility to have workshops that provide engaging learning and designing experience for learners and team members. In this section, we describe details of our first two workshops, what kind of voices we hear from learners, and what the implications were for our design. In order to make connections between the two workshops, we will specifically present examples and discourses of four participants from one group (this grouping is done during the second workshop). This group, who called themselves T-Rex, consists of four participants (three boys -Tony, Victor, and Weilong, and one girl - Irene) who belonged to different groups and schools during Workshop 1 but were grouped together randomly in Workshop 2.

Workshop 1: Learners' Earth Science Concepts – Where are They From?

Our first workshop aimed to uncover and analyze students' concepts in earth science by getting them to respond to a range of questions (see Appendix 1). We conducted after-school workshops with 20 students from two schools. This cohort was at the beginning of their Secondary 1 school year (equivalent to US grade 7) and most of them had not started lessons covering these topics on Earth system science. We intended to establish deeper understanding of students' preconceptions of earth science ideas prior to their undergoing formal class lessons that would 'deliver' the content. However, some students in one of the schools had gone through the topics immediately before this workshop. Among the four participants we are using for our discussion below, Weilong is the only one who went through the lesson, coming from a different school.

Workshops were structured so that small groups of three to four students each worked with a group facilitator (one researcher) in responding to the provided questions, as shown in Figure 3. All students were provided with the opportunity to share their responses with their group

members and the group facilitator. Workshop activities began by presenting each group with a picture of a dinosaur fossil (Mesosaurus), which was a major piece of evidence for continental drift. We asked them to write a story about possible life, death and fossilization of the creature and how the same species could be found on two distant continents. Students were also asked to draw, write and describe what would happen if the Earth were sliced in half, and to also describe what they understood about volcanoes, in a manner similar to how Gobert (2000) studied 5th grade students' models of the Earth's interior and its causal and dynamic processes for plate tectonics, using their diagrams.

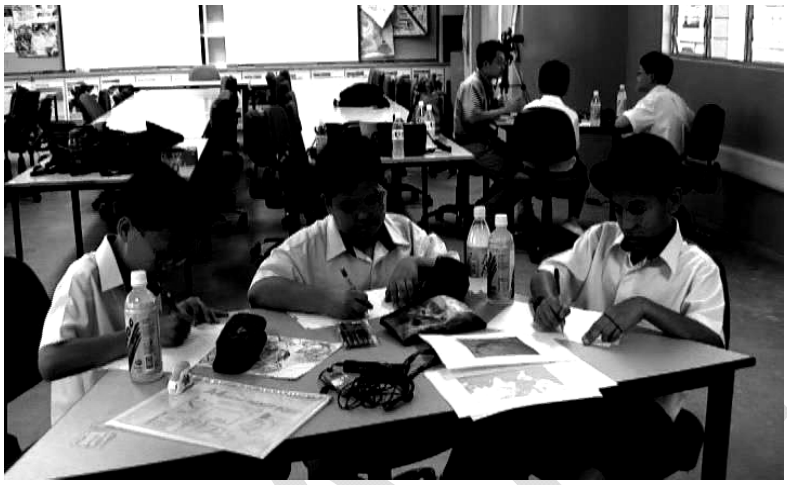

Figure 3. Workshop I –Tony's (on the left) Group

Participants during the first workshop were generally more passive, which is typical for Singapore's classroom context. In this workshop, we sought to create tensions to enable us to glean insights into how learners negotiated the dissonances and similarities between their own voices as compared to the dominant (authoritative) discourse. By eliciting their own discourse on earth science concepts, we were able to observe the various paths of negotiation. Most ideas generally were adopted from sources that were perceived by students as 'credible' such as parents (Victor & Tony), television programs (Irene), and teachers (Tony & Weilong) (see excerpts in Table 1).

From the excerpt turn 1 in Table 1, Weilong explains how Mesosaurus fossils could be found in both South America and Africa (see Appendix I, question 2), making inferences based on his knowledge from classroom lessons. As a "good" student who had gone through proper classroom lessons prior to the workshop, he predominantly speaks through the voice of his teacher. In turn 2-5, Matt and Tony try to check with each other whether or not what the other is saying is what they learned from their teacher, searching for the authoritative voices, which they probably feel more acceptable and presentable than their own.

Students look to classroom lessons as their source of knowledge, especially when they have gone through the topics in the classroom. However, they also bring in various resources they deem credible from outside the classroom. One salient characteristic of Victor was the frequent mention, and significance, of what his mother had informed him about earthquakes, tectonic plates (expressed as 'blades' by Victor in turn 6, Table 1) and volcanoes. It seems that his interactions with his mother in (probably) informal settings had made a significant impact on his scientific understanding. Interestingly, his account of "blades" as the cause of earthquakes (see Appendix I, question 4) reflects how Victor still possibly has his own

interpretations and imagination based on what he thought he heard from his mother. Similarly to Weilong's (discussed above), Victor's ideas were attributed to, and expressed as (authoritative) external sources or agents, which 'delivered' the knowledge to him.

Table 1. Student Voices Reflecting Authoritative Voices during Workshop 1[1]

Student Voices	**Excerpts**
Classroom lessons	1. Weilong : Last time during geography class, she [his teacher] say that once earth every part of it is connected. So probably that there is a chance that they [the Mesosaurus] might be travelling around South America to Africa. (*Previously during an Earth Science class, my teacher told me that every part of Earth was once connected. Therefore, there may be a chance that the Mesosaurus travelled from South America to Africa)*
	2. Matt: No, not forget, I don't know how volcano explodes (*No, I did not forget. I do not know how volcano explodes*) 3. Tony: Forget my teacher got say before (*I forgot if my teacher said it before)* 4. Matt: My primary six teacher say before. (*My primary six teacher mentioned it before)* 5. Tony: My teacher never tell me all these. I learn from myself one leh[2]. (*My teacher did not tell me all these. I learned this by myself*)
Conversations with parents and others, media	6. Victor: My mother said that the blades move, then it shakes the ground which will start to crack. (*My mother said that as the result of plate movements, the ground shakes and start to crack)*
	7. Tony: Hmm still parents taught me parents told me and some other people told me la[2]. (*Hmmm… My parents taught or told me and some other people may have told me as well*)
	8. Irene: I think I saw one on television leh[2]. Got a lot of documentaries on this dinosaur (*I think I saw this on television as there were a lot of documentaries on this dinosaur*)

We noted that both Tony and Irene have rich exposure to the media and conversations with adults: nonetheless, their uses of them in their discourses appear very different. Irene showed substantial preoccupation with getting her responses "correct" and was constantly trying to 'remember' what she had watched or learnt in her prior (informal) experiences (e.g., watching documentaries). We observed that Irene displayed a substantial level of hesitation in her attempts to explain volcanic processes and phenomena. She also seemed to couple or 'hedge' her inability to construct clear and "correct" responses, with her lack of knowledge ("I don't know") and inability to recall ("I can't remember clearly;" "if I remember correctly"). In turn 9, Table 2, Irene is trying to write the story about Mesosaurus and she is having hard time moving the story forward as she does not have enough factual information to describe the life of the Mesosaurus (see Appendix I, question 1). Irene seems to be uncomfortable when she is not sure about what the authoritative voices would say and tends not to come up with her own ideas and use imagination.

[1] Proper English, translated from their Singapore Colloquial English (SCE, otherwise known as Singlish) is in parenthesis beside the original transcript.

[2] "Lah, ah, la, leh, hor" are articles in SCE used to emphasize what is said and to build solidarity among the interlocutors. SCE is common in adolescents' spoken English in Singapore, and is generally used in casual and intimate (i.e. non-formal) contexts (Pakir, 1995).

Table 2. Student Stories Reflecting Various Voices during Workshop 1

Student Voices	**Excerpts**
Factual voices *(Pieces of information not credible, thus uncomfortable)*	9. Irene: Urm. Let me think ah. Urm. I also don't know leh. Is South America cold? [Ling: No. Africa] No, South America. Is it cold? [Ling: Brazil is not cold.] Uh, Brazil not cold. [Ling: Brazil is quite hot.] I don't know, never went there before. [Ling: Africa also quite hot. That means] Is around here right? That means it's near the equator leh. [Ling: Quite near.] Is it here? [Ling: Eh ya. That means it lives in hot weather ah?] Ya, maybe. [Elis: Not so hot?] Maybe, maybe. [Ling: Not so hot?] Not so hot cause last time, last million years ago.
Imaginative voices *(Various prior images and resources combined with his imagination)*	10. Tony: Meteorites coming down [Facilitator: Oh] (?) kill all destroy all the habitats, animal. Maybe wipe them all out. (*Meteorites came down, killed and destroyed all the animal habitats. It may also have wiped them out [from Earth]*) 11. Facilitator: Wipe them all out. 12. Tony: Volcano volcanic eruption blowing up everything small little stones flying everywhere. [Facilitator: Mm wow] Earthquake and tsunami. (*A volcanic eruption blew up and small stones flew everywhere. [It also caused] an earthquake and tsunami*.)
Factual voices *(Connecting the picture provided with his prior knowledge)*	13. Victor: Ah both in the water and the land. Uh. It can live in water, in water and on land as it's a reptile. 14. Facilitator: Ah ok. So what kind of reptile does it resemble? 15. Victor: Uh. Frog. 16. Facilitator: Ok, right which can live on land and in water. 17. Victor: Yeah. Its legs are bigger than its hands.
Academic voices *(Formal and procedural description reflecting classroom knowledge)*	18. Weilong: The mesosaurus is a freshwater reptile so it most likely spends most of their life in freshwater. It probably, probably preys on organisms that live in the water. Its body is quite small but it has a long tail. For their death of the mesosaurus there might be many causes. It could have been hated by its predator, run out of food or die naturally. For fossilization, when the mesosaurus dies, the muscles and the fats on the body will slowly decay, then, dirt and sand will cover it and after millions of years the pressure will make it fossilize.

On the other hand, Tony uses various prior images and resources to create his story about Mesosaurus (see turn 10-12, Table 2; Appendix 1, question 1). He was very expressive and even exaggerated in imagining and describing Earth's events verbally as well as visually through drawings (see Figure 4). He used various analogical expressions, which often included human figures or emotions and dramatic descriptions of catastrophe and urgency of situations. He was especially excited when talking about volcanoes and his initial drawing highlighted volcanic eruption as the main disaster that the dinosaur could have encountered. In Figure 4, his drawing about what happened to the Mesosarus in the fossil includes volcanic eruption (on the right, expressed with red lines and small balls for the volcanic materials), big tidal wave (on the left) where Mesosaurus is drowning (bottom left), meteorites (big round shapes expressed with lines for their falling from above), earthquake (middle bottom expressed as cracking ground), and some green trees on the land.

Figure 4. Tony's Drawing about his Mesosaurus Story

From turns 13-17, Victor is descriptive and detailed in his explanations about what he imagines about Mesosaurus. He foregrounds his ideas with the background of what he can interpret from the picture of the Mesosaurus fossil (see Appendix 1, question 1) and perhaps of his prior understanding about adaptation and anatomy of frogs. He is making an attempt to be as concrete as possible when he is inferring the type of reptile from the structural anatomy of the creature shown in the picture. The sharp contrast to Tony and Victor can also be found in Weilong's description of Mesosaurus, which we assume depends more on the authoritative voices from his classroom lessons. In turn 18 of Table 2, he is explaining his story to the facilitator of his group. His story is dominated by formal and sequential possibilities of what might have happened to some Mesosaurus based on factual details, without any analogy or personalized expressions. We found that Weilong's explanations of other earth science phenomena, for example volcanoes, also come across as detached, procedural and formal in tone and structure, like in an academic discourse.

Workshop 2: Learners' Stories and Voices

Our second informant design workshop was held over two days during school holidays in order to give students an opportunity to work together with students from another school, outside of school in a different environment, to brainstorm and develop ideas about dinosaurs, fossils, and the prehistoric environment by beginning to draft stories about dinosaurs based on their interests and ideas. Sixteen students participated this time. In Figure 5, the T-Rex group is writing their story together (from the left, Tony, Irene, Victor – behind Irene, and Weilong).

We intended to encourage diverse voices from students for the game scenario, but at the same time attempted to create commonalities of experience by getting the students more immersed in ideas surrounding dinosaurs by having activities centered around the dinosaur exhibits and Omni theatre movie at the Singapore Science Centre and the Evolution Garden at the Singapore Botanical Gardens. In Figure 6, students and a facilitator are reading some descriptions in the garden. These experiences would be then integrated into their funds of knowledge, from which the students were invited to co-create and share stories about

dinosaurs, and later on to create short digital movies from them - essentially enabling their voices to be established firmly.

Figure 5. Day 1: Story Generation at the Singapore Science Centre

Figure 6. Day 2: Experiencing the Prehistoric Environment at the Evolution Garden

Not knowing our intention to encourage their own voices, students initially wanted to use what they thought would be more "correct" coming from authoritative voices. When they first started writing the scripts together, after discussing the Omni theatre movie's storyline, Tony said to his group, "let's just copy teacher's example." Even though we intentionally changed the venues to be outside of their schools, they initially stayed in the passive "student" mode. Students gradually became empowered to be creative in using resources and ideas and take up roles they defined in order to make the movie together. For instance, Weilong initially stayed at the periphery of group interactions as the only person from a different school in his group. However, he gradually moved into the center of the interactions and played an active role as a "director" and cameraman. In Table 3, turns 19 and 22, and Table 4, turn 25, Weilong coordinates the actions and their timings for the filming.

We gave each group a set of scenes (mountain background, forest, etc.) and dinosaur props for their filmmaking (see Figure 7). We purposely did not show these sets to them while they were modifying their scripts because we did not want them to confine their ideas around the sets. The T-Rex group's movie starts with two students playing the role of Paleontologists (see Appendix 2 for the complete scripts and their movie screen captures):

> *Two paleontologists find a fossil of Confuciusornis, which is in the jaw of Dilong Paradoxus. This fossil reflected the fighting scene in Cretaceous period where Dilong chases Confuciusornis as its prey. At the moment when Dilong catches Confuciusornis volcano suddenly erupts, which causes the two fighting dinosaurs to be quickly covered with volcanic ashes to become the fossil that two paleontologists find.*

Once they started thinking about putting their story characters on the stage, they started seeing various details to be specified. They went through numerous iterations of the scripts while they were planning as well as filming the scenes. The group initially was searching on the Internet for appropriate cartoons or drawings of paleontologists they could use as props. They then decided to act out and use the area around their station as their stage. As Weilong and Irene had more behind-the-scene roles (cameraman/director and narrator), Victor and Tony became the two paleontologists. They made use of various resources, including scissors (brush), white power cord on the floor (fossil), their own bags, paper drawn mustache (characterizing paleontologists), and so forth. This change made this group even more

emotionally engaged in the story and filming as the characters were no longer 3rd persons, but themselves; there was a lot of laughter and coming up with more ideas.

Figure 7. Prop Dinosaurs for Movie Making

In turn 19, Table 3, Weilong suggests amplifying the happy emotions of finding a fossil by doing some celebratory acts. They start identifying with the paleontologists' activities, perspectives, and emotions, and trying to represent them in their movie. In order to contrast the success with the initial thought of failure, they "cry" to exaggerate the sadness of not finding any fossils and then "hug" and/or "dance" to express the happiness of finding one (Table 3, turns 21-23). Interestingly, Tony's remarks in turn 23 imply the images he has about fossils and the practice of paleontologists. He calls fossils "bones" probably because of what he had seen from different sources, as dinosaur fossils were in the shape of bones. He also asks Victor not to say immediately that he found a fossil, as he (or the group) takes the next part of the scene, where Victor takes out his brush to find out what that "something" is, as an important practice of paleontologists.

Table 3. Student Voices during Workshop 2 – the Characters on the Stage

Student Voices	**Excerpts**
Emotional amplification – finding fossils	19. Weilong: Eh, ok, ok, I got an idea. You all celebrate your way back right…. You all celebrate your way back ah. *(I have an idea. You both act to celebrate your fossil finding on your way back…. Remember to celebrate on your way back.)*
Paleontologists' emotions and actions	20. Weilong: OK ready ah. *(OK. Are we ready?)* 21. Tony: ((to Victor)) You shouldn't hug me leh, you should dance like that ((dancing)). *(I think you shouldn't hug me but you should dance like this.)* 22. Weilong: The first part, you all must cry, ok. *(In the first part of this scene, you must act like you are crying.)* 23. Tony: ((to Victor)) Later I cry then you start… Ok ready. Then you say "eh, I found something leh." Don't say you found a bone. Then you cry with me like that. *(When you say start, I'll act like I'm crying… OK, I am ready. You should then say, "Hey, I think I found something!" Don't just say you found a bone. You must also act like you are crying.)*
Making sense of dinosaurs' interactions	24. Yalar... how can, how can two make er, dinosaur chase the flying one? *(Yea… how can two dinosaurs, um… how can a land dinosaur chase a flying dinosaur?)*

In putting the Cretaceous dinosaurs on the stage, students also start to discuss the details: how they meet, what they are doing when they meet, how to sequence the series of actions, and so forth. Victor took over the computer and started typing because he was the fastest typist. As he starts typing, he questions the logic of a land dinosaur attacking a flying dinosaur (turn 24, Table 3). His question transforms the initial selections based on the looks of the dinosaurs into a learning activity by thinking more deeply, using his common sense and looking up the dinosaur catalog. They wrote the story with simplistic behaviors, without considering the characteristics of dinosaurs, but are learning along the way in order to make the story align with the paleontologists' findings. They also realized how small the dinosaurs were compared to what they would imagine or how dinosaurs are commonly depicted, as gigantic creatures.

Not only the human characters and living creatures, but also the dynamic Earth event, the volcanic eruption, had a very important role and meanings to this group. Illustrations of volcanoes, with labeling of their different parts, and text are the main means of representing the concept of volcanoes and their eruptions and impacts in the classroom. From the excerpts in Table 4, we can see that students are incorporating other means (i.e., sounds, movements, physical objects, etc.) of representing different aspects of this particular Earth event that are meaningful to them. To Tony, "lava" seems to be a specific and representative entity of volcanic eruption. The "red" color is a semiotic resource of illustrating the hot liquid that can melt objects and damage lives, similar to his drawing during the first workshop (see Figure 4). Tony (turn 25, Table 4) discovers a red disposable poncho and decides to use it as lava during filming. Prior to this particular excerpt, he has been searching for something red to use throughout the day and even considered using the red T-shirt he was wearing. In turn 26, Weilong means throwing the poncho to the stage. The extrusion of lava was illustrated with lines of red color in Tony's Figure 4 drawing; the illustration becomes a gestural mode of throwing the poncho over the stage in the movie.

Table 4. Student Voices during Workshop 2 – Making of the Volcano

Student Voices	**Excerpts**
Representation of volcanic eruption	25. Tony: I forgot I got lava. I remember. I got poncho *(disposable raincoat).* ((He takes out pinkish-red poncho and throws it onto the table. Irene picks it up and takes it out of the packaging.))
Creating meanings - making of the volcanic eruption	26. Weilong: Oi, Victor, you must make the shaking sound then throw. You don't immediately throw…but very good…OK…very good. *(Hey, Victor, you should make the rumbling noise first then throw the raincoat. Don't immediately throw it… but it was very good… OK…very good)* 27. Victor: How to make shaking? *(How do I make the rumbling sound?)* 28. Weilong: You make like ((making rumbling sound of volcano eruption)) *(You make some sound like)*

Weilong and Victor are the two acting out the volcano in the final scene. In turn 26 in Table 4, Weilong talks about the detailed sequence of the volcanic eruption: we need to hear the sound of the ground and mountain shaking before seeing the actual eruption happening. Behind the scene, Weilong shakes the camera to illustrate the shaking of the ground when Victor makes the rumbling sound. In Figure 8, Victor is about to throw the poncho from behind the mountain backdrop to the stage where Tony is manipulating two dinosaur props. On the right side, Weilong is holding the camera to film the last scene, probably shaking it a bit to give a

“tremor” special effect to the volcanic eruption. Irene is at the corner reading the scripts from the computer and also trying to be close to the camera in order to have her narration well recorded while filming.

Figure 8. Second Day - Shooting the Final Scene

In this context, students were able to foreground their voices by developing and enhancing their stories, even bringing in their own 'artifacts' and representations to the dramatic effects. Tony seemed to be fully immersed mentally and physically in the story generation and acting as a paleontologist, which transformed the dynamics of the group as well as the movie. However, group members voiced their understanding and ideas, which seems to be very important for sound story-making in addition to Tony’s emotional and dramatic turns. Excerpts in Table 5 demonstrate a short conversation in which the group members try to decide what kind of volcanic materials should be part of their movie and to make sense of the relationship between volcanic eruption and fossilization.

As Tony is excitedly describing the scene (turn 29, Table 5), Victor corrects him for the incorrect term he used (lava vs. magma; turns 29-30), which was a common mistake made by students in the first workshop. Irene suggests and Weilong supports the idea that volcanic ashes should cover the area instead of lava for the last scene (turn 32 and 36). Tony’s fascination with lava’s possible dramatic effects is challenged when Weilong brings his attention to the main storyline, which is the fossil that the two paleontologists found in the first scene (turns 39-41). Tony acknowledges the contradiction for preserving bones (turn 41), but still cannot totally agree that ashes could have such a fatal effect (turn 44). In contrast to the fossilization account of Weilong (see turn 18, Table 2) in the first workshop, which was more like factual descriptions, this group is trying make connections and meanings among the elements of the movie scene.

This workshop context afforded great latitude for various tensions to be navigated and learners' voices to be heard. While the research team prepared various resources to enrich the range of artifacts available for the learners' use, such as a dinosaur catalogue with images and information on various dinosaurs, and internet connectivity, the students were also free to use other resources and artifacts available in their immediate surroundings, or which they had brought with them. In addition to the few exemplified in the T-rex group’s excerpts above,

others groups extended the given props and backdrops by acting as human characters, making human figures, bringing leaves and rocks to enrich the stage, and so forth. In fact, all the groups used only limited number of provided props/backdrops, but still extended their resources beyond them. Their emotional engagements with characters, events, and meanings become stronger when their voices and ideas were reflected on the stage.

Table 5. Making Sense of the Relationship Between Volcanic Eruption & Fossilization

Excerpts
29. Tony: Eruption happens.... and covered with magma. *(An eruption occurs…and everything is covered with magma.)*
30. Victor: Lava.
31. Tony: …lava...
32. Irene: Volcanic ashes la. *(Volcanic ashes [not lava])*
33. Tony: Volcanic ashes cannot cover. *(How can volcanic ashes cover it?)*
34. Victor: No such things... *(There is no such thing)*
35. Tony: The ashes is like small little things flying down. *(Ashes are like small things flying down.)*
36. Weilong: Caaan.... *(It is possible)*
37. Tony: Can, but it won't kill you. Too many. (*Possible, but it will not kill you. You need too many ashes to die.)*
38. Victor: Just say lava and ashes la... *(We just say lava and ashes then)*
39. Tony: Lava better la. I want to see them melt to death la... *(Lava is better. I want to see them melt to death!)*
40. Weilong: If melt to death then the bones.... *(If they melt to death then what happens to the bones?)*
41. Tony: Oh yea hor. *(Oh yes, right)*
42. Teacher: Could be the lava cooled and solidified then covered them?
43. Irene: Ashes can kill people also right.
44. Tony: Ashes can meh? ((looking at the teacher)) Ok, fine, fine, fine... ok. So we make totally the same la. Very weird leh. *(Can ashes kill people? Ok, that's fine. We can have both ashes and lava then. It sounds very weird to me.)*

The Design Interplay

The first two workshops we presented above are more focused on our understanding of learners' concepts and ideas and foregrounding their voices, which may be not appreciated by the teachers, especially when we are addressing their concepts. During the workshop 1, students were more focused on factual accounts (what were the correct answers or facts), explanation of phenomena, and collaborative reasoning on how a certain phenomenon could have happened. Even though we were interested in hearing students' internal voices without depending on the authoritative voices, a teacher from one school who did not know the purpose of the workshop prepared a few students from his class; Weilong's excerpts in turn 18, Table 2 obviously showed how such preparation affected the representative voices in students' discourse.

In contrast, the workshop 2 provided the context where they could focus more on creative narration, highlighting affect such as the emotions of the actors, dramatization of phenomenal occurrences (e.g. sounds, the visual impact and the gestures). Their voices foreground their playfulness with ideas and representations, richly using an array of semiotic resources beyond language, specifically written language and geography terminologies. Unlike the preparation and implementation of the workshop 1, which was quite independent of the technology and

art teams, we worked closely with the art team to enrich their story generation resources (props and backdrops) focusing on the area (Liaoning, China) and the prehistoric era (Cretaceous). Figure 9 summarizes where we have been and where we are going for our design, starting from top left with the first workshop. The numbers represent the series of workshops, and the letters in the circle represent the teams of three main areas (learning, art, and technology) for our design. As we move from one workshop to the next, we have seen increasing interplay among stakeholders and increasing voices of learners and teachers within each workshop as to the design of game and of the following workshops.

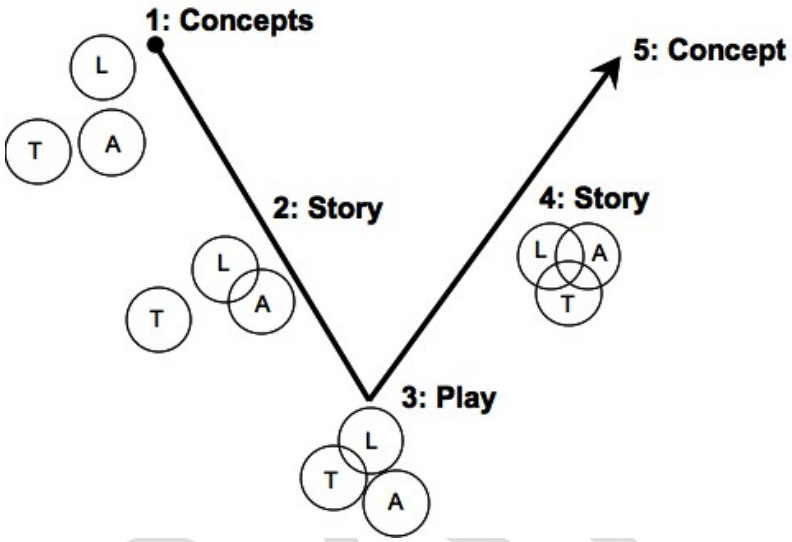

Figure 9. Informant Design and Design Interplay

From the workshop 2, where we focused on experiencing the stories of others (movie, scientists' exhibits and descriptions about dinosaurs and evolution) and creating their own stories, we have moved to the workshop 3 where they play different dinosaur games and our first computer game prototype, and design their own "hottest game" in town, which we are incorporating into our game development. The voices we heard about their play ideas were reflecting the current trend in violence in popular games, which we try to incorporate in generative and educative ways in interacting with dinosaur characters in the game. We are planning for the workshop 4, in which we would focus on learners experiencing our game storyline in the physical environment as well as in the game, so that they can provide more direct inputs to our design. For the workshop 5, we would like to give students an opportunity to experience the work of paleontologists by visiting the fossil site, so that they can foreground their voices and feelings about the conceptual part of the game experience, and be more directly involved in expanding and modifying the game design.

The first year and half of this project have provided a big challenge for us: to learn to use the languages of learners and teachers, as well as the collaborators of different disciplines. We can see that our various stakeholders are starting to understand better each other's intentions, needs, languages and orientations. Such effort is a very long journey and takes much more time than development that is driven by the voice of one discipline. We believe and hope that this effort of compromising, respecting and supporting the voices of various stakeholders will lead to a more meaningful design that can be used and expanded for a long run.

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Appendix I: : Workshop Materials on Earth System Science Conceptions

Questions for Student Workshop

(1) This fossil of Mesosaurus was found in Brazil, South America. Paleontologists have identified it as a freshwater reptile. What could have happened to it? Describe the life, death, and the fossilization of this Mesosaurus. (15 minutes, no limits)

In your group, share your descriptions. (15 minutes)

(2) The fossils of Mesosaurus have also been found in southern Africa. In your group, talk about how Mesosaurus, the freshwater reptile, could have been found from two different continents. (10 minutes)

(3) If we slice the Earth in half, what would its cross section look like? [Why?] Draw your idea on the piece of paper provided. (5 min)
Share your ideas to your group members (5 min)

(4) Individually, draw and explain how earthquakes happen. Draw your idea on the piece of paper provided. (5 min)

(5) Scientists think that earthquakes are caused by the movement of something called tectonic plates. Where do you think the tectonic plates are? In your group, discuss the movements of the plates. (10 min)

(6) Could you explain what a volcano is? Draw your idea on the piece of paper provided. (5 min)

(7) Where do think volcanoes are located across the earth? In your group, mark them with crosses on the map and discuss why. (10 min)

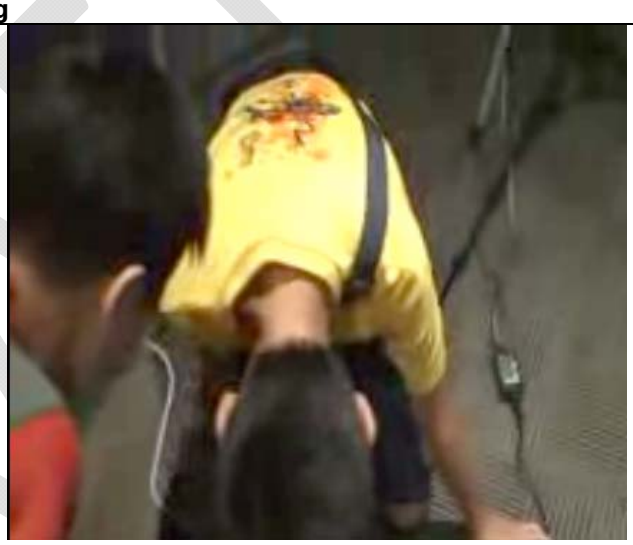
(8) Would you change anything from your Mesosaurus description after this workshop? (optional)

(For each question, ask students their sources of their ideas)
(The common misconception is that volcanoes are burning mountains that emit red lava. There are various types of volcanoes and more than just lava is emitted. Some believe that volcanoes only exist near the equator. This is not true cause volcanoes are located all over the world.)

Appendix II: : Story Scripts and Movie Screen Capture

Dino Design Workshop
Story Making

Names: Victor, Irene, Weilong, Tony

Dinosaurs featured	
 Confuciusornis	 Dilong Paradoxus
Scene 1: The beginning and the ending	
About to give up on the search, famous paleontologist Dr Tony and Dr Victor walked back to the jeep. When Dr Victor stumbled onto a bone, "Tony! Look, I think I found something!" Taking out the tools, he started to brush it, indeed it was a fossil of Confuciusornis……. The fossil of this Confuciusornis was in the jaws of Dilong Paradoxus was about to be eaten by the Dilong Paradoxus, when a volcanic eruption happened and covered them with lava and ashes.	
Scene 2: 100 million years ago	
A Confuciusornis was having it lunch happily. But it did not notice that a Dilong was eyeing it. Slowly but steadily, it crept closer to the confucisornis. Suddenly, the Dilong pounced on the conducisorins.	

Scene 3: Fighting	
The fight raged on. The confucisornis put on a good fight, but it was no match to the Dilong . Knowing that its life is at risk, the confuciusorins ran for its life with the Dilong catching up. After a long chase, the Dilong paradoxus caught the confucisorins in its mouth.	
Scene 4:	
Just as the Dilong paradoxus was going for the final attack, a volcano erupted, it instantly covered the whole area with ashes, and it also covered the two fighting dinosaurs with ashes and preserved it perfectly for millions and millions of years.