DEVELOPMENT RESEARCH WITH COGNITIVE TOOLS:

AN INVESTIGATION OF THE EFFECTS OF A WEB-BASED LEARNING

ENVIRONMENT ON STUDENT MOTIVATION AND ACHIEVEMENT IN HIGH

SCHOOL EARTH SCIENCE

by

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(Under the direction of Thomas C. Reeves)

ABSTRACT

This study is an example of development research with the twin goals of solving an educational problem at the local level and generalizing design principles that other educators and researchers can apply. The local problem involved a high school science teacher from the northeast Georgia who reported that his tenth grade students had low motivation and inadequate achievement with respect to learning earth science. Working closely with the science teacher, a Web-Based Learning Environment (Web-LE) was designed by a group of graduate students and faculty in the Department of Instructional Technology at University of Georgia to improve the students' motivation and achievement in the context of topic of fossilization. Development research was the most appropriate methodology for this study because of its capacity to have direct impact on teaching and learning while also yielding generalizable design principles.

For approximately twenty-two months, the team worked closely with the teacher to define the instructional problems, clarify the traits of his learners, understand the context for implementation, and create alternative solutions. Several factors (challenge, control, curiosity, and fantasy) for increasing students' intrinsic motivation were involved in the design of Web-LE. The team met frequently with the teacher to revise the prototype

Web-LE. A pilot study was conducted in the middle of the production phase to evaluate the usability of the Web-LE and ensure that the design met the teacher's needs.

The Web-LE was implemented in the teacher's 10th grade classroom in January and February 2003 as a three-day student-centered learning activity. Data collection methods included individual student interviews, teacher interviews, motivation questionnaires, an observational protocol, and analysis of student responses to a teacher-created assignment. The assignment was designed to encourage students to use the Web-LE as a cognitive tool to solve higher order problems.

Findings revealed that the Web-LE and associated student-centered learning activity improved students' motivation and enabled the students to visualize the various conditions of fossilization at a level not attained before. The teacher expressed the belief that student achievement improved significantly, and stated that he intended to use the Web-LE with other classes in the future. This study suggests that educational researchers should maintain strongly collaborative working relationships with teachers and school level technology specialists throughout the development research process to successfully solve instructional problems and increase the likelihood that instructional technology research will improve teaching and learning in practical ways. Specific design principles for the development of similar Web-LEs were also revealed.

INDEX WORDS: Development Research; Web-Based Learning Environment; Cognitive Tools; High School Science

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by

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Dedication

This dissertation is dedicated to my grandparents, who named me after the sunflower, expected me always to rise up bravely after falling, and were always optimistic about my life. Although it is not yet possible for them to walk with me again, I know they will always watch over me from heaven.

Acknowledgements

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Chapter 1

Introduction

Background

Since 1999, two professors and several doctoral students from the Department of Instructional Technology at the University of Georgia have been working in collaboration with teachers and support staff at a private K-12 day school in northeast Georgia to evaluate the effects of laptop computers on teaching and learning. This longitudinal evaluation, planned for 1999-2003, has been funded by a private foundation that has also helped to support the laptop initiative in the school where the study is taking place. This evaluation is one of several similar initiatives to investigate the educational effects of providing ubiquitous computing via laptops in schools that have been conducted in recent years (Newhouse & Rennie, 2001; Rockman, 2000).

As part of this laptop program evaluation, I have been working closely with the teachers and students at the private day school in two primary roles. First, I have been engaged in the data collection and analysis for the evaluation. Second, and more importantly for the purposes of my doctoral dissertation research, I have been involved in a long-term development research project (van den Akker, 1999) with one of the science teachers at the school. Throughout this process, I have endeavored to maintain good rapport with this teacher and his students. By spending substantial time in the teacher's classroom, I have had many chances to see firsthand the instructional challenges he faces in teaching science to high school students. Specifically, the tenth grade science teacher

with whom I have been working sought our help in integrating the laptops into his learning environment to solve the problem of students failing to develop robust mental models of fundamental scientific processes such as "change over time" and "fossilization."

After evaluating his problems and potential solutions, several graduate students and professors teamed up with the teacher to develop an interactive Web-Based Learning Environment (Web-LE) to provide his students with opportunities to learn this complex material. I have been the leader of this collaborative research and development project over the past two years. This dissertation documents the cooperative development research process we have followed, including instructional design, software development, a pilot study, and a summative evaluation.

Statement of the Problem

The World Wide Web (WWW) has captured the attention of educators around the world for its capabilities of providing rich multimedia resources and connecting students with experts, teachers, and other learners via global networks. Information scientists estimate that the WWW now has nearly one billion pages, and the Web continues to grow at a rapid pace (Burbules, 2001). Although many Web sites may be inaccurate, misleading, biased, or even criminal in nature, there are still millions of pages that students and their teachers can access to enhance teaching and learning.

Unfortunately, although there continues to be enthusiasm in many quarters about the integration of the WWW into education in general (Ferry, Ferry, Gillette, & Phillips, 2002), there appears to be a lack of substantive thinking about the goals, pedagogical dimensions, and outcomes of using the Web in education, especially at the secondary

level. At the same time, the benefits of the integration of new technologies into education are being questioned by some (Cuban, 2001). Hence, there is a strong need to develop and test new models of the factors that will enable the effective use of the WWW in schools. One such model is based upon the concept of the WWW as a "cognitive tool" (Reeves & Reeves, 1997). Cognitive tools refer to technologies that enhance our cognitive powers during thinking, problem solving, and learning (Jonassen & Reeves, 1996). Using the WWW as a cognitive tool, students can tackle difficult problems and complex tasks, organize unique knowledge representations, and share what they have learned with others for analysis, critique, and revision.

Personally, I believe that the Web has great potential as a cognitive tool at all levels of education, but my research is focused on secondary education. There are at least three major challenges in using the WWW as a cognitive tool in secondary education. First, the majority of the instructional Web sites currently available consist of arrays of links to other information sources or simply Web-based copies of print documents. Pages of links and print documents on the WWW fail to take advantage of the unique features of the Web as a learning environment. These existing Web formats represent "asynchronous communications" that primarily treat learners as passive rather than active. There are also Web-based examples of synchronous communications that can be used in high schools, but for the most part these are imitations of face-to-face instruction, e.g., online chat rooms used to replace classroom discussions. Owston (1997) noted that many of these uses are merely extensions of what is already being done with more established media.

Without employing appropriate theories and instructional strategies in harmony with the unique features of the WWW, the expectations of higher learning outcomes will

not be reached (Windschitl, 1998). It is unfortunate that existing Web sites used in high

school instruction do not sufficiently engage students in active learning. A basic principle

of contemporary cognitive learning theory is that the greater the investment of mental

effort during acquisition, the more transferable and usable any knowledge gained will be

(Salomon, 1984). Learning effects will be very limited if Web resources do not demand

or encourage strong mental effort and cognitive investment from learners.

A second problem with Web-based instruction (WBI) is the challenge of raising and

sustaining learners' intrinsic motivation (Reeves & Reeves, 1997). Miller and Miller

(2000) stated that "motivation is a particularly important learner characteristic because of

its reciprocal effects on performance in hyperspace" (p.168). The motivation problem is

especially worrisome in high school science because science and math are the traditional

gateways to postsecondary studies and careers in science, engineering, and technology.

Some Web sites may initially attract students' attention because of unique screen designs

or the inclusion of features such as animation and sounds, but unless the interactions are

designed to be cognitively engaging, students will become disenchanted and unmotivated

(Reeves, 1997).

The third problem pertains to the challenge of how to develop and implement

Web-based instructional innovations in high schools. Mandinach and Cline (2000)

concluded that "there continues to be an abyss between research and development

projects and actual classroom practice" (p.378). They suggested reasons for this

frustrating gap, including "a dearth of adequate evaluation research designs, a paucity of

appropriate measures of cognitive activity, and a plethora of financial and practical

problems" (p.378). The notion that teachers themselves can develop or even locate all the

Web resources that their students will need is misguided, especially at the high school level.

Fortunately, these and other problems can be solved by rigorous development research (van den Akker, 1999) leading to the design and implementation of effective WBI. That has been the goal of my dissertation research, which I have conducted in a science class at a private K-12 day school in northeast Georgia. As noted above, the impetus for this research was a tenth grade science teacher who reported that his students have motivation and achievement problems. Many of his students were "turned off" by science, and they were failing to develop robust mental models of scientific processes.

Early in our discussions, the science teacher developed a list of topics with which he has had difficulties motivating students to learn. He based this list on decades of teaching experience. Major concepts included:

- Importance of fossil formation
- Half-life/Radio-dating
- Extinction
- Geologic time
- Continental drift

Due to time, budget and personnel limitations, only one topic, fossilization, was selected as the focus for this investigation of the impact of a Web-based cognitive tool on student motivation and learning performance. To achieve the developmental goals of my research, I have worked for two years with the teacher, along with other graduate students and university professors, to develop a Web-LE capable of influencing motivation and extending learning in science related to the importance and process of fossil formation. A

unit on fossils, which enables students to develop mental models of how fossils form over very long periods of time in various environments, was selected to be the major topic of the Web-LE. This topic involves difficult concepts as well as motivational challenges.

Purpose of the Study

The purpose of this study, in accord with the principles of development research (van den Akker, 1999), has been twofold. First, I wanted to solve a real world problem, i.e., motivating this teacher's students and helping them to develop conceptual understanding and richer mental models related to science. Development research is intentionally focused on solving practical problems in education. Second, in the process of solving the problem, I wanted to discover some general principles about designing Web-LEs and implementing them in high schools that can be shared with others confronting similar problems. Development research is not simply a problem-solving tool; it also seeks knowledge that can be shared beyond the context of one particular problem (Collins, 1992).

There have been two major phases to this development research initiative. During the first phase, the features of the Web that increase and sustain the intrinsic motivation of high school learners were identified through literature review and interviews with teachers and experts. This phase lasted for over a year, beginning in 2000. During the second phase, using design experiment processes (Brown, 1992; Collins, 1992), a Web-LE about fossils that incorporates these intrinsic motivational features was designed, developed, and tested in the aforementioned private day school. The design and development component of the second phase was completed in December 2002, and the formal testing was carried out in January and February 2003.

Although the selection of the particular school where this study was conducted was driven primarily by the nature of the teacher's problem, it was beneficial that the technological infrastructure for such a study was already in place there. In addition, the teacher, technological, and administrative staff there were very supportive of my research. A key component of any development research project is close collaboration between researchers and practitioners (van den Akker, 1999). In addition, I was already a key member of a team conducting a four-year evaluation of ubiquitous computing at this school. An earlier dissertation (Grant, 2002) was conducted in the same school under the auspices of the same longitudinal evaluation.

Research questions

The research questions examined in this study were:

1) How do the interactive features of the fossils Web-LE affect students' motivation to learn fossilization in this high school science class?

2) How do the interactive features of the fossils Web-LE affect students' academic performance with respect to learning fossilization in this high school class?

3) What general principles concerning the design and implementation of an effective Web-LE for improving motivation and achievement in high school science can be derived from this development research project?

Stages of the Research Process

Earlier, it was noted that there have been two major phases during this research project. First, there was an investigation phase to reveal the features needed in a Web-LE to enhance students' intrinsic motivation to engage in learning science, and second, there was a development and testing phase to determine the outcomes of the Web-LE. The

details of the actual research process that I employed are further specified in the following five research stages.

Stage 1: Identify the determinants of intrinsic motivation on the Web-LE

The first stage of the research was to identify factors that could influence intrinsic motivation from an extensive literature review. This stage started in late 2000 and continued throughout the year 2001. The Web-LE developed during subsequent stages was designed to maximize these determinants.

Stage 2: Design and production of the Web-LE

After an extensive review of the literature, as well as numerous discussions and debates with instructional designers, science education experts involved in the project, and the collaborating teacher, I began developing an educational Web-LE for grade 10 students with the help of several other graduates students and two professors. The goal of the Web-LE is to help students develop better conceptual understanding of the processes of fossilization and to improve student motivation to learn difficult scientific concepts. The tested version of this Web-LE contains a total of 18 fossil units.

Stage 3: Pilot study

The first four fossil units were implemented in a classroom to conduct a pilot study to determine the feasibility and effectiveness of the Web-LE in April 2002. The information provided in this stage was used to revise the interaction design of the Web-LE as well as to refine the research methodology used in stage 4.

Stage 4: The implementation and testing of the Web-LE

After reviewing the results of the Pilot Study and completing the rest of the units for the fossils Web-LE, the whole revised Web-LE was implemented in the science

classroom of the collaborating teacher to assess the intrinsic motivational determinants defined in stage 1 of the study as well as the students' learning achievement. The data from this stage of the study has been used to address the first two of three major research questions defined above:

1. How do the interactive features of the fossils Web-LE affect students' motivation to learn fossilization in this high school science class?

2. How do the interactive features of the fossils Web-LE affect students' academic performance with respect to learning fossilization in this high school class?

The results of this stage of the study are related to the first major purpose of development research, i.e., solving a specific educational problem. The collaborating teacher can use these results to refine his science instruction related to fossilization.

Stage 5: The analysis

In this stage, I analyzed the results of the use of our Web-LE in the science classroom. The effectiveness of the Web-LE and the reactions of learners were evaluated. The last major research question addressed during this stage was:

3. What general principles concerning the design and implementation of an effective Web-Based Learning Environment (Web-LE) for improving motivation and achievement in high school science can be derived from this development research project?

The results of this stage of the study are related to the second major purpose of development research, i.e., deriving design principles. Although the results of Stage 4 will eventually be used to refine the Web-LE further, that is beyond the scope of this dissertation. The most important outcomes of this analysis stage are general principles

related to the design and use of Web-LEs. Researchers who have similar interests may refer to these principles and apply them to their research designs. At the same time, practitioners may apply them into their own classrooms.

Assumptions

A major assumption of my study is that some methods of applying technology in education are more effective than others. Historically, there have been two major approaches to employing computer technology in a learning environment. The first approach involves learning "from" computer technology and the second approach involves learning "with" computers. Salomon, Perkins, and Globerson (1991) describe the benefits of learning "with" technology in detail. According to them, the learning "with" technology approach sometimes simply involves changes in performance that result when students are equipped with technological tools. For instance, students might calculate better and faster with an electronic calculator. Alternatively, the learning "with" approach sometimes involves using technology as a cognitive tool, i.e., as an intellectual partner with whom students can share the cognitive burden of carrying out more complex tasks. The latter learning "with" approach enables students to interact with computer tools to obtain cognitive benefits, rather than simply enhanced performance.

The use of computer technology as a cognitive tool rests on the basic assumption that students learn better "with" it rather than "from" it (Jonassen, 1996, 2000; Lajoie, 2000; Reeves, 1998). Jonassen (2000) provides further explanation of this assumption:

I do not believe that students learn from computers or teachers — which has been a traditional assumption of most schooling. Rather, students learn from thinking

in meaningful ways. Thinking is engaged by activities, which can be fostered by

computers or teachers. (p.4)

My project is based upon this fundamental assumption. By learning "with"

computer technology as opposed to "from" it, students will more mindfully engage in

tasks and ultimately enhance their cognitive capacity (Jonassen & Reeves, 1996).

Limitations and Delimitations

First, in this research project, the context for the study is high school science,

specifically tenth grade earth science. Due to time, personnel and budget constraints, the

earth science Web-LE for this study focuses only on the fossilization of dinosaurs. As a

result, the findings of this research may not apply to other subjects or units, or to other

levels of education.

Second, the students participating in this study have relatively higher computer

literacy than do students of the same age at schools where there is less of a ubiquitous

computing environment in place. Therefore, the specific research results apply only to

tenth graders in this particular school. However, as in other development research studies,

some design principles have been revealed that others may choose to generalize to other

educational contexts.

Third, the collaborating teacher involved in this study is an exceptionally talented

and experienced teacher, with over thirty years of science teacher experience, twelve at

the school where this study was conducted. Therefore, the design implications of this

study may not generalize to teachers with less experience or expertise.

Fourth, the school where this study was conducted is a private day school with an

unusually sophisticated technological infrastructure. All 7th – 12th grade teachers and

students in this school have laptop computers and access to a campus wide wireless network. Thus, the results of this study may not generalize to other types of schools, e.g., public, or to schools that lack the technological features and support available in this school.

The organization of the dissertation

Chapter 1 has presented the background, purpose, and research questions for this dissertation. Chapter 2 presents the literature review that has informed my study. Chapter 3 provides a description of the development of the fossils Web-LE. Chapter 4 specifies the Methodology for the investigation as well as the results of the pilot study. Chapter 5 presents the results. Finally, Chapter 6 presents a discussion of the implications of the results as well as recommendations for further research.

Chapter 2

Review of the Literature

Introduction

The purpose of this study was twofold. First, the study employed development research procedures to produce a Web-based Learning Environment (Web-LE) designed to enhance the motivation and achievement of students in a high school science class. Second, the study sought to derive general design principles concerning the use of Web-LEs through the process of engaging in collaborative development research with a high school science teacher and other faculty and graduate students from the Department of Instructional Technology at The University of Georgia. Fundamental to the research project has been an on-going literature review. The literature informing this study fits into three general research areas: 1) motivation in learning; 2) using the Web as a cognitive tool; and 3) using the Web in high school science. Specifically, my intentions in reviewing the literature have been to address the following questions:

1. What strategies does educational research on motivation suggest can be used in a Web-LE to enhance student motivation and achievement?

2. What strategies does educational research suggest can be used to design Web-based cognitive tools for learning?

3. What strategies does educational research suggest for how the Web can be used to support learning in high school science?

My literature review in these areas began in a formal sense with my comprehensive exams during the Fall Semester of 2001, and it has continued throughout my study. The core resource for the literature review has been the *Handbook of Research for Educational Communications and Technology* (Jonassen, 1996). Several available literature retrieval databases have been used to locate more current research, e.g., GALILEO, the online databases of the University of Georgia library, ERIC, and Dissertations Abstracts. My primary search keywords have included cognitive tools, mind tools, intrinsic motivation, web-based instruction, online learning, and science education (primarily focusing on the topic of fossilization). I utilized the World Wide Web as a secondary resource, using search engines such as Yahoo and Google.

Part I – Motivation Research

It is widely accepted that motivation affects academic performance (Jonassen & Grabowski, 1993; Westrom & Shaban, 1992). However, specifically how to enhance the academic performance of students is an ongoing question in education theory and practice that deserves more attention. The educational research literature on motivation provides extensive evidence that children's motivation toward learning declines as they get older, especially in mathematics and science areas (Eccles & Wigfield, 1992; Eccles, Wigfield & Schiefele, 1998; Epstein & McPartland, 1976; Haladyna & Thomas, 1979; Hidi & Harackiewicz, 2000). This problem seems especially exacerbated in high school science classes. Academic performance is influenced by many factors: intelligence, environment, aptitude, effort, and so on. Educators cannot do much about most innate or environmental factors. What we can do is to help students work harder voluntarily. In other words, we can develop procedures and tools that promote their interest in learning.

The role of intrinsic motivation has been a focus of current research in achievement motivation. Intrinsic motivation refers to behavior that is engaged in for its own sake (Deci, Vallerand, Pelletier & Ryan, 1991). Rigby, Deci, Patrick, and Ryan (1992) report that many studies focused on the relationship between motivation and learning achievement confirm that when one's self is more engaged in learning, one will more fully understand new knowledge and be more flexible in utilizing the newly acquired knowledge. Therefore, successfully raising and enhancing one's intrinsic motivation may help one become more involved in the task and promote learning achievement. However, this hypothesis rests on the fundamental premise that appropriate strategies for increasing intrinsic motivation can be incorporated into a curriculum design and that these strategies are feasible in most schools. Identifying the appropriate strategies to enhance motivation and then creating practical ways to implement these strategies in actual high school classrooms are not easy tasks, but we must endeavor to accomplish them if we want to enhance and sustain learners' motivation, and thus make the learning process more enjoyable, effective, and lasting.

Students experience enhanced information processing and have higher learning achievement when fully engaging in a learning task (Rigby, Deci, Patrick & Ryan, 1992). What educators do to help students actively engage in learning may be more important to academic success than how much information is presented to them through materials or other forms of instruction. To enhance the active engagement of students in learning science, the Web-Based learning environment developed during this research project employs four intrinsic motivational strategies suggested by Malone and Lepper (1983). These are challenge, curiosity, control, and fantasy.

Other studies have shown that using these strategies (challenge, curiosity, control, and fantasy) enhance intrinsic motivation (Lepper & Hodell, 1989). These four strategies are used to optimize the motivational appeal of educational materials in order to enhance and sustain students' intrinsic motivation. Incidentally, these four strategies are very prevalent in computer game design.

1) **Challenge:**

Engaging in activities that challenge the learners' abilities may enhance intrinsic motivation. However, it is important that the level of challenge of the activity and the skills of learner should be matched. Once an appropriate match of challenge and ability is realized, learners may experience "flow" (Csikszentmihalyi, 1985). Csikszentmihalyi (1985) defined flow as "the holistic sensation that people feel when they act with total involvement." When learners experience flow, they are extremely involved with the tasks and may even lose awareness of time and space.

Anxiety

Action
Opportunities
(Challenges)

Worry

FLOW (Play, Creativity, etc.)

Boredom

Anxiety

Action
Capabilities (Skills)
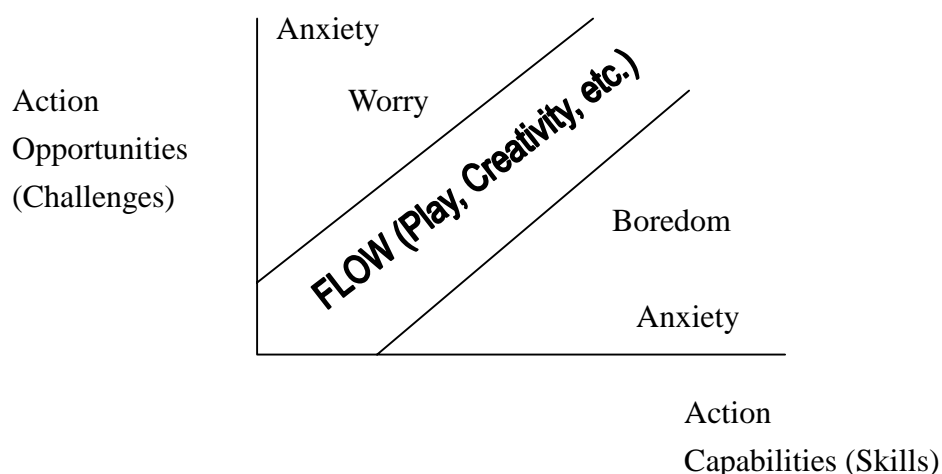
Figure 2.1. Model of the flow state.

Figure 2.1 illustrates that the flow status happens only when the challenge of activities matches the skills possessed by learners. Learners will get bored if the

challenge is too easy to meet; on the contrary, tasks that are too difficult make learners

fail frequently, feel frustrated, and cease learning. Ideally, tasks should be designed so

that there is an ongoing adjustment between the level of difficulty of the tasks and the

learner's developing skills. Learners who achieve challenging goals feel they are

becoming more competent and are apt to set new, even more challenging goals, which

serves to maintain intrinsic motivation (Pintrich & Schunk, 1996). Being in flow is

practically synonymous with high motivation (Csikszentmihalyi, 1985).

Malone and Lepper (1983) specified three characteristics of activities that can

provide a challenge to learners: 1) presenting proximal goals; 2) providing uncertain

outcomes; 3) providing frequent, clear, constructive, and encouraging feedback. These

challenging strategies are frequently employed within the context of RPG (Role-Playing

Games). The players in RPG have to gain experience by achieving proximal goals and

gradually approaching the final goal. The attainment of experience enhances the players'

confidence and encourages them to conquer the next goal. For learning activities to

encompass these principles, the curriculum should be divided into smaller segments, and

students should be encouraged to finish each part with clear feedback and information.

2) Curiosity

Curiosity is a response to any novel and extraordinary ideas that drives students to

discover. Curiosity can be achieved by using technical events to attract the learner's

attention, e.g., animation on a computer screen. Highlighting incompleteness or

inconsistency is another technique to arouse curiosity. In addition, the provision of

unpredictable or random events may motivate learners to continue the learning processes.

Malone and Lepper (1983) made a distinction between sensory curiosity and cognitive curiosity. Using computer technology to simulate various events (e.g., changes in view angle) can promote sensory curiosity. Modifying the instructional environment to stimulate cognitive curiosity by making people believe that their existing knowledge structure is not well formed or adequate can motivate them to pursue a cognitive structure that is well formed.

A world famous simulation game – The Sims – successfully gains the attention of game players by providing various unpredictable scenarios. Players can manipulate different variables or properties of an actor, and the simulated actions of the actor change according to these variable settings. The desire to observe the final simulated results of the actors greatly enhances the curiosity of the players. Another successful simulation game – SimCity – provides a variety of information that taxes the player's initially limited knowledge of being the mayor of a waiting-to-be-built city. Initial attempts to run the city inevitably fail, and the player is stimulated to wonder: "What if I try this?" This uncertainly leads to curiosity that in turn stimulates players to have more cognitive drive to pursue the knowledge needed to be successful. Uncertain results, riddles, and various forms of feedback have long been added to learning activities to arouse curiosity.

3) Control

Learners' intrinsic motivation may be enhanced if the activities can provide a sense of control and allow learners to direct their own learning performance. Lepper and Malone (1983) made two suggestions for promoting the sense of control in computer based instruction environments: 1) allow learners to control instructionally-irrelevant aspects of activity (e.g. choice of character's names, gender; provision of fantasies or

music); 2) provide limited choices concerning other variables (e.g., pace) with computer technology.

Three characteristics of a power environment promoting the sense of control are identified by Malone and Lepper (1983): 1) contingency: make sure that the learner's outcomes are dependent upon his or her responses; 2) provide explicit and organized choices; 3) create environments in which students' different actions have significant or salient effects. Learners' intrinsic motivation may be enhanced even by trivial or instructionally irrelevant choices (Cordova & Lepper, 1996; Mitchell, 1993; Parker & Lepper, 1992).

"Where is Carmen San Diego" is a well-known interactive learning CD-ROM. This program provides learners with a variety of choices to promote the sense of control. Learner must follow various clues to make correct decisions about where to travel to trace the actors in the context of a mystery game. Whether one can achieve the goals depends on one's choices at multiple points. Honebein, Carr, and Duffy (1993) conducted a study that confirmed that the Carmen San Diego software did contribute to the development of cognitive skills, although it had no significant impact on achievement.

4) Fantasy (contextualization)

A fantasy environment is defined by Malone and Lepper (1983) as one that evokes mental images of physical or social situations not actually present or in some cases not possible. Many studies provide considerable evidence that fantasy environments can promote intrinsic motivation (Fein, 1981; Parker & Lepper, 1992; Singer, 1977). Embellishing a computer-based instructional program with a fantasy context can heighten students' intrinsic motivation (Cordova & Lepper, 1992).

Fantasy elements have been adopted in many computer-based learning environment and games. Although not explicitly educational, one of the most popular games of all time, Myst, places players on a mysterious island. Popular educational games ranging from MathBlaster to Reader Rabbit have also incorporated aspects of fantasy. Computer technology provides the capabilities to create simulated fantasy contexts that are difficult or impossible to experience in the real world.

Each of these four strategies (Challenge, Curiosity, Control, and Fantasy) plays a role in instructional design, and they complement each other in enhancing and sustaining students' intrinsic motivation. One aim of this research is to investigate the effectiveness of a Web-LE employing the intrinsic motivation determinants of Challenge, Curiosity, Control, and Fantasy as its theoretical framework. In other words, working closely with the teacher, my colleagues and I have produced a prototype Web-LE that explicitly incorporates these determinant factors into its design.

Part II – Using the WWW as a Cognitive Tool

How to use the World Wide Web (WWW, or Web) as a cognitive tool is still open to interpretation (Sugrue, 2000). In this study, I have tried to find a new approach to improving or enhancing learners' cognitive processes to encourage engagement in higher order thinking. I believe that Web technology has versatile functions that can be used to extend learners' cognitive capabilities further than other instructional media. From the literature review, the features of the Web can be categorized according to the levels of interaction that various Web resources have been designed to afford learner. For example, some Web sites merely deliver educational materials that were previously delivered via other means, e.g., file downloads of readings. Other Web sites are designed to engage

learners in complex interactions with simulations that might involve multiple participants around the world (Haynes & Holmevik, 1998).

The Web is an increasingly popular method for delivering learning content as well as learning activities (Shank, 2001). The Web clearly has the potential to offer a rich and stimulating educational environment (Windschitl, 1998). New Internet technologies (e.g., streaming video) enhance the interactive functions of Web and encourage more and more educators to use the Web to support traditional instruction or even to replace it altogether.

Based upon the construct of using the WWW as a cognitive tool, teachers and instructional designers can develop and test more and more effective learning environments (Sugrue, 2000). Cognitive tools refer to technologies that enhance our cognitive powers during thinking, problem solving, and learning (Jonassen & Reeves, 1996). Using the Web as a cognitive tool, students can deal with difficult problems and complex tasks, organize unique knowledge representations, and share what they have learned with others for analysis, critique, and revision.

Owston (1997) indicated that the key to promoting improved learning with the Web is in how effectively the medium is employed in the teaching and learning situation. Simply adding Web resources to an existing educational environment such as a college course will have little affect on learning unless those resources are aligned with the course's content, objectives, methods, and assessment strategies. According the literature that I have reviewed, the features of WBI include: 1) net-like structure (Jonassen, 1991; Miller & Miller, 2000; Starr, 1997), 2) multimedia (Miller & Miller, 2000), 3) various communication opportunities (Miller & Miller, 2000), 4) modes of interactivity (Hillman, 1994; Gilbert & Moore, 1998; Yacci, 2000), 5) cross-platform distribution (Starr, 1997),

6) immediate updating, and 7) an open environment. These features are further described

as:

1. Net-like structure: The Web provides associative, nonlinear, and hierarchical

    structures (Jonassen, 1991; Miller & Miller, 2000; Starr, 1997). The hyper-linking

    function emulates the net-like organization of memory (Jonassen, 1991). Learning

    paths are not restricted to a linear structure.

2. Multimedia: The Web is compatible with text, image, graphic, audio, video,

    animation, and a variety of applications. The ability to display multimedia content

    enables representations of real-world contexts that produce authentic learning

    situations (Miller & Miller, 2000). The streaming audio and video technology

    increases the fidelity of simulations; interactive animation and scripts enhance the

    potential for integrating various pedagogies into the design of a Web-LE.

3. Various communication opportunities: The Internet affords a variety of

    synchronous and asynchronous communication opportunities (Miller & Miller,

    2000). The synchronous communication technology (e.g., chat room) enables

    students and teachers to communicate at the same time. The asynchronous

    communication technology (e.g., bulletin board, e-mail) provides opportunities

    for students and teachers to communicate while separated in space and time.

4. Interactivity: The definitions of interactivity in Web-based learning contexts vary

    (Gilbert & Moore, 1998; Hillman, 1994; Yacci, 2000). The Web enables three

    forms of interaction that correspond with Moore's (1996) classification scheme: 1)

    among learners; 2) between learners and the teachers; 3) between learners and the

    learning materials.
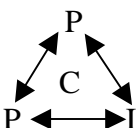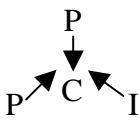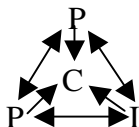
5. Cross-platform distribution: Designers of WBI no longer must worry about producing separate versions of a program for different operating systems (Starr, 1997). HTML is compatible with Windows, Mac, and Dos OS. Neither WBI designers nor learners have to deal with wearisome cross-platform problems, although keeping up with constantly evolving plug-in requirements can be a challenge.

6. Immediate updates: Web-based learning materials are located on the server side, but not the client side. Once the data on the server side is updated, learners can immediately access the latest information. There is no need for the learners to update their own personal copies of learning materials.

7. Open environment: The Web provides an open environment in which learners can access and share information within or beyond the immediate learning community. Indeed, learners can share representations of their learning globally.

Compared with previous major instructional media, the features of the Web – multimedia content, synchronous and asynchronous transmission, and an open environment – can be viewed as making the Web an ideal learning environment for both instructor and learners. It incorporates some of the most powerful affordances of broadcast media such as television as well as the uniquely powerful interactive capabilities of computers. Figure 2.2 lists the comparisons of three major instructional technologies (Web-LE; CBI or Computer-Based Instruction; and Television) to clarify the distinct features of Web-LEs.

	Content	Interaction	Participants communication	Immediate update	Open Environment
Web-LE	Multimedia, applications, and scripts	Among participants, participants to instructor, participants to contents	Synchronous and asynchronous	Yes	Yes
CBI	Multimedia	Participants to contents	None	No	No
TV	Multimedia	Participants to contents	None	No	No

Figure 2.2. Instructional technologies comparison.

Figure 2.2 reveals that the capabilities of communicating with other learners in the same learning environment, the rich interactivity, synchronous and asynchronous communication, and immediate information are the most distinct features of the Web. The Web is capable of carrying multimedia and integrating various applications to enrich learning interactions. The communication function provides synchronous or asynchronous three-way interactions among participants, contents, and instructors. Participants can cross boundaries to gain access to the latest information anywhere. These features provide numerous and powerful opportunities for instructional designers to enrich the educational materials for purposes of raising and sustaining intrinsic motivation (Shank, 2001).

	Tools	Content	Interaction	Synchronous	Asynchronous	Open Environment
Level 1	Bulletin Board	Text	P C P I		Yes	Yes (*)
	Chat room	Text		Yes		
	Video conference	Audio/Visual		Yes		
Level 2	Dynamic or still page	Multimedia	P P C I		Yes	Yes
Level 3	Multimedia Applications	Multimedia	P P C I	Yes	Yes	Yes

P: participant; C: content; I: instructor

* Based on how teacher designs the content

Figure 2.3. Interactive types of Web-LE.

With the appropriate instructional design, technology can extend or enhance the cognitive capabilities of learners (Salomon, Perkins, & Globerson, 1991). The appropriate design and usage of a Web-LE depends upon a number of important factors such as the nature of the content (e.g., static versus dynamic), the sophistication of the target learners (e.g., comfortable or uncomfortable with technology), and focus of the instructional goals (e.g., knowledge versus skills). The Interaction column in Figure 2.2 illustrates various interactive types of current Web technologies that have the potential for supporting the enhancement of learning. These are described in more detail below:

1) Participants to participant, and participant to instructor interaction

Bulletin board, chat room, and video-conferencing tools play essential roles when forming an online community and can enable communication with other participants. The construction of knowledge occurs through the process of interacting with other learners within a learning community (Palloff, & Pratt, 1999). The synchronous feature of videoconferences and chat rooms make them common tools for imitating face-to-face interaction. Bulletin boards and chat rooms can be employed by multiple learners so that they can collaboratively contribute to the same project, for instance, to enhance interaction and to improve quality of instruction (Collins, 1996). On this level, learners interact primarily with other humans instead of manipulating instructional content in the learning process.

In level one interaction, common pedagogies can facilitate online conversation, encouraging each learner to share knowledge through discussion in the communication environment (Bonk et al., 2000; Northrup, 2001; Palloff, & Pratt, 1999; Shotsberger, 2000). WebCT (http://www.webct.com) is a well-known example of level one approach that has been employed commonly in higher education. Students who are unable to be present on campus in specific time slots can participate in a class via WebCT. WebCT integrates several types of communicational tools to enable communications among participants and instructors. Britto (2002) found that instructors use WebCT primarily for convenience reasons whereas students have greater expectations for learning support.

2) Participants to contents, and instructor to contents interaction

Providing easy access to interactive instructional materials is one main advantage of dynamic Web pages. Dynamic pages are pages with no cacheable content and allow

learners to interact with contents directly to process the information individually. They

are highly transactional in nature. Dynamic content provides personalized views that can

improve user experience and extend the "stickiness" of the Web site (enhance the Web

site return rate). The information provided by dynamic pages may be customized to the

needs of the individual user, or reflect changes as learners manipulate objects on the

screen (Gepner, 2001). WISE (http://wise.berkeley.edu/welcome.php) is an example of

this level of interaction. WISE is a Web-based Inquiry Science Environment developed

by researchers at the University of California, Berkeley. Linn and Hsi (2000) describe the

principles underlying the design of WISE and earlier interactive learning environments as

well as the results of the extensive research conducted with them. Generally, it has been

found that implementation factors and teacher support are primary determinants of the

success or failure of the integration of WISE and similar web-based learning

environments into science education classrooms.

    Static Web pages are commonly used to carry multimedia contents and enable

learners to access rich resources through hyper-linking. The level of interactivity depends

on how the designers design the Web pages. Dodge (2001) describes how WebQuests, a

popular example of Level 2 interaction, should be designed. Static Web pages also

provide some tools to stimulate cognition; however, they lack synchronous

communication features and cannot provide extended communicational channels. Using

static pages, learners work alone on the Internet by interacting with the contents – simply

reading materials or manipulating multimedia objects. There may be hyperlinked items

on pages that help students flexibly use complex knowledge (Jacobson et al., 1996).

Presenting information via static web pages remains the typical format of instructional

Web sites.

Another approach to using the Web as a cognitive tool is to ask students to

construct their own web pages to represent their cognitive understanding of a specific

concept or process. There are many available free Web page authoring tools that enable

learners to create their Web pages without learning difficult programming techniques.

While developing Web pages, learners must construct their own meaning based on their

experiences and prior knowledge of the subject first, and any additional information they

find on the Web. The unique mental structure of each individual will be shaped through

the constructivist process of designing a knowledge representation (Leflore, 2000).

Working as designers, learners think more meaningfully as they construct their own

knowledge representations (Jonassen & Carr, 2000).

3)   Participants to instructor, participants to participants, and participants to

contents interaction

The online tools mentioned above offer restricted choices to instructors seeking to

offer experiences that match the complexity and dynamics of classroom experiences. We

need new tools to enable a variety of effective pedagogical interactions (Hughes &

Hewson, 1998), but they are evolving quickly (Shank, 2001). With contemporary

authoring tools (e.g., Macromedia Shockwave, Flash, Authorware, JAVA), instructors

and/or instructional designers can design learning activities based on more authentic

goals and tasks (Herrington, Oliver, & Reeves, 2003). The features of an open

environment and immediate communication can be embedded in the WEB-LE to enable

collaborative learning strategies (Pittinsky, 2003).

The ability of these tools to carry interactive multimedia content supports the design of situated learning strategies by simulation, problem solving, or authentic activities (Leflore, 2000) and fosters information processing, situated learning, and collaborative learning. There is no standard interactive format on this level; how students interact with contents and other participants will be determined by the curriculum design and learning objectives. InkLink (http://www.shockwave.com/sw/content/ inklink15) is a multiplayer online application developed by Macromedia Shockwave that can enable level three interactions via Web technology. Learners can join InkLink together as a group to do the same activity. Participants can draw with drawing tools to present the clues generated randomly by the computer and have other participants make a guess. Points are awarded for guessing the secret words and for providing winning clues. The first player to guess the object or phrase correctly scores points, as does the player who created the picture. The quicker the answer, the more points awarded. The InkLink's game rooms hold up to eight players, with a multitude of rooms available. Players can choose a game room based on their skill level. Participants can communicate via chat rooms during the game. There is no available research about the effect of InkLink on learning, perhaps because it is considered a game in the US, but InkLink has been adopted as an English vocabulary learning tool by many Asian students studying English as the second language. It is an interesting and creative online application that has captured much attention from online users.

Over and above the aforementioned features, Owston (1997) pointed out three distinct advantages of Web-LEs that can be employed to improve learning: (1) Learning mode that appeals to students: this generation of students are accustomed to play with and

learn with a computer, (2) Flexible learning: teachers can convey or help the students construct knowledge with various learning activities and Web-based projects, and (3) New kinds of learning: with the features of Web, students have chances to foster critical thinking, problem-solving, written communication, and collaborative learning skills.

Although I am certainly aware of critics and skeptics (Noble, 2001; Stoll, 1999), the analysis of the Web features and functions found in my literature review encouraged me to employ the Web as the learning environment for this development research project. With the features of Web-LE, instructional designers and teachers have greater flexibility to produce learning activities aligned with the different pedagogies. I was further encouraged by the capabilities of Macromedia Flash is to support the development of highly interactive online learning activities. The detailed interactive format of the fossil Web-LE that we developed is described in Chapter 3.

Using the Web as instructional media is increasingly common and widespread throughout different educational levels, but Web technology is less commonly used as a cognitive tool. Jonassen and Reeves (1996) identified several principles of cognitive tools for learning: 1) we can regard learners as active knowledge constructers in order to maximize effectiveness, 2) we can use computer technologies to enable learners to access and interpret information as well as to organize and construct their own knowledge, 3) we can develop realistic contexts and tasks that are personally meaningful for learners, and 4) we can encourage the reflective thinking that is necessary for meaningful learning.

To use the Web as a cognitive tool, it is important to verify its capacity to enable and achieving the aforementioned principles. Also, we must document how instructors use the Web as cognitive tool in the learning environment to support learning effectively.

Ideally, given motivating tasks, learners should be able to interact with content to perform tasks, access information to construct knowledge representations, and finally express and share their representations with other participants or the instructor. The complete cognitive process that the fossils Web-LE has been designed to support will be explained in the next chapter.

As described in Part I of this literature review, a Web-LE must also be carefully designed to have a positive impact on learners' intrinsic motivation (Reeves & Reeves, 1997). Motivation is also related to completion of learning activities. Miller and Miller (2000) stated that "motivation is a particularly important learner characteristic because of its reciprocal effects on performance in hyperspace" (p.168). The motivation problem is especially worrisome in high school science because science and math are the traditional gateways to postsecondary studies and careers in science, engineering, and technology. In this study, my team and I have attempted to integrate factors that can influence students' motivation into the Web-LE design and to reveal better methods for enhancing intrinsic motivation for learning in high school science classes.

Part III – Learning Science on the Web

Two of the most frequently listed components of scientific achievement are 1) constructing accurate scientific conceptual understandings and 2) using scientific concepts to solve problems (Bruning, Schraw & Ronning, 1999; Greenwald, 2000; Tobin, Capie & Bettencourt, 1988). Hence, motivating students to integrate prior knowledge with new scientific knowledge and to apply scientific knowledge to solve problems is the primary goal of science education. Constructivist methods in science education have gained widespread attention over the last decade (Appleton, 1993; Ritchie & Rigano,

1996; Solomon, 1994). According to constructivist learning theory, to achieve the goal of constructing new knowledge on existing cognitive foundations and learning to apply that knowledge requires that a constructive learning environment be provided. One of the features of a constructivist learning environment that distinguishes it from a traditional learning environment is that students undertake realistic tasks and solve meaningful problems (Tobin, Capie & Bettencourt, 1988). In short, students must learn science as a problem-solving process that is constructivist in nature by engaging in constructivist tasks (Bruning, Schraw & Ronning, 1999).

Of course, students should not be thrown into such environments without any support. They should be provided with "scaffolding" to enhance their cognitive processes and nurture their success in completing the tasks or solving the problems (Winnips, Collis, & Moonen, 2000). Such successful learning experiences enhance students' self-efficacy and help them engage in additional learning tasks more willingly.

Currently, I have been unable to find research that focuses on the learning effects on high school students of using the Web to study earth science per se. However, some research about the learning effects of the Web technology has focused on other topics such as chemistry and biology. Figure 2.4 summarizes several research findings about learning through Web technology. Upon reviewing these research findings, I found that asynchronous communication (e.g. Bulletin board), multimedia contents, and simple learning activities developed with JAVA or similar technologies are the primary methods for delivering instructional content through the Web in secondary schools. Their impact on learning has been modest.

Topic	Application of the Web's features	Research findings
High school biology *Net-Frog* (http://curry.edschool.virginia.edu/go/frog/)	Enormous texts, images, and quick time movies about how to dissect frogs	One study primarily examines the popularity of the instructional web site. (Kinzie et al., 1996)
High school chemistry *ChemViz* (htp://chemviz.ncsa.uiuc.edu/)	Provides an online converter and calculator and animations about abstract concepts. Students can input numbers to change the visual representations of chemical models.	Students become active researchers using the techniques of scientific visualization to explore the quantum mechanical model of the atom. (Beckwith & Nelson, 1998).
For college students who major in kinesiology, exercise science, and physical education *DigiNet* (http://www.kines.uiuc.edu/digi-net98/index.asp)	Uses JAVA technology to help students understand elementary measurement techniques used in biomechanics.	Based on the result of effectiveness evaluation, the advantages of digitizing to the Web are not obvious on the participants. However, students indicate that flexibility is the best advantage of the instructional web site. (Chow, Carlton & Ekkekakis, 2000)
For college students who major in neuroscience *ICON* (http://mbb.harvard.edu/)	Uses an asynchronous interaction developed by Web Crossing to enable interactions among faculty and students. The teacher posts problems on the Web, and students provide solutions and share with others.	Students became more engaged in solving problems as a group, and they took substantial responsibility for what they learned. One challenge that the web site presents is to have teachers actively participate in the students' learning. (Quattrochi et al. 2002)

Figure 2.4. Research studies of learning science through the Web.

Of course, there are also numerous free instructional web sites that can be adopted by secondary teachers and students in the classroom. For instance, high school students can use online databases to analyze the ecological data preserved in local ecological research sites (LaBare, Klotz & Witherow, 2000) or use a collection of simple physical activities in the classroom (Clark et al., 1998). However, these examples are somewhat primitive attempts to take advantage of the features of Web technology, and there has been little substantive research conducted to confirm their learning effects.

A recent study (Kumar & Libidinsky, 2000) analyzed fifty-one K – 12 science and technology Web instructional resources, and the results revealed that only 12 percent of these sites include 25 percent or more of the science and technology competencies recommended by national organizations. This finding brings the Web's educational benefits into question. Although the Web provides enormous opportunities for learners to access information and communicate with others, it is a daunting challenge to employ the Web as a cognitive tool that presents interesting tasks and problems as well as accurate information. Cuban et al., (2001) describe how the historical legacy of traditional practices limit the impact of computers and related technologies in high schools.

In the face of these challenges, something must be done to enhance the motivation and achievement of learners. I am committed to exploring the potential of the Web in meeting these challenges. Ideally, the design of an effective Web-LE should be based upon appropriate learning and motivational theories in close collaboration with science teachers. Such an approach has been the aim of my development research project.

Chapter Summary

Transferring existing instructional materials into a Web format will not guarantee the enhancement of learning performance. The challenge of developing an effective Web-LE involves designing new and appropriate learning activities with Web technology. No important impact can be expected when the same old activity is carried out with a technology that makes it a bit faster or easier; the activity itself has to change (Salomon, Perkins, & Globerson, 1991). Owston (1997) indicated that many existing Web-LEs are merely extensions of what is already being done with more established media. Without employing appropriate theories and instructional strategies in harmony with the unique features of the WWW, higher learning outcomes will not be reached (Windschitl, 1998). Hence, using the Web as a cognitive tool for learning instead of as a medium for delivering content is the primary challenge of this development research project. Based on the literature review of intrinsic motivation and interactive features of the Web, a fossilization Web-LE has been developed to incorporate intrinsic motivational strategies as well as apply sound pedagogical strategies. The next chapter provides a detailed description of this Web-LE.

Chapter 3

Development of the Learning Environment

Introduction

A host of decisions goes into creating anything as complex as a Web-LE. This chapter describes how I made these decisions over the past two years. In addition, this chapter includes a description of the fossilization Web-LE as it was "completed" for formal testing in the collaborating teacher's classroom during the first two months of 2003. Of course, a Web-LE of this type is never completed because it can be enhanced and extended indefinitely.

Selecting the topic

As described in Chapter One, this development research project has involved a close collaboration with a high school science teacher from a local private day school. At our first meeting, this teacher, who is recognized as a very knowledgeable subject matter expert in earth science, explained his instructional strategies to a team of faculty and students from The University of Georgia. He identified several concepts that have been very difficult for his 10th grade earth science students to learn, including the origins of the Universe, radio-dating, half-life, volcanism, and fossilization. Each team member selected one concept, searched for related articles individually, and read through textbook material and other information provided by the teacher. At a later meeting, we discussed our findings and determined which topics were the most difficult and the most likely to be addressed by a Web-LE.

Fossilization was chosen for this study because it was viewed as being both difficult and viable for Web enhancement. More importantly, it was considered to be the unit that would most likely help the teacher reach his instructional goals most efficiently. Traditionally, when teaching this unit, the teacher assigned readings that describe certain specific types of fossilization. In class, he asked questions to find out how well to his students understood the print material. He was often disappointed by their responses.

He also used the white board to draw sketches of stratification to explain the process of fossilization. Enabling students to "visualize" the process of fossilization this way was very difficult because there were few available outside resources. To reach his goal, the teacher asked students to draw their own graphics repeatedly until they demonstrated an accurate understanding of the process. However, this activity took too long because there are so many different ways for fossilization to occur. Students could not illustrate and thus visualize every possibility. In addition, the teacher had to draw everything on the board again and again whenever he began a new semester.

After developing knowledge about the effect of different conditions on types of fossilization, students should be able to explain why one scenario is more conducive than others to fossil development. The teacher indicated that accurate animated illustrations would be the best tool for helping students learn the concepts underlying fossilization. He believed that graphics and movies, along with pictures of actual fossils, could help students visualize different types of fossilization, and develop more robust mental models of the processes involved as well as a greater appreciation for why fossilization is such a rare geological event.

The instructional designers on our team carefully reviewed the materials that the teacher had previously used for this unit. After further discussions with the teacher, we identified eighteen possible scenarios of fossilization. We determined as our overall instructional goal that, after using the cognitive tool (Fossilization Web-LE), students would be able to identify the necessary conditions for fossilization and construct possible scenarios for fossil formation by manipulating variables within a simulation. Fossilization is a rare event and not all parts of animals and plants become fossilized. Indeed, the chances that any given organism will be preserved in the fossil record are very small. Whether a living thing becomes a fossil depend on three general conditions (organism, ecological status, and physical burial). A living thing can become a fossil only when all three conditions are matched. Combining the three conditions generate eighteen possible paths of fossilization (1 organism, 3 ecologies and 6 physical burials, 1 x 3 x 6 = 18 paths). Figure 3.1 lists these conditions.

In addition to presenting and explaining each object and environment visually, the Web-LE had to have the capabilities to illustrate the interaction of the three conditions. I do not think that any of us on the team, certainly not me, anticipated how challenging the design task that we had undertaken really was. From the earliest days of prototyping to the "finished" Web-LE that was used in the formal testing at the school in early 2003, hundreds and hundreds of hours were spent by various team members in rendering graphics and animations, improving the interface, developing the interactions, and so forth. Our collaborating teacher set a high standard for accuracy in the simulation that we believe we have accomplished. He also expressed high expectations for production value that we have endeavored to meet.

Organism	Ecological Status	Physical Burial
Brachiosaurus	Temperate Rainforest	Weathering
		Ashfall
		Lava flow
		Pyroclastic
		Flood
		Swamp mud burial
	Tropical rainforest	Weathering
		Ashfall
		Lava flow
		Pyroclastic
		Flood
		Swamp mud burial
	Tropical mountainous rainforest	Weathering
		Ashfall
		Lava flow
		Pyroclastic
		Flood
		Swamp mud burial

Figure 3.1 Instructional units of fossilization.

The development team

The development team for this interactive Web-LE project consisted of:

- Project manager: As the primary researcher, I personally undertook the critical responsibility of managing this project. Essential tasks of the project manager include maintaining regular team meetings and negotiating or coordinating problems between the subject expert and team members.

- Subject expert: The subject expert is a veteran teacher of high school science. He has strong expertise in geology and teaching as well as extensive experience in discovering and preserving fossils.

- Instructional designer: Two graduate students, another and myself, designed the instructional materials under the supervision of a professor in the Department of Instructional Technology, University of Georgia.

- Project consultants: Two professors of the department of Instructional Technology supported the team in various ways, e.g., eliminating potential barriers to completing the project.

- Evaluator: One doctoral student conducted the formative evaluation of this project starting at the storyboard design phase.

- Graphic designer and computer programmer: Three graduate students, two others and myself, developed the necessary media elements (graphic, video, animation) and wrote the programs underlying the Web-LE.

Choosing the media

In the past, the materials that the teacher used to teach the topic of fossilization included: a college level textbook with limited CD and web resources, handouts, wall charts, videos and a dinosaur cartoon film. Every student in this class has a laptop computer with access to a wireless network. We chose to develop a Web-LE because it was deemed to be the best medium to provide the learning support the students needed.

Of course, the teacher plays an important role in any digital learning environment intended for use in schools. Computer technologies do not "teach by themselves" (Jackson, 1997), and a teacher must develop his/her own strategies for making a program

serve specific learners and goals. This Fossilization Web-LE was designed to be used in the classroom or at home, according to the teacher's directions. In Chapter 2, the features of the Web and the principles of cognitive tool development are described. We chose the Web as the instructional medium because the interactive features of the Web provide us with an environment that supports the design of a cognitive tool. Table 3.2 explains how the features of the Web support cognitive tool development.

Cognitive tool principle	Features of the Web support these principles
Learners should be engaged as active knowledge constructers rather than passive receivers of information.	The Web can carry multimedia instructional materials and provide an open environment for learners to access and explore. The teacher can assign various tasks, and learners must to use the Web to find solutions from different perspectives.
Learners should organize and construct their own knowledge.	The Web allows learners to record each path that they have observed to help them organize information. Easy-to-use multimedia web authoring tools can enable the construction of unique knowledge representations.
Learners should engage in realistic contexts and tasks.	Streaming video technology enables students to observe the scientific processes with high quality video and sound effects. Special effects such as stop motion, slow motion, and fast motion can be applied.
Learners should engage in the reflective thinking that is necessary for meaningful learning.	Bulletin board and other tools enable students to share their thoughts and insights with others. The development of their thinking over time can be assessed.

Figure 3.2 Features of the Web supporting a cognitive tool for the fossilization unit.

Instructional design

The team found and analyzed existing web sites about fossilization to ensure that we were not "recreating the wheel." These web sites were classified into three categories:

- Abundant articles, pictures, and detailed text information: ("Learning From the Fossil Record" [http://www.ucmp.berkeley.edu/fosrec/], developed by The Museum of Paleontology of The University of California at Berkeley.)

- Online searchable database: ("Dinosaur Database" [http://palaeo.gly.bris.ac.uk/dinobase/dinopage.html], developed by University of Bristol.)

- Extensive hyperlinks, the latest information, animation, and feedback forums that allow authors to interact with learners: ("The Dinosaur Interplanetary Gazette" [http://www.dinosaur.org/], developed by a group of dinosaur fans.)

Most of these web sites contain hyperlink information, pictures, and crude animations. These sites could not solve the teacher's problem because they did not fit his needs. Our review of current web sites confirmed the need to develop a Web-LE that could fulfill the teacher's goals to have his student thoroughly explore the unique processes involved in fossilization. The teacher expected the tool to provide enough information to help students visualize the process of fossilization; hence, the design of dynamic animations with accurate in-depth description was necessary. The team spent nearly a year working with the teacher to refine the Web-LE.

For the teacher to integrate this cognitive tool into his instruction, the program had to provide realistic animations and a detailed explanation of each condition of fossilization. He required that learners be able to explore every possible condition of fossilization and to find enough information to solve the tasks and problems that he assigned. After extensive meetings with the teacher, we designated three levels of conditions (type of organism, ecological conditions, and type of burial).

We all desired that this Web-LE arouse and sustain the students' motivation to ensure that they explored all these conditions. We understood from the beginning that capturing the interest of these students and maintaining it would be difficult. With the teacher, the team analyzed students' characteristics. Based on the students' past performance in his science class, we found that:

- most of them are difficult to motivate,

- some try hard but are academically weak,

- a few belong in accelerated group but are lazy,

- many have low interest in science because of past failures,

- they tend to focus on consequences not reasons.

- they are not detail-oriented,

- they are visually-oriented, and

- they have preconceived notions that are hard to remove.

Anyone experienced with teaching high school students would recognize the characteristics listed above. They represent the vast majority of students rather than the exceptions. Motivation to study science and math subjects has always been low among most high school students. Therefore, we have endeavored to design a Web-LE that would directly address these challenges. Accordingly, the four intrinsic motivational determinants of challenge, curiosity, control, and fantasy were carefully integrated into the instructional design of the Web-LE to address the motivation challenges. Figure 3.3 presents the relationships between these motivational determinants and the instructional design strategies incorporated into the Web-LE.

Motivational determinants	Instructional Design Strategies
Challenge	Teacher can set goals for each student based on the individual progress.
Curiosity	The final animation reflects the student's selections and the interaction among the three conditions (organism, ecology, and physical burial). Thus, computer technology can arouse attention and promote curiosity.
Control	The Web-LE promotes direct learning performance by providing explicit and organized selections. Several tools allow learners to control their learning progress, access an online encyclopedia, and browse or post to the bulletin board. The program provides an environment in which the students' different selections have distinct effects.
Fantasy	Realistic graphic simulation and multimedia effects are provided in this program to enhance the sense of fantasy. Embellished activities were added into the Web-LE to maintain students' intrinsic motivation (Cordova & Lepper, 1996).

Figure 3.3 Integrating intrinsic motivational determinants into the Web-LE design.

Interface design

A good instructional interface – one that is instantly recognizable – allows learners to interact with the contents effectively. However, there are no specific rules for developing an effective interface for instructional purposes (Jones, Farquhar & Surry, 1995; Lohr, 2000). When designing the interface of this system, we adopted three principles that are suggested by Lohr (2002) and promoted by experts from related fields.

    (1) Make the most important information distinct:

        To communicate the most important information, we used clear graphic

        designs and contrasting colors to highlight keywords and important messages.

Gray is employed to identify the dysfunctional buttons. The interface

balances visual weight so that no particular parts stand out on the screen.

(2) Establish a visual order of importance for users:

Information in the system is presented in three layers so learners can access

the contents according to a hierarchical organization. Learners have to

understand one concept before entering the next level. The organism level is

the highest in the hierarchy, followed by the ecological level, then the

physical burial level. The hierarchical arrangement presents the information

in a non-threatening manner. Thus, users are not overwhelmed by the

amount of information contained in the program (Jones, Farquhar & Surry,

1995).

(3) Organize information so learners see the "big" picture:

In addition to the hierarchical organization of information to help learners

explore the contents one level at a time, a map of paths is provided to give

learners an overview of all sections and how these sections are inter-related.

We also followed the interface design guidelines suggested by Suess (1997) and

Hobart (1996) to develop the navigation, buttons, labels, and menu.

(1) Consistent button design:

An interface must provide an effective navigational tool for interacting with

the contents. To help learners focus on the instructional content instead of

being distracted by the interface itself, labels are placed on the buttons so

learners can choose functions easily. The design of these labels is consistent

throughout the program to prevent frustration and confusion in the learners.

(2) Visual feedback:

When loading video, a visual index is provided as an indicator to let learners track the progress. Each behavior that learners perform results in some visual feedback to prompt and direct them to interact with the system. The interface design should be in harmony with these and also anticipate all possible interactions that may occur in the learning process. Figure 3.4 illustrates the functions of this system as they appear on the screen.
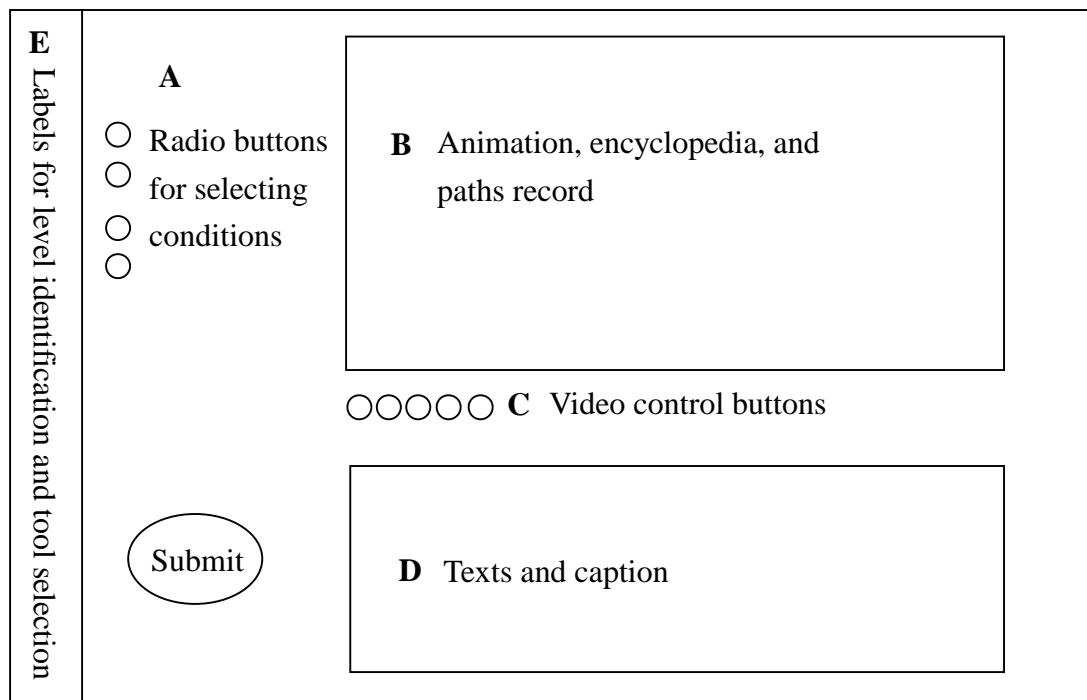
Figure 3.4 Initial interface design.

A. Condition selection: Radio buttons designed for learners to make selections.

B. Media representation: Animation and encyclopedia appear in this window.

C. Video control buttons: Provide opportunities for students to control the learning path or repeat presentations to master the information. Learners can pause, play, and rewind the animation if necessary.

D. Text explanation: Explanations of different organisms, ecological system, and physical burials appear in the text screen.

E. Identification: To ensure that learners can identify where they are in the system, we designed a path recorder to help learners track their own progress.

Based on these needs, our first draft interface (see Figure 3.5) included all these functions. The prototype interface was designed to test all buttons and functions.
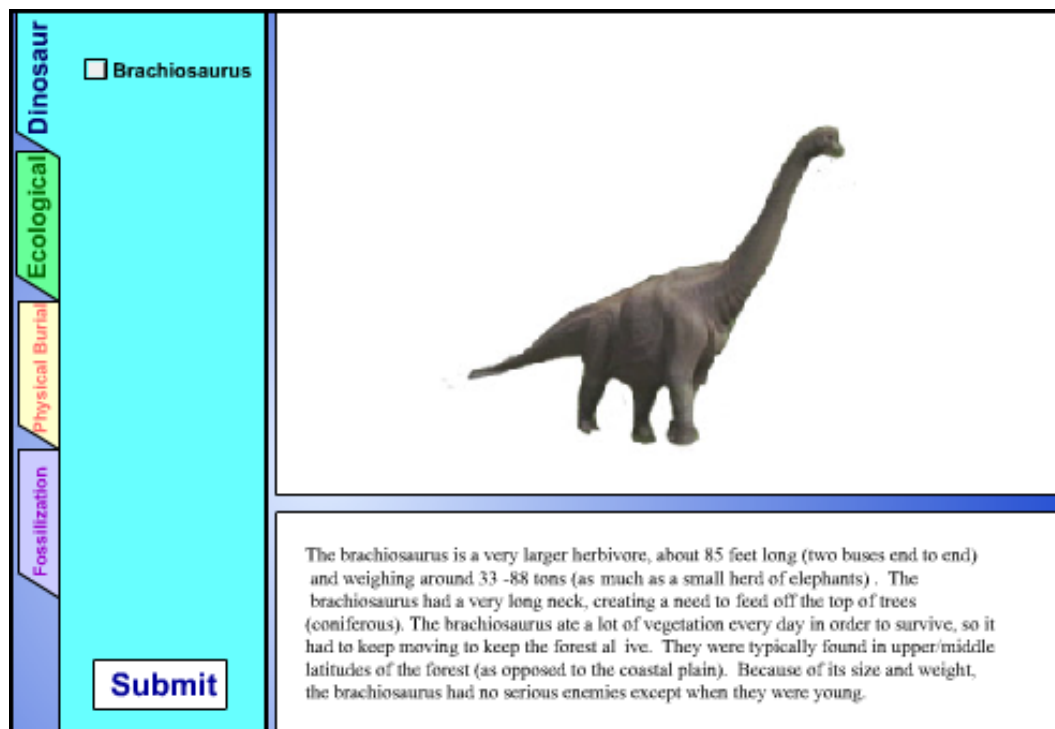
Figure 3.5 First draft of interface design.

The design team members constantly searched for good interface design examples for this topic for teenagers and received consultation from experts while programmers tested the system. In addition, the teacher described features of the target learners and

gave us directions to embellish the design. The version of interface design that was

employed in the formal testing research is shown in Figure 3.6.
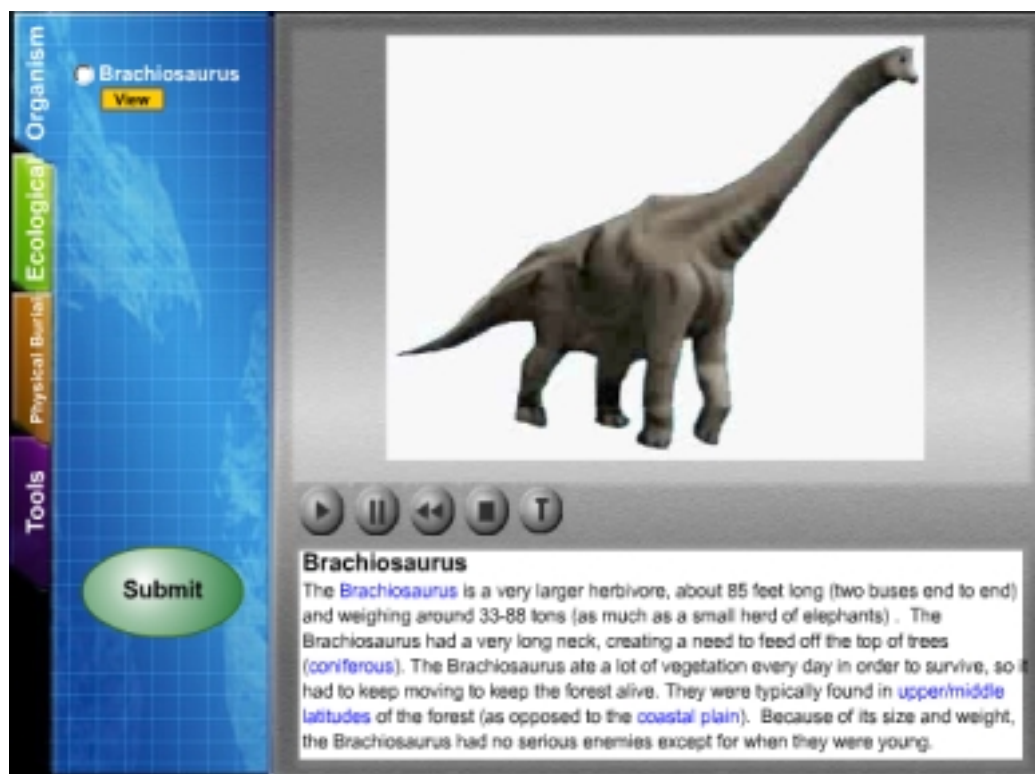
Figure 3.6 Current version of interface design

Instructional process

Figure 3.7 is a flow chart of learner interaction with fossil Web-LE. Before the

students enter the program, the teacher assigns a task to them orally or on the Bulletin

Board. When entering the Web-LE, learners must input their names. A learner's name is

visible on the screen at all times to increase involvement. Next, learners select different

organisms to observe going through the fossilization process. The dinosaur is the only

available organism in the Web-LE at this time.

```
                    ┌─────────────────────────┐
                    │ Introduction of fossil unit │
                    └─────────────────────────┘
                                 │
                                 ▼
                    ┌─────────────────────────┐
                    │ Input name              │
                    └─────────────────────────┘
                                 │
                                 ▼
                    ┌─────────────────────────┐
                    │ A) Select organism (Figure │ - - - - ┐
                    │    3.5)                 │         ┊
                    └─────────────────────────┘         ┊
                                 │              ┌────────────────┐
                                 ▼              │ Interact with  │
┌──────────────┐    ┌─────────────────────────┐│ teacher and    │
│ E) Record paths│   │ B) Select ecological status││ other students │
│ and make     │    │    (Figure 3.6)         │└────────────────┘
│ other        │    └─────────────────────────┘         ┊
│ selections   │                │              ┌────────────────┐
│ (Figure 3.8) │                ▼              │ Refer to online│
└──────────────┘    ┌─────────────────────────┐│ glossary (Figure│
                    │ C) Select physical burial ││ 3.10)          │
                    │    (Figure 3.7)         │└────────────────┘
                    └─────────────────────────┘         ┊
                                 │                       ┊
                                 ▼                       ┊
                    ┌─────────────────────────┐         ┊
                    │ D) Simulation of fossilization│- - -┘
                    │    (Figure 3.9)         │
                    └─────────────────────────┘
                                 │
                                 ▼
                    ┌─────────────────────────┐
                    │ F) Solve tasks that teacher │
                    │    provides             │
                    └─────────────────────────┘
```
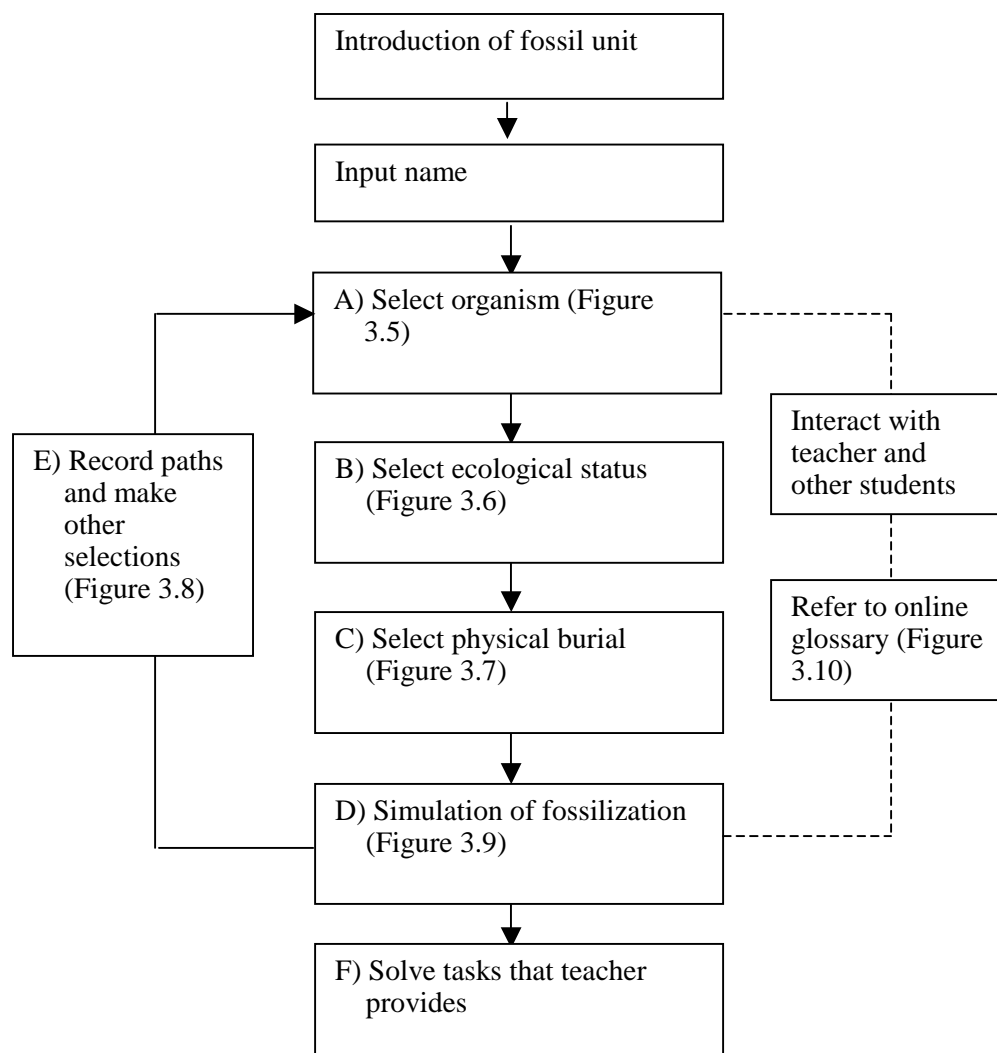
Figure 3.7 Flow chart of the learning process.

The description of this organism was placed in the text screen (Figure 3.6). By

clicking blue keywords learners can access the online encyclopedia to look up

information if they have any questions. They then select the ecological status (Figure 3.9)

and physical burial conditions (Figure 3.10). The combination of their three decisions

determines how the fossil will be developed. The fossilization simulation begins when

decisions are finalized. The system records paths that learners have taken and helps

learners identify the learning process (Figure 3.11). After experiencing all 18 possible

paths, learners are able to identify the situations that can create fossils and solve the tasks

the teacher has given them. Learners can access the online encyclopedia (Figure 3.13) to look up information about these situations. With the Web-LE's communication tools, learners can also discuss questions and share knowledge on the bulletin board.

The system provides visual feedback to reflect what selections the learners have made. Figures 3.8 to 3.13 illustrate the process of selecting fossilization conditions. Each layer adds more background or embellishment to help learners visualize the situation.
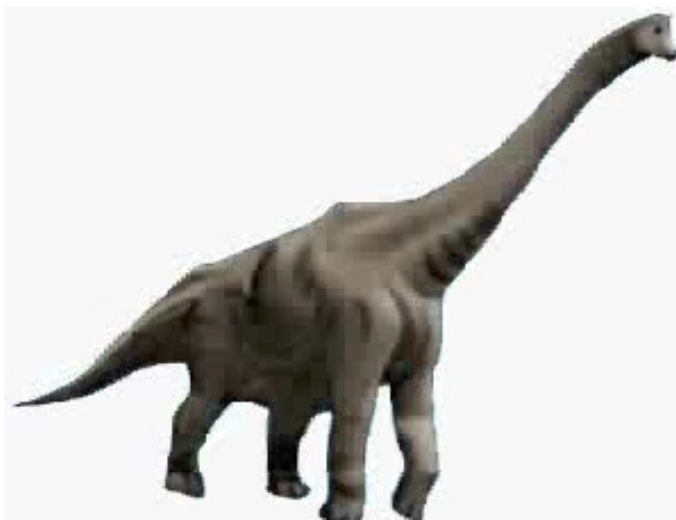
Select Brachiosaurus

Figure 3.8 Choose organism.

Select tropical mountainous rainforest. The background changes to mountainous rainforest and provides the text screen provides an explanation..

Figure 3.9 Choose ecological status.

Select ash fall and the condition is added on the mountainous rainforest background.

Figure 3.10 Choose physical burial.

This path is highlighted and indicated learner's selection
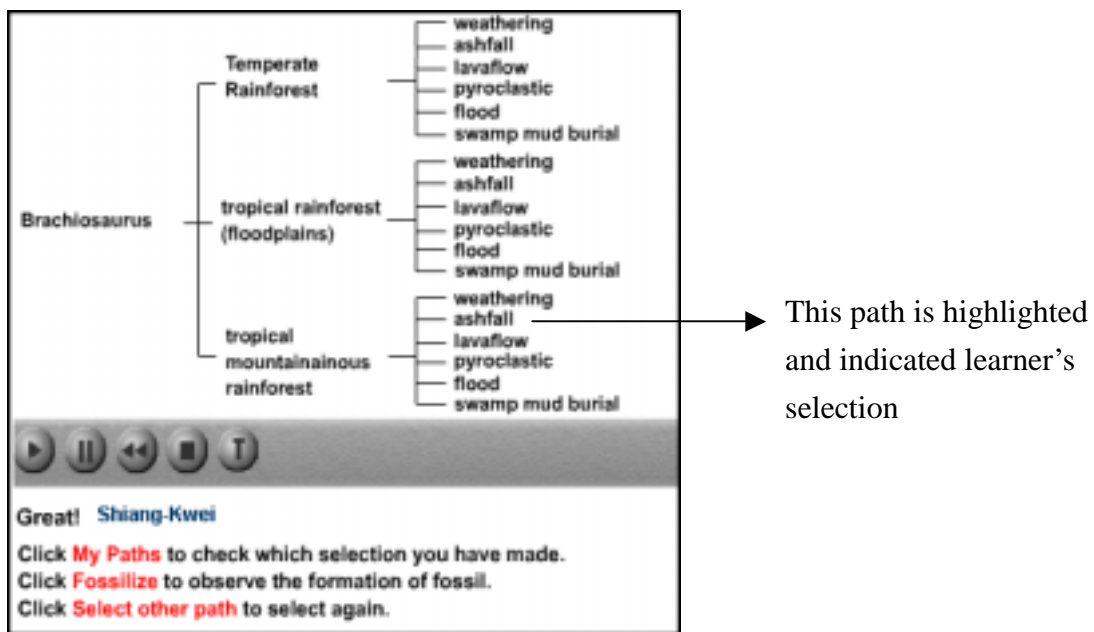
Figure 3.11 Path tool records learner's selection.

Once decisions have been made, the path tool records the choices and provides a hint to observe fossilization simulation. The learner's name is always on the screen.

Figure 3.12 Simulation screen

The learner can launch the simulation and observe the animation. Video control buttons are provided to enable the learner to pause, stop, or repeat the animation. The caption of the animation appears in the text screen.

Figure 3.13 Encyclopedia

The learner can select blue keywords at anytime to review explanations of specific keywords. They can jump between the main program and the encyclopedia section whenever they need to.

Media elements production

To determine whether web and video technology affect cognition differently from earlier technologies involves pitting one medium against another (Solomon, 2002). This is not the concern of this study. This study is designed to assist a teacher who wants to apply computer technology to a specific context, based on his particular challenges, and in the process to reveal effective combinations of technology and pedagogy.

Video and animation can represent the complexity, ambiguity, and continuity of concepts. Research supports the usage of interactive video to improve student achievement when it is integrated into the learning environment effectively, and also supports the conclusion that interactive video is more efficient in conveying concepts than traditional approaches (Doulton, 1984; Stevens & Zech, 1987). Yair, Mintz, and Litvak (2001) concluded that scientific visual representations provide students the opportunities to observe phenomena that are difficult or impossible to observe directly.

The primary target audience of this Web-LE is high school students, to whom realistic graphics and vivid animation appeal. The science teacher also stressed that the representation of the fossilization process should be realistic and credible. Several endeavors have been made to achieve is requirement. The dinosaur has been developed with correct proportion, color, and movement. 3D software (Corel Bryce©) was used to develop the realistic landscapes and objects, including ancient plants, volcanoes, lakes and fossils. Macromedia Flash© was adopted as the primary authoring tool because of its ability to integrate multimedia and the capacity to optimize high quality media to enhance the speed of transmission.

Online encyclopedia and bulletin board

One major function of this tool is to provide extensive and detailed explanations of selected keywords. These hyper-linked keywords are designed for learners who have difficulty understanding the explanation of the fossilization process. Learners can choose to learn about any keywords without suspending the whole learning process. Streaming animation and hyperlink functions are used to present the encyclopedia information via a hyperlink function. Students can link to the open environment to access other web sites and extend their knowledge about the topic. Furthermore, the online encyclopedia can be employed as a separate tool without launching the main program.

The bulletin board is designed to enable interaction between the teacher and learners. The major purpose for the bulletin board is to provide an environment where learner can complete tasks and investigations as they use the Web-LE. The teacher can post leading questions on the bulletin board and have learners to write open-ended answers or reflections. As a result, learners can share their knowledge with other participants. Knowledge accumulates through the usage of bulletin board, and can be reviewed and assessed as needed. The bulletin board was developed using Microsoft Access© and ASP scripts and executes on a Windows NT© server.

Formative evaluation of the project

To ensure that the team made accurate or appropriate decisions in each stage of the Web-LE development, formative evaluations were conducted starting at the storyboard design phase. To do the formative evaluation, the following methods were employed to collect data:

1. Reviews by the subject expert: The team met with the subject expert every week in the first half year to review and check instructional contents. During the production stage, the programmer and graphic designer met with him two or three times a week to ensure accuracy.

2. Peer review: Peer review is one way of usability testing. Each team member went through the program to figure out potential problems of interface design.

3. Expert consultation: Two experts provided consultation and professional opinions of interface design during development.

4. Student responses: Seven target learners went through the first four paths and provided useful feedback for improving the interface design. The prototype was implemented in a 10th grade science classroom as part of a pilot test. Students filled out surveys about this program, and the researcher observed their behaviors and interactions while using the program in the classroom. These methods were employed to obtain information to modify and refine the program. More information about the research methodology and the results of pilot study are provided in the next chapter.

Chapter 4

Methodology and Pilot Study

Introduction

As described in the previous chapters, the purpose of this study has been to apply

the principles of development research to the actual instructional problems faced by a

local high school teacher. Development research (van den Akker, 1999) has two primary

goals: first, solving local problems through collaborative research and development, and

secondary, revealing generalizable design principles. Van den Akker clarifies the

meaning of development research:

> More than most other research approaches, development research
> aims at making both practical and scientific contributions. In the
> search for innovative 'solutions' for educational problems,
> interaction with practitioners…. is essential. The ultimate aim is not
> to test whether theory, when applied to practice, is a good predictor
> of events. The interrelation between theory and practice is more
> complex and dynamic: is it possible to create a practical and
> effective intervention for an existing problem or intended change in
> the real world? The innovative challenge is usually quite substantial,
> otherwise the research would not be initiated at all. Interaction with
> practitioners is needed to gradually clarify both the problem at stake
> and the characteristics of its potential solution. An iterative process
> of 'successive approximation' or 'evolutionary prototyping' of the
> 'ideal' intervention is desirable. Direct application of theory is not
> sufficient to solve those complicated problems. (pp. 8-9)

This chapter describes the research methodology, research design, and details of

conducting this development study. In addition, the results of a pilot study are presented.

Through the design and development process, the Fossilization Web-LE was "finished" in December 2002, and implemented in the collaborating teacher's classroom to reveal its strengths and weaknesses in January and February 2003. Using an earlier prototype of the Web-LE, a pilot study was conducted in April 2002 to ensure that the design of the Fossilization Web-LE matched the teacher's needs and that the target learners had no usability problems using the interface. Based upon the results of the pilot study, the team revised the Fossilization Web-LE and fleshed out the other components of the program such as the Encyclopedia.

Methodology

Hundreds of media comparison studies have tried to show how learning is affected by different media with few significant results (Clark, 2001). Of the many factors that influence research of this kind, the most critical problem is the expectation that the medium makes the difference (Salomon, 2002), leaving human and situational factors unconsidered. In these experimental research designs, the researcher controls specific factors (e.g., choice of media) in the environment and compared the performance of different groups to discover the impact of these factors. However, numerous unpredictable factors are involved in the daily life teachers, students, and classrooms. The findings of quasi-experimental research are often limited by the fact that the studies were conducted in controlled environments that are rare in the real world. These controlled environments lead to unwarranted over-generalization of findings, and thus the research results fail to provide sufficient guidance for teachers, students, or others involved in the learning environment. Several scholars (Chen, 1994; Reeves, 2000; Richey, 1997; van den Akker, 1999), perceiving this lack of influence on practice as a serious problem,

encourage researchers to conduct development research in the field of instructional technology.

The definitions of development research are various and vague. Seels and Richey (1994) use the term "developmental research" to refer to "the systematic study of designing, developing and evaluating instructional programs, processes, and products that must meet the criteria of internal consistency and effectiveness." Reeves (2000) describes six research goals and states that the purpose of development research is to improve, not to prove, the efficacy of the learning innovations. In other words, when engaging in development research, questions such as "what works in this situation?" and "How can it be improved?" should be addressed. The main purpose of development research is to offset the gap between research and practice (van den Akker, 1999).

Although efforts to develop learning software have continued for decades, front line teachers rarely integrate these programs in their classrooms (Cuban, 2001). The critical reason is that these programs do not fit the teachers' needs. Helping teachers solve instructional problems through the use of instructional technology is the first purpose of this type of development research study. To reach that goal, we worked closely with a local teacher to define the instructional problems, clarify the traits of his learners, understand the context for implementation, and create alternative solutions. As detailed in Chapter 3, our team members reviewed the teacher's instructional resources in the fossilization unit, and then we met frequently with the teacher to revise the prototype Web-LE. A pilot study was conducted in the middle of the production phase to evaluate the usability and ensure that the design met the teacher's needs. The specific focus of this research was to enhance learner motivation and to improve learning achievement in a real

world context; hence, the research methodology chosen was development research. A secondary goal of development research is to yield design principles that can inform future efforts to develop or implement instructional innovations.

Methodologies of development research are varied. Any approach, quantitative or qualitative, is legitimate as long as the goals are to enhance the effectiveness of the solution and to derive design principles to inform the research and practice of others (Reeves, 1998). This research has relied predominantly on qualitative research methods to clarity the strengths and weaknesses of the Web-LE we designed. The specific data collection methods used in this study were classroom observations and interviews with students and the teacher.

Research Design

The overall development research study began in June 2001 and continued through February 2003. The culminating test of the Web-LE occurred in the collaborating teacher's 10th grade science classroom in January and February 2003. Figure 4.1 displays the complete research timeline.

There have been two major phases to this development research project. First, the literature review and interviews with the teacher helped our team to develop an effective web-based cognitive tool for this specific context. The collaborating teacher reported that most of his students have motivational and achievement problems. Based on this dilemma, we clarified the instructional problems and built prototype solutions using computer technology. The eventual product of this phase was the fossilization Web-LE described in Chapter 3.
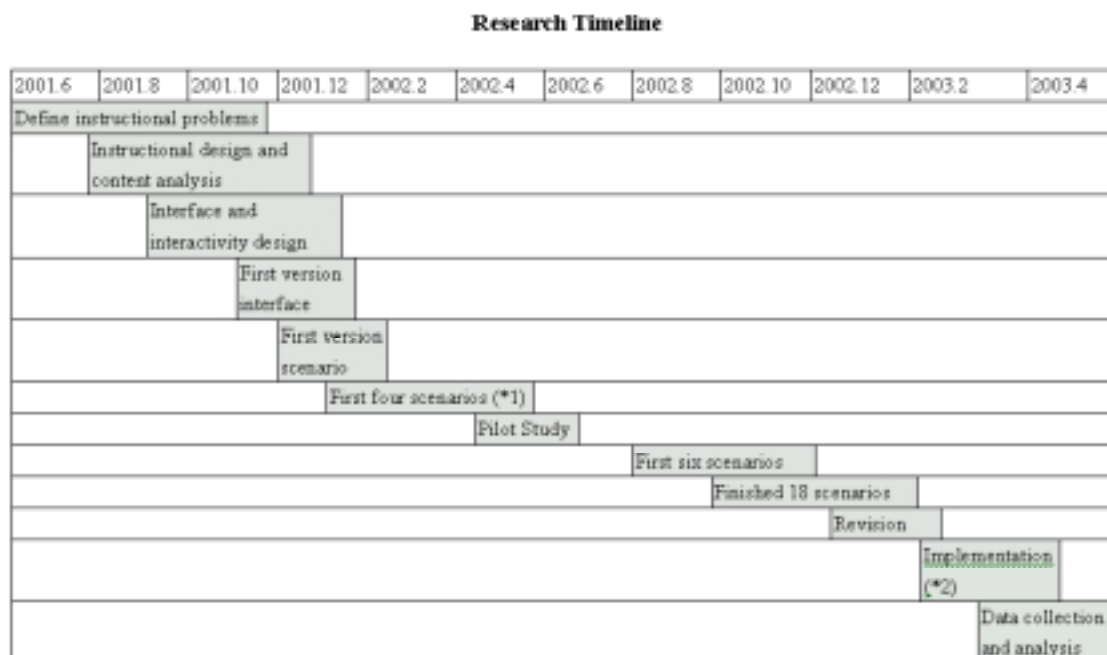
Research Timeline

Figure 4.1 Research timeline.

*1. The teacher added two more scenarios in each ecological environment and the researcher needed to add

six scenarios totally.

*2. Refers to figure 4.4 for implementation timeline.

The second major phase has involved testing the Fossilization Web-LE that

integrates the principles of using technology as a cognitive tool with appropriate learning

principles that raise and maintain learner motivation. After revising the Fossilization

Web-LE based upon the pilot study results, this tool was implemented in our

collaborating science teacher's classroom in January and February 2003. The data

collected during this second phase was analyzed between January and March 2003.

Whereas the entire team played important roles during the first phase, I carried out this

second phase primarily by myself. Working with the guidance of my dissertation

committee chair and other committee members, I have carried out the analysis and reporting of the data by myself as well.

Context

This research project was conducted in two tenth grade science classrooms in a school that is part of a larger project involving the evaluation of the impact of using laptops on student performance (Hill, Reeves, Grant, & Wang, 2001; Hill, Reeves, Grant, Wang, & Han, 2002). The primary setting was a highly-rated private day school located in Athens, Georgia, a small university town where The University of Georgia is located. Student participants were observed, interviewed, and tested to document their learning performance and motivation while studying fossilization within the context of a tenth grade science class in January and February 2003.

This private day school is infused with computer technology, including laptops and a wireless network. The students and the science teacher always bring their own laptops to the classroom where they can access the Internet or the school server at anytime. The excellent infrastructure of network technology in this school was very advantageous because it prevented me from having to deal with hardware problems.

Participants

For sample selection, this research study employed the purposive sampling method, based on the specific need to work closely with the science teacher and his students to promote learner motivation and learning achievement. The participants included one male teacher and 27 tenth grade students, constituting two science classes. There were fourteen females and thirteen males in this study, ten students in class A and eighteen in class B. One student in class B did not fill out the survey form; therefore, this participant

was ruled out for data analysis. The students were grouped by the teacher's estimation of their past performance in his class. He designated six students as belonging in the high performance group, ten in the average group, and eleven in the below average group. Table 4.1 lists the numbers of students in each group in this study.

Table 4.1

Participating Students' Past Performance in Science

	High performance	Average performance	Low performance	Total
Class A	3	5	2	10
Class B	3	5	9	17
	6	10	11	27

Although 27 students participated in the instruction and filled out the survey form, classroom observation and student interviews focused on twelve students, six from each classroom. These students were identified by their teacher as representing three achievement levels (high, average, and below average). The selection was based on an overall assessment of students' past academic performance. The twelve students include four from each achievement level; six were girls and six were boys; eleven were Caucasian, and one was an African-American student. Consent forms (see Appendices A and B) were completed by the students and their parents before participation in this study.

The teacher is an experienced science instructor. As described in earlier chapters, he has encountered problems over the years conveying the concept of fossilization to students and experienced difficulty in motivating them to study science. Each student

obtained a laptop in 2000, and most of them began to use computers in elementary school. After two years of using laptops, these students possess high levels of computer and information literacy. Both classes were supervised and instructed by the same teacher who is the same teacher who has collaborated with us from the beginning.

Data collection

A variety of qualitative data collection and analysis methods were used to investigate the effectiveness of the Fossilization Web-LE. Guidelines were developed for systematic classroom observation and protocols were developed for conducting interviews with the participating students and their teacher. Figure 4.2 lists the sources that provided data for addressing the corresponding research questions.

Research Questions	Data Sources
How do the interactive features of the fossils Web-LE affect students' motivation to learn fossilization in this high school science class?	● Interviews with teacher and students ● Classroom observations ● Motivation questionnaire
How do the interactive features of the fossils Web-LE affect students' academic performance with respect to learning fossilization in this high school class?	● Interviews with teacher and students ● Classroom observation ● Assignment grade analysis
What general principles concerning the design and implementation of an effective Web-Based Learning Environment (Web-LE) for improving motivation and achievement in high school science can be derived from this development research project?	● Classroom Observation ● Interview with teacher and students ● Usability testing

Figure 4.2 Research questions and data sources.

(1) Strategies for investigating how the interactive features of the Web-LE affected students' motivation to learn fossilization in this high school science class.

Brophy (1987) pointed out that "measures of student motivation to learn must reflect the quality of student engagement in academic activities" (p.183). Hence, successfully measuring students' academic engagement can help us understand their motivational status. Measuring the motivation to learn continues to be a challenging task (Turner & Meyer, 1999; Bong, 1996). Academic motivation is complex, and relying on a single "unit" of measurement does not usually produce accurate results. Bong (1996) compared several studies that employed the same framework to measure motivation, but she found discrepancies in the results of these studies. Bong suggested that there is a need for diverse designs and methods in order to address the nature of academic motivation adequately.

Academic engagement is difficult to measure because, as many research studies indicate, students may complete academic work and perform well on exams without really engaging with the learning content (Eckert, P., 1989; McNeil, 1986; Weis, 1990). Newmann (1992) suggested that levels of engagement must be estimated from indirect indicators such as the amount of participation in academic work, the intensity of student concentration, the enthusiasm and interest expressed, and the degree of care shown in completing the work.

Lee and Brophy (1996) employed Newmann's levels of engagement to examine six graders' motivation to learn Science. They identified three aspects of task engagements based on Newmann's levels of engagement: (1) observable behavioral responses, (2) covert cognitive responses activated during learning, and (3) interest. Following this

advise, this research employed various data collection strategies to measure the level of

academic engagement and investigate the impact of the Fossilization Web-LE on student

motivation. In this study, questionnaires, classroom observations, interviews with

students, interviews with the teacher, and assignment grades were the major methods for

estimating motivation. The triangulation strategy of using multiple methods and data

sources (Mathison, 1988) have produced reliable evidence for determining the extent to

which the Web-LE affected student motivation and learning performance in this context.

Figure 4.3 lists protocols corresponding with the examined engagement indicators. All

protocols and measurement instruments are included in the appendices.

Engagement indicators	Measuring instrument
Behavioral responses	● Observational protocol ● Students interview protocol ● Motivation questionnaire
Cognitive responses	● Teacher interview protocol ● Observational protocol ● Assignment grades
Interests	● Observational protocol ● Motivation questionnaire ● Students interview protocol

Figure 4.3 Instruments for measuring student engagement while using the Web-LE.

● *Teacher interview protocol number 1 (Appendix C).*

The science teacher was interviewed throughout the nearly two years of this project

to gauge his opinions about the Fossilization Web-LE. The purpose for interviewing the

teacher before developing the Web-LE was to help us understand his instructional

problems and his expectations of a Web-based learning tool. He also provided

information about the target tenth graders' learning characteristics. In April 2002, the

researcher conducted a formal interview with the teacher regarding the effectiveness of

prototype Fossilization Web-LE. The primary interview questions for the teacher

concerned the following: past experiences with teaching the concept of fossilization,

focusing on the learning performance and motivation of the students; common learning

activities and their outcomes in the traditional classroom; his personal impressions and

opinions toward the prototype Web-LE; his expectations of the tool; and how he planned

to integrate it into his classroom to solve his instructional problems.

- *Student interview protocol (Appendix D).*

Interviews with the students elicited their ideas about using the Fossilization

Web-LE, and their suggestions for improving it. The primary interview questions for the

students concerned the following: whether their past experiences using multimedia

learning programs and Web-LE were enjoyable and/or helpful; success with learning the

concept of fossilization; and opinions and suggestions about revising Fossilization

Web-LE in terms of usability and motivation enhancement.

- *Observational protocol (Appendix E).*

When implementing the Web-LE in the science classroom, I served as a

non-participant observer. I documented the learning process, including the students'

learning behaviors, indicators of engagement, impressions of teacher interactions with

students, and student interest. While observing Fossilization Web-LE usage, I

documented potential problems that the learners may have encountered. Observational

methods were employed to answer questions related to (1) improving instruction through

Fossilization Web-LE, (2) instructional problems encountered in the classroom, (3)

assessing non-verbal cues of students' motivational status, and (4) ascertaining what was and was not happening in the classroom regarding the use of Fossilization Web-LE.   To conduct the classroom observation systematically, I constructed an observational protocol to help record detailed indicators of each target student's academic engagement. The topic of fossilization covered three class periods, and six students were observed in each of the two tenth grade classes; hence, 36 observational notes were produced.

- *Motivation questionnaire (Appendix F).*

All students from the two classrooms filled out a Likert-type motivational questionnaire that probed their motivation for using Fossilization Web-LE. This questionnaire was developed for this study and consists of fourteen statements for which the students were asked to state their agreement on a scale of 1 – 5 (strongly disagree, disagree, neutral, agree, and strongly agree). The statements reflect three levels of engagement. In this questionnaire, four items probed the cognitive process, one probed behavioral responses, four focused on interest, and seven focused on an overall evaluation of Fossilization Web-LE.

(2) Strategies for investigating how the interactive features of the fossils Web-LE affected students' academic performance with respect to learning fossilization.

While a major focus of this development research project has been on increasing student motivation to study complex science topics, it was also deemed important to determine the influence of any attempted solution on achievement or academic performance. I could not find any preexisting measures of knowledge and skill related to fossils, and therefore several different methods were employed to triangulate the learning results.

- *Teacher interview protocol 2 (Appendix G).*

The teacher was interviewed again in February 2003 after the implementation of the Fossilization Web-LE. These latter interview questions for the teacher concerned the following: gaps between his expectations of the tool and the students' performance; the degree to which his instructional problems have been solved; his impressions of the Web-LE on his students' motivation; and how he would continue to use the tool in his classroom.

- *Observational protocol (Appendix E).*

To investigate indicators of cognitive responses while using Fossilization Web-LE, classroom observation were also focused on the signs of cognitive engagement. For instance, I looked for examples of students watching the scenarios from beginning to end and using the movie control buttons of the tool to watch animations repeatedly.

- *Assignment grades (Appendix H).*

Assessment of student performance was based upon a teacher-created assignment sheet that was intended to tap into their ability to explain why fossilization does or does not occur under certain conditions. The assignment required them to provide detailed explanations for their responses. Students' assignments scores were collected after the implementation of Fossilization Web-LE. Their assignment grades provided information about learning performance and how well their performance matched with the teacher's instructional goals. The assignment sheet included fourteen questions divided into five categories. Arranged in order of easiest to most difficult, there were five questions at the minor reasoning level, one on graphical interpretation, three at the moderate reasoning level, two asking for explanations of a choice, and two asking for synthesis.

It was not feasible to use this assignment sheet as a pretest. First, the questions on the sheet could not be answered without access to the Web-LE itself. Second, the teacher's lesson plan did not allow for time for any pre-testing. Third, the teacher said that he already understood the students' capabilities with the type of reasoning assessed via this assignment sheet before introduction of the unit. His understanding was based upon the students' prior work in other science units.

(3) Strategies for investigating the general principles concerning the design and implementation of an effective Web-LE for improving motivation and achievement in high school science that can be derived from this development research project.

● *Usability testing in the Pilot Study (Appendix I).*

After working closely with a very experienced high school science teacher in a local high school, the team identified the mental models of scientific phenomena and processes that this teacher's students had difficulty mastering (Jih & Reeves, 1992). Then, working closely with the teacher, we developed a prototype Fossilization Web-LE to implement the theories and pedagogies identified earlier. The "completed" Fossilization Web-LE includes an online encyclopedia and a function for tracking the paths each learner has taken. Details of the Web-LE development are described in Chapter 3. Usability testing was conducted in the pilot study phase to help revise the interface design. Students involved in the pilot study spent thirty minutes exploring the Fossilization Web-LE and filled out a questionnaire about its usability. The Fossilization Web-LE was revised based on the pilot study results. Several design principles for Web-LEs have been derived from the process of testing and revising this program.

● *Interview and observation.*

As noted above, interviews with students and teacher as well as classroom observations were used to investigate the components of Fossilization Web-LE most helpful for increasing motivation and helping the students to learn more about the concept of fossilization. This data also provided the basis for deriving principles related to the design and implementation of Web-LEs in the future.

Procedures

To determine the effectiveness of the Web-LE in terms of knowledge construction, the teacher assigned tasks to learners at the beginning of the first period class and had them find solutions using Fossilization Web-LE during that period and two subsequent class periods (each period lasts forty five minutes). Except for a five-minute introduction about the basic operation of Fossilization-Web LE, the teacher did not provide any academic instruction about the topic.

Focusing my observations on six students from each class, I gathered in-depth notes on how students used the tool to do their assignments. To minimize their awareness that they were being observed, I designed nametags for all students and put the nametags on the tabletop before the class began. All students were told that the nametags were randomly assigned and that they should find their seat. In each class, the six students selected for my attention were grouped together to facilitate the observations.

The teacher told the students to use the Web-LE to finish the assignment by the end of the third class. During the three class periods, I conducted my observations from the rear of the classroom to minimize any disturbance of the learning process. At the end of the third class period, all students filled out the motivation survey questionnaire and students turned in their assignments. During following week, the researcher conducted

twenty-minute individual interviews with each of the twelve observed students. The interviews were designed to reveal more in-depth information about their opinions of the tool and their attitudes toward it. The interviews were conducted during their study hall time. I used Mini Disc to record twelve student interviews and transcribe these interviews.

Once students had received their grades, the researcher conducted an hour-long interview with the teacher to understand the nature of the assignment, the student learning performance, and the effectiveness of the tool from the teacher's perspective. The researcher also gathered the students' grades for analysis.

Figure 4.4 represents the implementation timeline that was followed for this phase of the research project. Data analysis began during the data collection, and continued into the third week of March when this document was completed.

Implementation Timeline

Week 1 – Jan. 29-31			Week 2 – Feb. 3-6	Week 3 – Feb. 12
Wednesday	Thursday	Friday	Monday - Thursday	Wednesday
Teacher distributed assignment	Class A: second period	Class A: third period Class B: third period	Conduct twelve individual student interviews	Conduct teacher interview and gathered assignment grades
Class A: first period Class B: first period	Class B: second period	Students turned in assignment Students filled in motivation questionnaire		
Classroom observations focused on twelve students; students completed motivation questionnaire			Student interviews	Teacher interview and analysis of grades

Figure 4.4 Implementation timeline for data collection.

Data Analysis

(1) Interview: The levels of engagement were categorized by analyzing interviews with students and the teacher. Significant themes found in both the teacher and student interviews were compared and analyzed to determine similarities and differences. The results were helpful in confirming the integration of motivational indicators (control, challenge, fantasy, and curiosity) in the tool design.

(2) Classroom observation: The observation notes were analyzed to investigate students' level of engagement while using the Fossilization Web-LE during class. Special attention was given to students' motivation, and how to make this Web-LE a better instructional tool. Based on research conducted by Newmann (1992) and Lee and Brophy (1996), the researcher designed the observational protocol focusing on the following indicators of level of engagement:

a. Behavioral engagement: Indicators of behavioral engagement include level of attention, response to distractions, engaging with the task that the teacher assigns, and using the Web-LE to search for possible answers or other available information.

b. Cognitive engagement: Indicators of cognitive engagement include understanding the contents, finishing the class requirements assigned by the teacher, expressing confusion or learning difficulties to the teacher, and asking for further explanation.

c. Interest toward learning science: Indicators of interest toward learning science include paying attention to lectures or explanations, enthusiasm

about learning the topic, looking for extra resources, and consistent curiosity about the subject.

(3) Motivation questionnaire: I used SPSS to analyze the motivation questionnaire and identified the significant factors that may have impacted student motivation and learning achievement.

(4) Assignment analysis: I analyzed the nature and difficulties of the assignment with the assistance of the science teacher. The purpose of the assignment analysis was to substantiate students' learning performance and to assess how well they used Fossilization Web-LE to solve problems.

Pilot study

As a precursor to implementing the actual study with more participants, a pilot study was conducted in May 2002 with seven learners. The purpose of the pilot study was to examine potential usability problems with the interface design and to gather teacher and student opinions about using Fossilization Web-LE. Results of the pilot study were used to revise the Fossilization Web-LE design as well as the research design. The questions addressed by the pilot study were: (1) are the media elements effective enough for the target audience?; and (2) do the usability testing results support the effectiveness of the interface design?

- Procedures

The prototype for the pilot study included four scenarios of fossilization. Seven 10th grade students (four males and three females) were selected to test the prototype after school. Parents had filled out the consent forms to allow their children to participate in the pilot study.

The prototype did not include the bulletin board. Also, we copied files to their laptops before the pilot study was conducted to reduce download time. The researchers put all files in the share folder on the school's server, and each student copied those files to their own laptop. The researchers gave them a handout and spent about two minutes explaining which paths worked in this tool at that time. They could also refer to a handout about the available paths when using the tool. The students were not given specific instructions for using the interface; we let them explore the functions of the program by themselves. Students were asked to undertake an assigned task (to find out which scenario has the best chance to preserve the complete skeleton of a dinosaur) by going through the program. The students spent approximately 30 minutes with this tool and spent another five minutes filling out the usability questionnaire. The science teacher was present in the classroom the whole time, and I interviewed him shortly after the test session. There was constant communication among the students while they used the prototype Fossilization Web-LE.

- Methods

Classroom observation, a usability testing questionnaire, and an interview with the teacher were the primary methods for gathering data in the pilot study.

- Results

A. Usability testing questionnaire.

The usability testing questionnaire focused on students' opinions of the program. Sample questions included "Using this software was _____," "Figuring out the path I already completed was _____." Students had to make a selection that best represented their opinions, on a scale from one to five. Means of the students' usability testing results

are graphed in Figure 4.5. Generally, students thought the interface design was effective

and enabled them to explore all scenarios and the encyclopedia. They could find certain

buttons on the interface and use the path record function to track their learning history.

Usability testing result
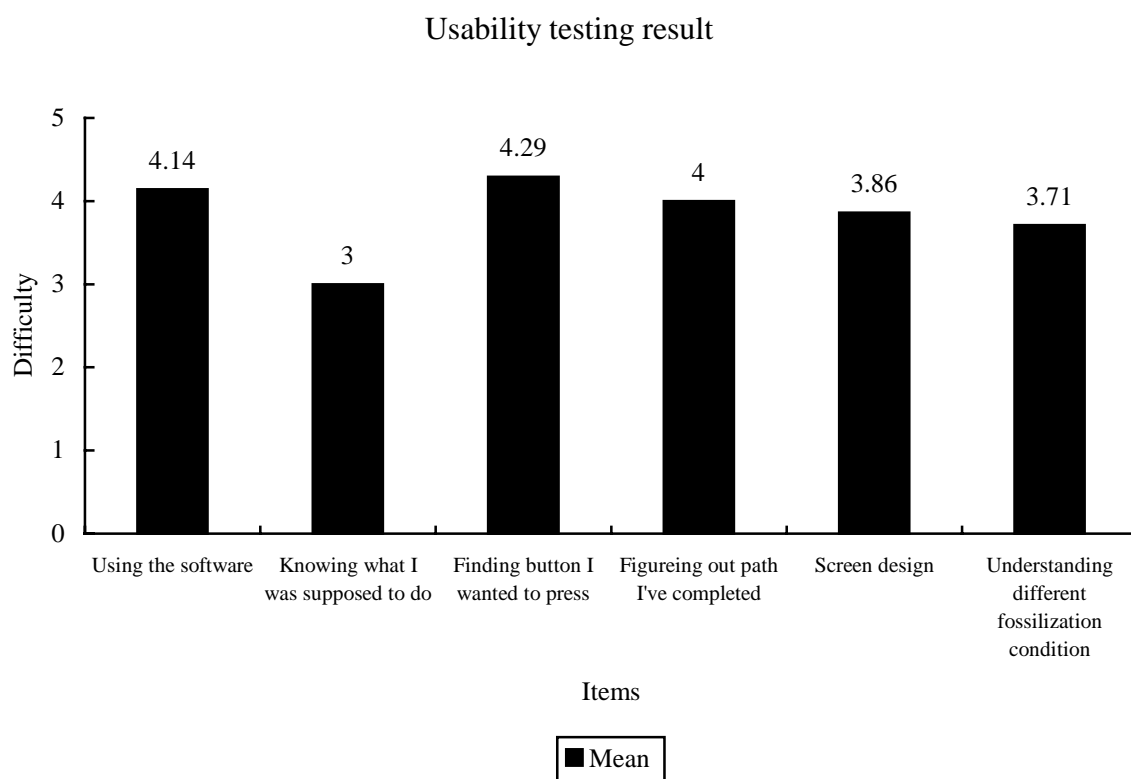
1 = Very difficult, 2 = Difficult, 3 = Neutral, 4 = Easy, 5 = Very easy

Figure 4.5 Usability testing results.

One item that required attention was "Knowing what I was supposed to do."   The

overall mean for this item only reached "neutral." A possible explanation of this result is

that to activate any one scenario, students had to go through three different layers and

might have been distracted by the keyword explanations. When they make the final

decision, the simulation does not automatically occur until they press the "submit" button.

Several buttons were available on the same screen, and the students may not have

understood which button they were to press to enter the next level.

Two other questions on the questionnaire were designed to test whether students

could use the program to complete the assigned task and how helpful the Web-LE might

be in improving their learning achievement. The teacher asked students to figure out

which scenario has the best chance to produce the complete skeleton of a dinosaur. All

the students selected the correct conditions, and all the students pointed out that the

fossilization tool indeed helped them to learn the concepts of fossilization underlying this

solution. Figure 4.6 categorizes comments from the students who tested the program.

Categories	Themes
Improving learning achievement	● Could learn much more if given more time. ● Learned a good amount of information in a short time. ● It has detailed information to go with the clips and pictures. ● It is an easy way to observe the fossilization of dinosaurs. ● Animation and vocabulary helped with understanding the process.
Interface design	● Caption of animation was a bit fast. ● It is easy to use.
Motivation	● It is interesting and I hope I have more time to use it.
Other comments	● It does not replace the textbook or teacher.

Figure 4.6 Categories of students' comments about the Fossilization Web-LE.

B. Observation notes.

I observed the whole process of instruction and took observation notes along with

two graduate student assistants. Classroom observation focused on how individual

students interacted with the program, their expression of interest and motivation, which
part of the program attracted their attention most, what kind of navigation problems they
encountered, and conversations about Fossilization Web-LE among students. Figure 4.7
lists three categories of special themes from classroom observation: interface design,
motivation, and other significant events.

Categories	Themes
Interface design	● Some students had problems finding where "submit" button is and knowing when to press "view" button. ● In the animation part, they were supposed to roll over on the screen and click on these objects to get further explanations. Some of them had difficulty discovering that function. ● Need more explanation of buttons on the screen. ● Nobody selected the "tool" tab.
Motivation	● Students laughed and shared what they saw with each other. ● Conversation revealed that most of them thought it is cool and educational. Some students asked the researcher when the final version would be available and if they could use the program at home.
Others	● Students tried to explore every path even though only four were available in the pilot study. ● They liked the encyclopedia part because it provided the instant explanation. ● Once students chose a path and viewed animation successfully, they could figure out what was going on. They had no problems on the next selection. They became familiar with the interface control through practice. ● Some students wanted to repeat the animation again and again.

Figure 4.7 Categories of classroom observation notes.

The classroom observation provided clear information about some flaws in the interface design, especially that students experienced difficulty figuring out how to continue the instruction when selecting a scenario. However, student overall attitudes toward using the Fossilization Web-LE were positive. There was good evidence that they were highly interested in learning fossilization concepts with this Web-LE and looked forward to integrating the program into their learning environment.

C. Interview with the teacher.

The purpose of interviewing the teacher was to figure out how he planned to integrate Fossilization Web-LE into his learning environment and how Fossilization Web-LE could improve instruction from his perspective. Figure 4.8 illustrates the themes derived from my analysis of this interview.

From the teacher's point of view, the Fossilization Web-LE has great potential to solve his instructional problems by providing animations of fossilization processes, a visually-oriented encyclopedia, and a range of different fossilization scenarios. He already has a plan for how to integrate the tool and how to use the tool to help students learn. The teacher did express concern about the schedule for the development of the tool because he was looking forward to integrating it into his instruction in February 2003. We adjusted the timeline so that the Web-LE could be completed in time for classroom use in early 2003.

Categories	Themes
Traditional teaching strategies	• Rely on textbooks, drawing, and pieces of available resources such as cartoon animation and actual fossils • Require each student to spend a long time drawing one scenario • Lecture about differences in textures between sandstone, siltstone, and mudstone, and how they affect fossils formation.
Problems of traditional teaching environment	• Students can explore only one fossilization scenario by drawing. • No moving illustrations to display the process of fossilization • Students spend too much time on drawing • Have to repeat everything when starting a new term.
Experience of teaching with computer technology	• No available products matched his needs • Students are visually-oriented; text information hardly maintains their interest or helps them understand.
Strategies of integrating Fossilization Web-LE into learning environment	• Teacher is the key to making the tool useful. • Assign tasks to students and ask them to solve problems with the tool
Advantage of integrating the fossil Web-LE into learning environment	• Gives them real experiences, scenarios, and displays of what really happens in fossilization processes, and they can combine visualization and memories to solve problems. • Encyclopedia section provides enough information to identify the chemical processes and physical processes. • Reading a book or looking at pictures will not do the same job Fossilization Web-LE does.
Concerns about the Fossilization Web-LE	• Needs to have completed version as soon as possible.

Figure 4.8 Categories of interview with the teacher.

Research Revisions

Based on the pilot study results, several adjustments were made to enhance the reliability of the research methodology to be applied when the Fossilization Web-LE was implemented with whole classes.

Research design revisions:

The classroom observation in the pilot study identified general themes of motivational issues. In order to obtain more detailed information about the students' intrinsic motivation toward learning with Fossilization Web-LE, it was decided that individual interviews would be conducted in the actual research. In addition, it was decided that after coding the classroom observation data with the coding system in Figure 4.7, students who were classified as level one or two (high motivation) and six (low motivation) would be selected for individual interviews.

Program changes:

While students used the program in the pilot study, they found some typographical errors, and this information was used to revise the software. Also, some students hesitated to press buttons necessary for launching the fossilization simulation or to exit the explanation sections of the encyclopedia. These buttons were redesigned to attract learner's attention and direct the learner to choose them (e.g. bright colors). Concise voice effects were added the program to help students explore the program. However, the pilot study results showed that once a learner selected one scenario successfully, they became get familiar with the interface. The redesigned prompting effects were not numerous enough to delay their interactions or bore them.

Instruction changes:

It was decided that the students should be given specific oral instructions for using the interface by the teacher so they can become familiar with the program before beginning to use it for completing the assignment. The teacher also suggested developing a simple manual for students to refer to. When we implemented the tool in January 2003, I designed a simple online manual for students to use.

Additional details about how the teacher planned to use the Web-LE emerged from the pilot test. The teacher intended to use the Web-LE as a multifunctional lab. He would introduce geological time scales to students and show them real fossils in the science classroom before introducing the Web-LE. The students would be asked to use the tool afterward and to describe scenarios that are more likely to produce fossils. Their answers would have to match the actual fossilization scenarios that the teacher assigns. After watching the animations in the tool, students would have to be able discuss the scenarios in a cogent manner. An assignment sheet with questions would be used to structure their engagement with the Web-LE.

Validity and Reliability

Expert reviews of the instruments and procedures for this development research by co-researchers and advisors have been the primary strategy for enhancing the validity of this research. The coding system for analyzing the classroom observation data has been adopted from previous research (Brophy & Lee, 1996). The interview questions and usability testing questionnaire were developed and refined based upon experts' opinions.

To attain reliability, the classroom observation were applied to two different classrooms for several hours until the fossilization unit is finished. Another designer of

this tool used the same observational protocol to conduct classroom observation with me simultaneously. We discussed our findings after each session to ensure the consistency.

Several strategies have been employed to maintain the reliability of this research (Tashakkori & Teddlie, 1998, p.90):

1. Prolonged engagement: the researcher has spent a great amount of time learning the research context, becoming familiar with the teacher, getting used to the classroom culture, and creating rapport with the teacher and students. The researcher has participated in the laptop evaluation project since 1999 and was given chance to establish a long time relationship with teachers and students at the school in this research context.

2. Triangulation techniques: multiple qualitative methods (triangulation of sources) have been employed to gather data. Two researchers conducted classroom observations and then their observations were integrated to enhance consensus about the data (triangulation of investigators).

3. Peer debriefing: The researcher obtained suggestions and opinions from other researchers.

Limitations

Although many general and theoretical papers have been written about motivation and interactive learning programs, there are relatively few research studies on the subject. This study is informed by the research that relates to the design of online learning environments to increase achievement, but it is important to note that such research is also sparse. In many ways, this development research project is breaking new ground.

This development research initiative is a collaboration of researchers and practitioners in a specific context, and the research results will only apply to this selected learning environment. However, the final version of Fossilization Web-LE will be released online for public benefit. To maximize the generalization of the research results, recommendations of appropriate learning processes will be given online for teachers and students who want to integrate the Web-LE into their classroom. The recommendations will include information about the fossilization unit introduction, instructional process and length, learning tasks, characteristics of target students, manuals for teachers and students, and required hardware and software.

Chapter Summary

Media comparison studies have not enabled practitioners to use technology effectively to improve learning outcomes (Clark, 2001; Cuban, 2001). This research adopted a development research methodology to work collaboratively with educational practitioners to explore instructional problems and needs in a specific context. The goal of this research has been to help the teacher improve learning achievement by using the computer as a cognitive tool to enhance student motivation and learning. During the middle stages of program development, a pilot study was conducted to examine the usability of the Web-LE and how well the program reduced instructional problems. Several corrections were made based upon the pilot study results to improve the potential effectiveness of the Web-LE that was tested during the actual study in early 2003. The results of this study are presented in the next chapter.

Chapter 5

Data Analysis and Results

Introduction

The twofold goal of this development research project has been to solve the

instructional problems of a collaborating teacher and to derive generalizable principles

concerning the design and implementation of Web-based cognitive tools. A critical

subcomponent of the overall research project has been to investigate the kinds of effects

that a Fossilization Web-LE had on student motivation and learning. The tool was

developed with the collaborating teacher's input over a twenty-month period and

implemented in his classroom during January and February 2003. Chapter 1 outlined the

questions addressed by this project and described the five stages of the overall research

project. Chapter 2 presented my review of the scholarly literature related to motivational

theories, using the Web as a cognitive tool, and applications of Web technology in

science education. Chapter 3 illustrated the development of the Web-LE. Chapter 4

described the research design, methods, and data analysis employed in this study. This

chapter presents the data analysis and results of using the Web-LE in the collaborating

teacher's classroom.

All the data collected through assignment grades, motivation questionnaires,

observations, student interviews and the teacher interviews are presented below. First, I

explain the baseline data of student performance obtained from the assignment grades;

then I quantitatively analyze the motivation questionnaire data to determine factors influencing student learning performance and motivation. The observational data regarding the twelve students upon whom I focused my observations illustrates different levels of ability and motivation. The observational data describes the learning process and substantiates the data captured from the motivational questionnaires. Student interview data provides a wider range of perspectives on Fossilization Web-LE: its impact on motivation, its impact on learning performance, and its effectiveness as a learning tool in the classroom. Teacher interview data is presented to substantiate and triangulate the data from the student interviews.

Cognitive Assignment Analysis

The teacher designed what he viewed as a college-level student assignment to test how much they had learned from the using the Web-LE. This assignment consisted of fourteen questions and covered six categories: minor deductive reasoning (questions 1, 3, 7, 10, and 11); interpretation of graphs and extrapolation (question 12); moderate deductive and inductive reasoning (questions 2, 9, and 13); synthesis (questions 4 and 5); synthesis and induction (question 14); and explanation of choice (question 6 and 8). The complete assignment is listed in Appendix H. Figure 5.1 identifies levels of difficulty in this assignment.

To finish the assignment, students had to engage with the Web-LE and use critical thinking skills to find answers and make rational explanations. This assignment was not designed for information retrieved but to demonstrate how well the students could use inductive and deductive reasoning to explain different processes of fossilization. Therefore, the assignment also reflected the teacher's instructional goals, which included

helping his students to understand how fossils are really formed and to be able to

compare the actual physical scenarios. Students had complete control over their progress

through this assignment during the learning process.
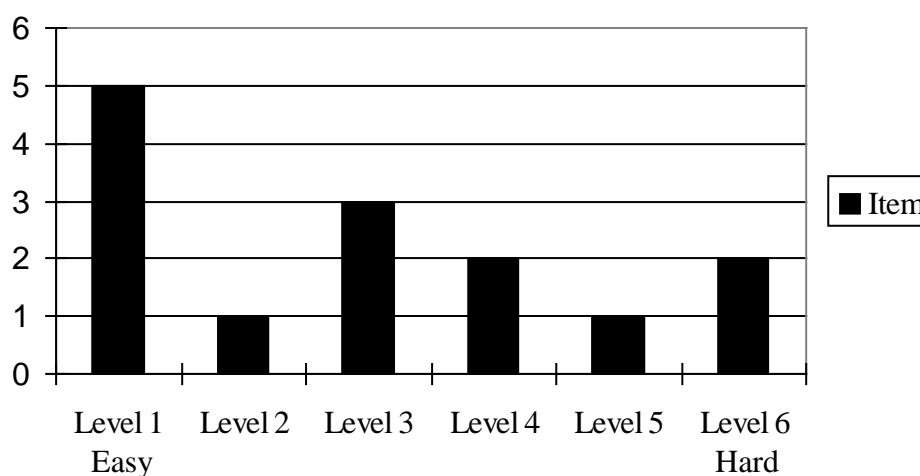
N=14

Figure 5.1. Levels of difficulty in the assignment.

Table 5.1 presents the means of student scores on the assignment by groups (high,

middle, low) based on past science performance in the science class. Among the 27

students participating in this study, there was spread of previous achievement skewed

toward the lower end. Not surprisingly, the high ability students earned the highest scores

on the assignment. The performance of middle and low ability students was essentially

equal.

Performance of different groups

As described in Chapter 4, the teacher grouped the students into high, middle, and

low ability categories based upon his perceptions of their achievement in previous

science units. The high ability students performed relatively well on this assignment; the grades of the middle and low ability students were almost the same. Initially, it was unclear whether the middle students performed worse than expected, or the low students performed better than expected on this test. In his interview, the teacher expressed the belief that the lower ability actually students performed better than expected.

Table 5.1

Means and Standard Deviations of Student Performance in Science (highest score is 40)

	High (N=6)		Middle (N=10)		Low (N=11)	
	M	*SD*	*M*	*SD*	*M*	*SD*
Grade	32.00	4.60	24.6	5.72	23.09	4.16

N=27

Factors that may have skewed student performance

I identified several factors that might have influenced student performance.

1.   How the teacher introduced the tool.

The teacher did not give any academic instruction about the topic of fossilization. He only spent about five minutes at the beginning of the unit to explain the procedures for doing the assignment. Because the teacher was part of the development team and he had his own ideas for evaluating the effectiveness of the Web-LE in his classroom, he insisted on implementing the tool without instruction to assess how well students would perform in this situation. In his interview, the teacher asserted that this investigation proved to him that the tool works, and that he would add his own academic instruction

when using it in the future. Two weeks after the study, he implemented the tool in ninth graders again. He did preliminary work for ninth graders to introduce the unit of fossilization and ninth graders performed better in their assignment. The teacher was fully aware that the assignment grade would be one of the evidences to evaluate the effectiveness of Fossilization Web-LE. However, he did not design easier questions to provide higher scores to prove the tool was effective in terms of enhancing student achievement. For him, the tool provided him opportunities to design tasks that he could not do before using the tool.

2. Design flaws in the tool.

Although severe interface problems were fixed after the pilot study, students still encountered a few problems when interacting with the Web-LE during the classroom implementation. For example, some students had difficulty accessing the encyclopedia. Users were required to go to a specific screen to activate the encyclopedia, which caused problems for some students when doing the assignment. This deficiency was fixed after the implementation.

3. Different perspectives on how to use the tool.

One question in the assignment asked students to point out the most useful function of the tool for doing the assignment. The teacher believed that the page displaying all scenarios (the summary page) would be the most helpful page, but most students selected the online encyclopedia and animations. Seventy five percent of the students disagreed with the teacher's expectations.

4.   Lack of time to do assignment.

Students revealed in the interview that they needed more time to finish the assignment. The teacher also confirmed this in the interview, and he said that he will extend the time to do the assignment in the future.

5.   Subjectivity of the assessment procedure.

The scores that students received on the assignment were given by the teacher alone. Obviously, this teacher was well aware of the previous performance of his students, and therefore, his assessments of their work on this assignment may have been influenced by his perceptions of their abilities and past performance.

Motivational Questionnaire Analysis

When the motivation questionnaire was collected, students did not yet know their actual grade for the assignment. Data collected from motivation questionnaire provided indicators to determine levels of student engagement with the tool. Student motivation while using Fossilization Web-LE was measured using several perspectives: self-evaluation of quality and quantity of learning, interest, and overall evaluation about the tool. Several conclusions were drawn from the questionnaire analysis: (a) the Fossilization Web-LE provided enough information to do the assignment and was helpful for understanding this unit, (b) high ability students believed they had performed at a high level, whereas middle and low ability students believed they had performed almost the same; (c) student motivation was higher when learning about fossilization using the Web-LE than when using other instructional methods; and (d) students were satisfied with the interface design. The motivation questionnaire is provided in Appendix F.

Quality and Quantity of Learning

Students confirmed that the Web-LE was helpful (M = 4.26) and provided enough

information for doing assignment (M = 3.56), and they were satisfied with the quality of

information they received the tool (M = 3.85). Similar results were gathered from the

student interviews. The results confirmed that the assignment was well designed for this

tool and there were no unrelated questions. If they used the tool correctly, students could

figure out answers without looking at outside sources. Table 5.2 lists the means of student

ratings of using the Fossilization Web-LE. These ratings confirm general student

satisfaction toward using the tool. Criteria for judging the meanings of these numbers

were relative. The student interviews and the teacher interview provided additional

information to interpret meanings of their response in the motivational questionnaire.

Table 5.2

Means and Standard Deviations of Students' Ratings of the Fossilization Web-LE

(Scale from 1 to 5).

Item	M	SD
The fossilization software was helpful for doing my assignment	4.26	0.53
This software provided me with enough information to do assignment	3.56	0.89
I performed well in this assignment	2.92	0.93
I am satisfied with the quality of information that I received about fossilization through this software	3.85	0.60
Compare to my teacher's other assignments, I spent more time on the fossilization assignment	2.67	0.92

N=27

The students reported that they did not spend more time on this assignment than on other tasks in their science class because this assignment was relatively small-scale compared to those in other units. They indicated that the time they spent on the assignment relative to other assignments was less. In their interviews, the teacher and students all confirmed that this assignment had relatively fewer questions than other assignments in this science class. Overall, students expressed the belief that they had not performed well in this assignment. The researcher analyzed this trend among three ability groups, and the results are listed in Table 5.3. According to the questionnaires, the high ability students believed they had performed well, whereas the other two groups were not as confident in their achievement. These survey results indicated that the students were aware of their performance since their actual performance corresponded with their self-evaluation. However, the data gathered from the questionnaire conflicts with the data gathered from the student interviews, during which most students alleged that they had performed well on the assignment. However, the interview results may be less reliable because the students possibly felt uncomfortable discussing their grades with an outsider.

Table 5.3

Means and Standard Deviations of Student Self-evaluation on Assignment

	High (N=6)		Middle (N=10)		Low (N=11)	
	M	*SD*	*M*	*SD*	*M*	*SD*
I performed well on this assignment.	3.5	0.55	2.8	0.92	2.7	1.06

N=27

Interests in Learning Science with the Web-LE

In the section about their interests, students expressed interest in using similar software in the classroom in the future. How interest impacted their learning performance is illustrated in the correlation analysis section. Students pointed out that using interactive software indeed enhanced their motivation to learn about fossilization, and they hoped the teacher would use similar tools in the future. The results of interest related items are provided in Table 5.4. The third item, "My motivation to learn fossilization is greater than my motivation to learn most other units," confused some students in that they were not sure whether to rate their motivation to learn fossilization in general or with the software. Students mentioned this confusion to the researcher during their interviews.

Table 5.4

Means and Standard Deviations of Student Interests in the Fossilization Web-LE

Item	M	SD
I like science more than other subjects.	3.11	0.97
Using software like this fossilization program to learn science is exciting.	3.44	0.80
My motivation to learn fossilization is greater than my motivation to learn most other units.	3.41	0.93
I hope teachers will use more software like this in my classroom.	3.67	0.92

N=27

Fossilization Web-LE Evaluation

Table 5.5 lists results of student evaluations of using Fossilization Web-LE. Most students gave high ratings. They pointed out that the tool was easy to operate (M=4.15), that they easily found the functions they needed (M=4.26), that they could easily check the scenarios (paths) they had completed (M=3.78), and that the screen design was appealing (M=4.15). They also expressed agreement that through the process of using the tool to finish assignment, their knowledge of the different conditions for fossilization was enhanced (M=4.07).

Table 5.5

Means and Standard Deviations of Student Evaluations of the Web-LE

Item	*M*	*SD*
This software was easy to use.	4.15	0.66
Finding the button on the screen I wanted to press was easy.	4.26	0.71
Figuring out the path I already completed was easy.	3.78	1.09
The screen design was appealing.	4.15	0.53
I understand the different conditions of fossilization after using the software.	4.07	0.55
I think the fossilization software is helpful to learn about fossilization.	4.07	0.62
Using software like this is a good way of using our laptops.	4.11	0.64

N=27

These students had been using laptops in the classroom for over two years and had experienced different learning activities with computers in different subjects. The novelty of using technology should not have been a factor influencing their answers in this section. However, all students pointed out in their interviews that they had never used interactive software like the Web-LE in the classroom before. Therefore, the novelty of using this type of interactive multimedia and the autonomy they enjoyed while doing the assignment might have had a positive impact on their answers.

Correlation analysis

The information obtained from the correlation analysis includes the following: 1) performance positively correlates with past performance in the class, interest in science, confidence in their performance, perceptions of how much they learned from the tool, and the belief that this tool was a good use of their laptops; 2) time spent on the assignment correlates with satisfaction with the information they received and the belief that the tool was helpful; 3) motivation to learn fossilization with the tool correlates with the sense of being able to control the learning process; 4) excitement of using the tool correlates with expectation of using similar tools in the future; and 4) correlations among evaluation factors indicate that their attitudes about the tool are consistent. Correlations discovered in the motivation questionnaire data are presented in Table 5.6. P<.05 was interpreted as moderate relationship and p<.01 was interpreted as strong relationship.

Table 5.6 Correlation Analysis Matrix of Motivation Questionnaire

Correlations

	Performance	Grade	Helpful for doing assignment	Performed well	Satisfied with quality of info	Spent more time	Like science/program to learn more	Using program to learn is exciting	Motivation is greater	Hope use more software	Easy to use	Finding button was easy	Easy find completed path	Screen design appealing	Understand condition	Software is helpful	Good way of using laptop
Gender	-.135	.345	-.197	.380	.242	.192	*.430	-.079	.138	.309	.122	.279	.131	-.273	.280	.127	.183
Performance		**.550	.159	-.310	.142	-.071	-.379	-.084	-.317	.348	-.055	.048	.050	-.008	-.122	.129	-.195
Grade			.000	*.467	.038	.161	*.484	.061	.331	-.238	.222	.143	.270	.251	*.478	.157	*.420
Helpful for doing assignment				.122	**.613	*.424	-.134	.173	.090	.186	.217	.122	.240	.269	.197	.295	.025
Performed well					.348	.288	.096	.312	.265	.243	.210	.148	.058	.102	**.574	.005	*.420
Satisfied with quality of info						*.394	-.102	.222	*.387	.304	.154	.183	.360	.071	.387	.342	.244
Spent more time							.129	.209	.075	.364	.337	.254	.192	-.082	-.025	-.091	.065
Like science more								-.066	-.009	-.129	.033	-.209	.133	-.107	.200	-.078	.041
Using program to learn is exciting									.212	**.574	.089	-.142	-.059	.110	.097	-.069	.350
Motivation is greater										.075	*.460	.357	**.664	.184	.089	.214	.308
Hope use more software											.210	-.098	.077	.104	.127	.045	*.392
Easy to use												*.486	**.582	.153	.286	.161	.322
Finding button was easy													*.425	.097	.244	.218	.019
Easy find completed path														.304	.093	.063	.343
Screen design appealing															.355	.199	*.400
Understand conditions																*.438	**.522
Software is helpful																	-.022

Note. *p<.05; **p<.01.

Learning achievement

1. A positive correlation was observed between the grade (learning achievement) and following factors: past performance in the class ($r=-.55$, $p<.01$), confidence in performance on the assignment ($r=.47$, $p<.05$), interest in science ($r=.48$, $p<.05$), self-evaluation of knowledge obtained (understanding different conditions for fossilization after using the tool, $r=.47$, $p<.05$), and belief that the tool was a good laptop activity ($r=.42$, $p<.05$).

2. Student interest in science differed by gender. Male students expressed higher interest in science ($r=.43$, $p<.05$) than females. In this assignment, there were no significant differences between male and female performance ($t=-1.84$, $p=0.97$).

3. Students who performed well in this assignment tended to have high past performance in the class, to have confidence in their performance on the assignment, to believe that they understood the topic of fossilization more after using the tool, and to think the tool was a good laptop activity.

4. The results indicate that higher cognitive engagement with the tool led to better learning performance.

Interest

1. The belief that the tool was helpful correlates positively with following factors: satisfaction with the quality of the information ($r=.61$, $p<.01$) and time spent on the assignment ($r=.42$, $p<.05$).

2. Students who believed that the tool was helpful for doing the assignment were more satisfied with the quality of the information they received from the tool.

They were also willing to spend more time on this assignment than other assignments in the science class. Such a correlation suggests that students knew the more time they spent with the tool, the more helpful information they received from it. One explanation is that the assignment questions were ordered from easiest to most difficult; success with earlier questions may have encouraged students to continue to invest energy to figure out the more difficult problems (Csikszentmihalyi, 1985; Malone and Lepper, 1983).

3. Correlation was also observed between the motivation to learn about and the following factors: satisfaction with the quality of information they received ($r=.387$, $p<.05$), how easy the tool was easy to use ($r=.460$, $p<.05$), and how easy it was to find the paths they had completed ($r=.664$, $p<.01$).

4. Students who expressed greater motivation to learn fossilization than to learn most other units tended to be more satisfied with the quality of information they received from the tool and to indicate that the tool was easy to use and that the paths they had completed were easy to find. These results correspond with the theory suggested by Lepper and Malone (1983) that promoting a sense of control in computer-based instructional environments should enhance learner motivation.

5. Strong correlation exists between the excitement of using the software and the desire to use more similar software like Fossilization Web-LE in the science classroom ($r=.574$, $p<.01$). Moderate correlation was observed between the desire to use similar software in the science classroom and the belief that the tool was a good way to use their laptops ($r=.392$, $p<.05$).

6.   In their interviews, most students pointed out that using Fossilization Web-LE

was a new experience for them even though they had been using laptops for

over two years. Students who showed excitement while using the software

tended to hope the teacher would use similar software in the science classroom

in the future. Novelty and curiosity of using a new tool might have influenced

their desire to use similar software in the future.

Evaluation

1.   Correlation was observed between the tool's ease of use and the following

factors: finding the right button was easy and finding completed paths was

easy ($r=.582$, $p<.01$). Additional correlations exist between the identification of

the tool as a good way to use their laptops and the assessment of the screen

design as appealing ($r=.400$, $p<.05$).

2.   Positive correlations were observed between the understanding of different

conditions for fossilization and the following factors: belief that the software

was helpful ($r=.438$, $p<.05$) and belief that the tool was a good way to use their

laptops ($r=.522$, $p<.01$).

3.   Their evaluation of the tool suggests that the students did not encounter severe

problems while using Fossilization Web-LE.

Observational Protocol

In order to characterize the learning process during the three class periods, an

observational protocol was designed for this study to look for patterns or indicators that

could not be discovered through the interviews and the motivation questionnaire. The

observational protocol is presented in Appendix E.

The observational protocol included the following criteria:

1. Curiosity and enthusiasm while using the tool: In addition to watching animations, students were required to click on "view," "keywords," and "online encyclopedia" to explore explanatory data. I interpreted the frequency of using these buttons as enthusiasm for retrieving in-depth information.

2. Concentrated interaction with the tool: I documented how students interacted with the contents of the tool. They had to use the movie control buttons to watch the animations repeatedly and the "My path" button to check all the paths they had completed. I observed whether the students watched each movie from beginning to end, viewed the same movie more than once, and checked all scenarios they had explored.

3. Signs of attention and time spent on the tool: I documented peripheral events, including conversations among students about the tool and whether they were distracted by other activities.

Setting the observational context

I conducted the observation with another designer of this tool. Twelve students from two classes were selected as the focus students to be observed. To minimize their awareness of being observed, I designed nametags for all the students in the classroom and told them to find their seats by the nametags. Six focus students at a time were grouped together in this manner to facilitate the observations. Students with similar past performance in the class were grouped together. They were seated in pairs according to their ability level. The teacher informed students that their seats were randomly assigned. During the three class periods, we were non-participating observers. We stood in the rear

of the classroom to document the learning process. Students were familiar with us since they had frequently seen me in the classroom during the past year.

The first day in the second class, two students I had intended to observe were absent, and another student in the observation did not bring her laptop. In the rest of the sessions, students were present and had their laptops with them. When they turned in their assignments on the last day, several students had not answered all the questions. The reason was that they saw the following statement in question 14: "Here is where you can really shine and earn some extra credit". Some students thought they did not have to answer question 14 unless they needed extra scores.

General learning process

The fossilization unit was a three-day lesson. For the first class, I had already installed the necessary software onto each student's laptop the day before. Therefore, no technology problems occurred there. In the second classroom, I had to take an additional fifteen minutes on the first day to install the software onto the students' laptops. The teacher spent about five minutes distributing the assignment and explaining procedures. Subsequently, the students used the tool to do assignment until the end of third period. The fossilization unit lasted three hours, and the teacher did not interrupt the students' usage of the tool. When students had problems with the assignment or the tool, he would provide them with further information individually. The teacher also reminded students how much time they had left before turning in the assignment. The students could also work on the assignment at home if they wished.

Students used the tool in several ways to finish assignment. One type of student would spend a few minutes examining the assignment first and then spend time exploring the

tool. By contrast, another type of student would figure out how to use the tool before

examining questions on the assignment. A third type of student explored both the

assignment and the tool simultaneously. This last type tended to do the assignment items

in the order presented in the assignment sheet by searching for information in the

Web-LE.

On the first day, most students did not spend too much time on the assignment. They

were curious about the scenarios included in the tool and wanted to examine as many

animations as they could and watch the different results of each scenario. Students

explored about six to ten scenarios during the first class period. Students could also work

on the assignment at home; therefore, on the second day, some students had already made

good progress on the assignment. On the second day, they did not spend as much time

exploring the tool as on the first day, but instead they focused on information in the

encyclopedia, keywords, and movie captions to find correct answers. On the last day,

students spent most of the time writing answers for the assignment. When they needed to

write something down they were not sure about, most students knew where to access the

information they needed in the tool. The encyclopedia was the most frequently used

component on the last day.

Observational Findings

Important findings from the observations made during the three class periods are

presented in the following section.

    1.   Autonomy of controlling learning progress

Autonomy in the classroom was given to students by the teacher, who played the role of

facilitator. Students could make decisions about how to use the tool, how much time to

spend on the assignment, whether they needed to find extra information on the Internet, the learning sequence, and strategies for finding solutions to finish the assignment. The teacher did not provide students with any instruction or strategies after the brief introduction. In this situation, most students appeared to remain strongly focused on the assignment. Having control over the learning process seemed to give students a sense of responsibility in finishing the assignment. Each student concentrated on his or her own tasks and gradually figured out ways to use the Web-LE to finish the assignment.

2. Curiosity

Not all the functions in Fossilization Web-LE were necessary to finish the assignment. Some functions were designed to arouse student curiosity or to provide further information beyond the scope of the assignment. For example, there is a little game playing in the opening screen after the software is launched. Students who noticed the game spent a few minutes playing it.

Students had to input their names before entering the tool, and all students put correct names into the system. The system recorded student input and displayed their name. This was a motivational embellishment used to personalize the learning context and to enhance student motivation (Cordova, & Lepper, 1996).

Students all used the "view" function to examine keywords even though it was not necessary to do so. Some keywords were displayed with interactive animations. Once students found one interactive animation, they usually examined more keywords to see more interactive animations. A similar phenomenon occurred when students used the mouse to click on objects on the screen. Once students examined these keywords or objects, they rarely viewed them again if they realized that the information was not

necessary to finish assignment. The motivation to use these functions seemed to be a desire to play rather than to learn.

Students spent a lot of time using the encyclopedia. Not only did it provide extensive explanations and information for doing assignment, but it also included several interactive activities.

3. Indications of cognitive engagement

Several functions of the Web-LE provided students with chances to examine scenarios based on their own learning progress. They could use the movie control buttons to pause and rewind animations if they missed anything. Students could skip animations and jump to the explanations section without spending time watching animations repetitively. However, some information was hidden in the movie captions, and some conclusions required observing several animations more than once. Therefore, I regarded watching each movie from beginning to the end and reviewing the same movie repeatedly as indicators of cognitive engagement. All students used the movie control functions to examine the same movie more than once on the first two days. During the last session, students spent little time reviewing the movies, but instead they concentrated on writing answers for the assignment or fixing errors in their earlier responses.

4. Concentration and dealing with difficulties

Students displayed great concentration while using the tool. For example, they rarely conversed with their peers during the three class periods. All students who were the focus of my observations paid attention to the assignment most of the time. The assignment questions included both easy and difficult levels, but students demonstrated concentration

even when dealing with difficult questions. Two students even found three typographical errors in the Web-LE and informed the teacher about them.

5.   Enthusiasm of retrieving in-depth data

The Fossilization Web-LE has four major sections. First is the interactive activity that helps students make combinations of various conditions and then access different scenarios; second is the introductory information about organisms, environments, and other objects; third are the descriptive animations illustrating the process of fossilization under different conditions; and the fourth section is the informative encyclopedia. Indicators of enthusiasm for retrieving in-depth data included using the encyclopedia frequently, clicking objects and keywords on the screen to examine explanations, and reviewing explanations of each animation. These actions occurred frequently during the first two sessions. In the last session, the function that students most frequently used was the encyclopedia.

6.   Use extra resources to do assignment

According to the teacher, if the Web-LE was used correctly, there would be no need to search for outside information to do the assignment. Most students used only the Web-LE to find solutions. On the last day, three students had difficulty finishing assignment, and they spent about thirty minutes searching for information on the Internet. Google.com was the search engine they used most frequently. One student gave up on searching the Internet and went back to the tool; the other two students printed out information from a Web site about fossils and tried to synthesize answers using it. One student also went to the Web page about the Montana dinosaur field trip that had been created by the teacher. No other materials were used during the three-day session. In their interviews, students

revealed that the software was the only source they used at home while doing the assignment.

7. Attention and distractions

Attention is an observable indicator of engagement with a task (Lee & Brophy, 1996). I documented any event that distracted student attention during the learning process. All students demonstrated a high level of attention on the assignment. The teacher did not have to use any strategies to manage the classroom because they were focused on the task. During the three sessions, conversations rarely occurred. Two students shared knowledge with each other about how to use the movie control buttons for approximately three minutes on the first day; one student took five minutes on the first day to examine the HTML script of Fossilization Web-LE. He was apparently interested in web design, and he knew how to access the source code of the Web site. On the second day, while waiting for the software to launch, one student checked her e-mail for two minutes. She went back to the tool immediately after it was ready to use.

Most students' laptops were capable of loading the software smoothly without freezing up; only one student had a problem with her laptop. Her laptop was extremely slow, and she had to wait several minutes for a complete animation to load while others could access the animation in a few seconds. She told me that her laptop also froze up at home. She checked her e-mail while waiting for the animation to load, which interfered with her learning progress. However, she was the only student who almost earned a full score on this assignment (38 out of 40). The teacher revealed that she was a consistently high performance student, always taking things seriously and turning assignments in on time.

Although technology problems caused a distraction for her, she was still able to maintain her high performance.

8. Technology infrastructure

Although the teacher told students to bring their laptops for the fossilization unit, a few of them forgot them on the first day. Some students did have their laptops, but they had not brought the wireless Internet card or the CD-ROM drive with them. For those who brought laptops to the classroom, I had to spend about fifteen minutes helping install the software on their laptops. If they had not brought a wireless Internet card or CD-ROM, they were unable to use the software on the first day. Six students out of twenty-seven were not able to use the software during the first session.

9. Interface design flaw

Observation revealed one interface design flaw that was not mentioned on surveys or in interviews. The encyclopedia was an important section for doing the assignment, but half of the students could not access to encyclopedia on the first day. They were unable to find the best way to connect to the encyclopedia and had to ask the teacher how to access it. Another significant design flaw was also mentioned in the student interviews. The sequence for selecting conditions for fossilization is to select an organism, an environment, and then the biological conditions. Students asserted that they could not go back to a previous selection if they had made a mistake. I fixed the problem one week after the study. When the teacher implemented the tool to the ninth graders two weeks later, they used the latest version to do their assignment.

The reason that this flaw was not revealed in the pilot study was because the prototype we used to conduct pilot study only included four scenarios. It was not as complex as the

final product including eighteen scenarios; therefore, the flaw was obvious when students had to explore all eighteen scenarios.

10. Other events

The teacher asked our team to design a summary page to collect the results of all eighteen possible scenarios so that students could compare all the conditions for fossilization. Not all students used the summary page to do the assignment, and some of them did not even notice this page. However, the teacher regarded the summary page as the most helpful function of the tool and included one question about the summary page in the assignment. Seventy five percent of the students choose a different function as the most useful component of Fossilization Web-LE.

My observations indicated that most students were not able to figure out all the functions in this tool. For instance, the movie control buttons allow students to fast-forward, rewind, pause, or skip animations. Not all students learned how to master these functions that would have saved time in working on the assignment.

Student Interviews

Twelve student interviews were conducted within one week after finishing the assignment and before they saw their grades. The student interview protocol is presented in Appendix D.

Elaboration of themes discussed in student interviews.

1. Past experience using interactive software in the classroom

Only one student reported having experience using interactive software at home. All other students reported that they had no experience using similar software in the classroom or at home. Therefore, using the Fossilization Web-LE in the classroom was a

brand new experience for these students even though they had been using laptops for over two years in the school. Students pointed out that Microsoft Word, PowerPoint, and Excel were most frequently used applications in the classroom, and that some teachers would use Web sites as additional instructional materials. However, these Web sites were primarily text-based, including some images and pictures as well as links to other sites. These Web sites were not interactive learning environments in the sense that the Fossilization Web-LE has been designed to be.

The one student who had used interactive software at home described differences between the software developed by commercial companies and the Fossilization Web-LE that we customized for the teacher:

> "*The software at home has better graphics; it's more of a game, but I probably did not learn as much as I did with this software (Fossilization Web-LE).*"

The Fossilization Web-LE was customized for this teacher to solve specific instructional problems. As a result, this tool differs from other commercial software that is not designed specifically to address an instructional problem.

As described earlier, the teacher designed unique assessment strategies to evaluate student performance and required students to use the tool. Students pointed out that assessment of this unit was different from others. Usually the teacher gave his students questions, quizzes, and tests to study for. The teacher tried to design the most appropriate assessment for this Web-LE. This teacher had decided not to use commercial software in the classroom, because none of it was designed to address his problems and context. Furthermore, the unique tasks on the assignment required students to engage with the tool

in a very specific way; commercial software did not offer the functions to help these students explore fossilization according to the teacher's plan.

2.   Initial impressions of the Fossilization Web-LE

Common words used to describe their initial impression of the tool included "interesting," "helpful," "easy to use," "cool," "fun," and "provided lots of information." They pointed out that the visualization of the tool was unique and that they had never had this kind of learning experience before.

A few students liked the opening game of searching for a skeleton. Others said that they were just fond of dinosaurs. As for the interface operation, two students mentioned that in the beginning, it was a little difficult to manage but that once they had gone through a scenario, it was easier.

One student stated that she was impressed by how my team designed the software from scratch. She was interested in the development process and expressed admiration and appreciation for our team.

3.   Patterns of using the Fossilization Web-LE to do the assignment

Students spent three to eight hours working on this assignment (including three hours of class time). High ability students and students who had higher scores tended to spend more hours working at home. Three to eight hours amounted to less time than they usually spent on assignments for other units. A few students thought the assignment was not too difficult since the software provided most of the information they needed. However, other students said that they hoped to receive one or two more days to finish this assignment. Most students said that they went through the entire assignment first and then went back to use the tool and start answering questions.

Some of the answers were difficult to find directly in the tool; critical thinking was required to figure out those problems. For example, there was one question that required students to go through each scenario and compare all the animations to figure out the answer. To answer this question, some students did use the summary page, which was identified as the most useful function by the teacher; however, the summary page did not include any explanation except in the form of pictures.

4. Satisfaction of the information in the tool

Most students mentioned that they were satisfied with the contents in the tool and the there was no need to seek outside information to answer the questions. When asked what they learned in this unit, the majority of students indicated that their misconceptions were corrected. For example, they told me that before using the tool, they would not have selected ashfall as the best conditions for fossils to develop. The students said that they would have selected swamp or mud instead of ashfall. Not surprisingly, the students who had higher scores were able to recall more information that they learned from the tool than the students with lower scores.

5. Motivation and interest in using Fossilization Web-LE

Half of the students interviewed believed that because they were visual learners, and they said that they would have a higher interest in learning with this kind of software than learning in the traditional classroom. Video, animation, and sound effects were major components that made students feel excited.

Ten students indicated that when learning without the software, they did not like the fossilization unit as much as the other units. Learning with the software appeared to enhance their motivation to learn about fossilization because this software enabled

students to visualize the process and was more fun than listening to a lecture or reading the textbook. Three representative statements follow:

> "*You got to see like actually how it happened, it wasn't just told you. It's hard to really understand if just somebody's telling you how a fossil is formed. It's hard to understand like what it looks like or what happens really. There are a lot of memorization, so you have to see it to really understand it. To visualize those conditions help us memorize things easier.*"
>
> "*I liked this one probably more than like any others we've done, just 'cause it's got like a bunch of different things going with it; it's not just like a web site, with like definition and like stuff like. It has videos, and like explanations and stuff, so it's pretty – I mean I like it. It was motivating I guess.*"
>
> "*I think it's a lot easier, cause I mean it's a lot more boring to actually read from a book and learn all this stuff, so with this you get like the animations, and it's a lot easier just to recognize. I'm more of a visual learner, so it's a lot easier for me.*"

Based on my observations, I estimate that the sense of controlling their own learning process also enhanced their motivation for many of the students. If they had difficulties with something, they could decide to observe the animation over and over again.

High ability students pointed out that learning with the software was easier because it included all information they needed; in the traditional classroom, students needed to search for information based on what teachers gave them. They tended to believe that

learning with this kind of software provides a faster way to retrieve information, and they could do it by themselves.

A few students who had always liked science pointed out that it did not matter whether they learned science with software or in the traditional classroom. Two students preferred learning in the traditional classroom than with the Web-LE. They said that, with the teacher, they could ask more questions and interact more easily. They thought the teacher was necessary in the process of learning.   One of these two students pointed out that she preferred learning with lectures and hands-on activities; she disliked using a laptop because of its technical problems.

6.   Expectation of using similar interactive software in the classroom

Ten of the twelve students expressed a strong desire to use similar software in this class or in other classes. They asserted that History, English, and Science could be better if teachers adopted similar software because there is too much memorization required in these subjects. They believed visualizing objects and concepts could help them learn and understand better. All students indicated that using the software to learn fossilization was a great way to use their laptops.

7.   Most helpful component in this tool

Instead of choosing the summary page as the most helpful component, students identified that animation, captions, and the encyclopedia were the most useful parts of the tool. Although all of them agreed that the encyclopedia included lots of useful content, not all of them looked through it once they had found enough information to do assignment. One student described how animation was helpful for doing assignment:

"Just 'cause I'm more a visual learner, so seeing the stuff helps me understand more; I mean, even if you're not a visual learner, you *can still read everything that goes along with it, so it's just kind of like the total package."*

8.   Tool evaluation and suggestions

The overall impression of students was that the Fossilization Web-LE was useful for developing better knowledge about the topic of fossilization. They identified two problems with the interface design: a "go back" button is needed, and accessing to the encyclopedia should be easier. Some students suggested adding some fun games into the tool. As for the learning process, they hoped next time the teacher would give some instruction about the topic and more time to do the assignment.

Teacher Interview

The teacher interview was conducted after the student interviews. I shared the initial data analysis results with the teacher, and exchanged impressions and opinions about the implementation, and then we reflected about the development research process. The teacher interview protocol is listed in Appendix G.

Elaboration of themes discussed in teacher interviews.

1.   The degree to solve instructional problems

When designing Fossilization Web-LE, the teacher expected the tool to solve his instructional problems and help students understand concepts of fossilization better. These concepts included fossils formation and the ideal conditions for fossil development. The teacher also wanted students to be able to compare actual physical scenarios and determine the most efficient scenarios for producing fossils. He expected the tool would save energy spent searching for appropriate instructional materials that could show

students the fossilization process, and he pointed out the tool indeed provided students with the opportunity to visualize the process of fossilization:

> *"In a classroom we couldn't duplicate that any other way better. We could show a movie that somebody had made of it, which is what you can build on a computer, really, is animation, but there is no other way to do it in a classroom."*

There was no appropriate animation or movie on the market that met his criteria for showing students all the possible scenarios for developing fossils. Therefore, the Fossilization Web-LE included eighteen scenarios and provided him the best way to demonstrate for students the impact of various conditions on fossilization.

2.   Observation of student motivation

The teacher was impressed by the degree of student attention to the tool. From his perspective, the software and its implementation was brand new to these students; it allowed students to manipulate their own learning progress, and the students were highly interested in using the software. As a result, he concluded that the Fossilization Web-LE a good tool for computer age students. He confirmed that student motivation to learn about fossilization was improved with software. However, he also believed the novelty of technology was part of the reason that students put so much attention on it and that the novelty would wear off quickly.

3.   Evaluation of student achievement

There was a discrepancy between student performance and the teacher's expectations. Three questions out of fourteen confused students when they did the assignment. For question three, the teacher expected students to write down conditions instead of scenarios for answers. In question nine, the teacher asked students to identify

the most helpful component of the tool. Most students chose animation and the encyclopedia instead of the summary page, which was regarded as the most helpful tool by the teacher. This was a more subjective question, and seventy-five percent of the students disagreed with the teacher. In question fourteen, the teacher put down the following sentence at the end of the question: "Here is where you can really shine and earn some extra credit." A lot of students did not do this one because they thought this question was designed for earning extra points. The teacher was aware of how these questions were worded, and his interpretation was "they did not read the question correctly or did not read directions thoroughly." He also admitted that although the tool worked, the nature of the assignment questions influenced the average performance:

> *"Overall, the tool works. The bulk of the questions, more than seventy-five percent of the questions, were answered at least fifty-percent correct, mostly seventy-five percent correct by all the class. These three biggies [questions] there would kick their scores down, and especially that one [point the last question], when they didn't do it."*

The teacher interpreted this phenomenon as a sign that students did not carefully examine the question. He stated that he will do an academic introduction of the unit before asking students to use the software in the future. This will help to clarify interpretations of the questions.

In addition, the teacher had his own ideas for evaluating the tool. He insisted on having students finish the assignment without any instruction except the brief general explanation about operating the software. He acknowledged that these parameters help explain the lower student performance. He believes that the way he introduces the tool

will enhance student performance in the future if he make academic introduction to the students before using the tool:

> *"It works because…under no or very little introduction, they could perform like this… I'm satisfied to the degree for the purpose that we introduced it, and used it, they did ok. …I'll expect the grades to be significantly higher, when I do that [preliminary work-up with the students], but I have great confidence in the tool itself to do what I want to do [in the future]."*

4. Continued use of the tool in the classroom

Based on the preliminary findings, the teacher decided to continue using the tool in his science classroom. He will implement the tool for both tenth graders and ninth graders. In his opinion, to use the tool in the classroom more accurately in the future, some changes should be made. In the beginning of the unit, the teacher will introduce the subject of fossilization, explain important concepts (e.g. sedimentation process, conditions for fossilization), and explain the importance of the summary page in this tool as well as how to operate the tool to eliminate the difficulties he observed in the study. More time will be given to finish the assignment. The teacher expects that student performance will rise as a result.

5. Tool evaluation and suggestions

The teacher's observations described how students engaged with the tool and how effective the interface of the tool was for students to use:

> *"Soon after they asked few a questions about how to get from one place to another, they were pretty well able to take it themselves; they didn't need us [to show them how to use the tool]."*

However, three suggestions were made to improve the interface after the implementation, and those suggestions correspond with student interviews and observational data. There should be buttons on the main screen for students to access to summary page more easily. Changing the position of the online encyclopedia button on the main interface as well as minimizing the time required to access the online encyclopedia will improve the tool. The last suggestion was to add a "go back" function for each fossilization condition.

6. Desire to expand the tool

To maximize the learning effect, the teacher hopes to expand the tool. The first thing would be to increase the content. At this point, the tool includes only one large organism (a dinosaur); the teacher would like to add some smaller or less mobile organisms such as fish, birds and snakes to make comparisons with dinosaurs. In addition to the organisms, he also wants to add more environments to the tool; so far the tool includes three environments (tropical mountain, rainforest, and flood), and ideally, the tool should have twelve environments. The online encyclopedia needs to be expanded. For example, more animations and more keywords would also be helpful. The second thing would be to add some learning activities or interactive games relating to the topics of fossilization.

7. Cause other instructional problems

Based on the teacher's observation of the implementation and on the evaluation of student performance, there was one instructional problem associated with the tool. He pointed out that the speed of the animation and the texts that go with it were a little mismatched. This is a technical problem, because the time length of each scenario is

limited and only keywords or simple sentences can fit into the timeline. To eliminate the inconvenience the problem causes, students can use the movie control button to pause or rewind movie in order to catch up with the captions. But as noted earlier, most students failed to use these functions.

8. Suggestions to a teacher who wants to design similar software

This teacher was involved in the development research process for almost two years, and thus he gained lots of experience with the multimedia software design process. The demands of his time were significant to him as certain phases of this project. He had some suggestions to teachers who are interested in designing similar software:

1) Keep the software simple, and do not try to do lots of fancy stuff with it. Most students respond to clear and simple choices. Complex procedures could wear down their motivation and negatively influence learning procedures.

2) Be aware of data accuracy. Do not include wrong or contradictory information.

3) Know how you will assess your students before jumping into the design process. The teacher needs to know how to evaluate student performance when they use the tool; after developing strategies of evaluation, you can design the contents to answer those questions exactly.

4) Integrate different levels of difficulty to make the tool more flexible. That way, you can evaluate both high and low ability student performance, and even use the tool for different grade levels.

9. General opinions of the development process

The teacher expressed his thoughts about the whole development process, both during the interview and during the process itself. He pointed out that the process of developing this kind of software was very time-consuming and a slow process and also mentioned how he evaluated the benefit of the tool:

> "*Nobody should start unless they're willing to dedicate a whole lot time to do it. The question will always be "are the results worth the time and the energy required to make the tool?" At this point, I don't know. I think ultimately if it enables us to get the most difficult concepts better learned, than it probably is. But think of the hours involved so far.*"

The teacher knows that we had limited resources for developing the software and agreed that the process could be much faster if more personnel and money were allocated. The bottom line is that the teacher learned a lot from the process:

> "*If somebody were gonna try and do this, and they sat down with us, we could save them a lot of problems. And if I did it myself again, or even add things to the tool, there are a lot things that now we have learned that we could take advantage of.*"

The teacher also described the overall impression and evaluation of the project:

> "*If I had to say how satisfied am I on a scale from one to ten of what we have? I'd give two answers. Satisfaction as to how the tool works? Ninety five percent. Satisfaction as to the levels of learning that it challenges and the efficiency with which it does? I'd say probably seventy percent right now.*"

He explained that the major factor in the tool's low efficiency was the way he introduced the software. He intends to carry out a more careful introduction in the future.

Chapter Summary

This chapter reported the results of quantitative and qualitative data. The motivational questionnaire data was collected right after students finished the assignment to establish baseline information regarding all students who used Fossilization Web-LE. The qualitative data was used to measure their attitude about quality and quantity of information received from using the tool, interest, and overall evaluation of the tool. Observational data were collected during the three class periods to record student curiosity and enthusiasm while using the tool, concentration while interacting with the tool, and indicators of attention and time spent on the tool. Twelve students who were the focus of the observations as well as the teacher were interviewed to collect in-depth information about the impact of the tool on their learning performance and motivation. In Chapter 6, interpretation of the findings reported in this chapter are presented. Chapter 6 also includes a summary of this study, with recommendations for researchers who desire to conduct similar studies.

Chapter 6

Summary, Discussion, and Further Plans

Introduction

As detailed in the earlier chapters, this development research project (van den Akker, 1999) has been carried out to address the instructional problems of local teacher while at the same time deriving generalizable principles concerning the design and implementation of Web-based learning environments used as cognitive tools. This last chapter includes a summary of the results of the study as well as an in-depth discussion of the implications of the study. This chapter concludes with recommendations for future research.

Summary of the Study

Three years of working on the laptop evaluation project (Hill, Reeves, Grant, & Wang, 2001; Hill, Reeves, Grant, Wang, & Han, 2002) have provided me numerous chances to observe how teachers in different subjects and across different grade levels use laptops in their classrooms. The primary goal of our four-year evaluation is to evaluate the impact of laptops on teaching and learning. This project provided me extensive experience with helping teachers to integrate technology into a K-12 learning environment, and it enabled me to investigate potential ways to work with teachers to improve current instructional problems through computer technology.

Within the context of the large-scale laptop evaluation project, a tenth grade science teacher expressed his instructional problems: low student interest in learning scientific

processes such as "change over time" and low student performance in specific units related to earth science. After evaluating his problems and clarifying potential solutions, a cognitive tools study group that had been formed earlier by two professors and several graduate students, decided to work with this teacher to see if we could develop cognitive tools that would help solve his problems. I was a founding member of this group, and developed the study group's Web site. One of the first things we did was to analyze the teacher's instructional units to determine which one presented significant learning difficulties for the teacher's students and at the same time appeared to be susceptible to the application of cognitive tools. We decided to focus on the topic of fossilization.

This was also the point at which I decided to adopt this project as the focus for my doctoral dissertation research. The project seemed to fall within the category of development research goals described by Reeves (2000), a type of research that my advisor had encouraged me to pursue. The purpose of development research is twofold: to focus on developing approaches to improving situation-specific teaching and learning problems and to generate methodological directions for design and evaluation for future development and implementation efforts.

Five stages were conducted for this development research: (1) The team analyzed instructional problems and considered potential solutions through computer technology, (2) I chose and applied an appropriate motivational theory to the instructional design process and with the help of others, developed a prototype Web-LE, (3) I conducted a pilot study to test the usability of the program; (4) I implemented and tested the effectiveness of the solution, and (5) I documented the results of the tool implementation and reflected on the lessons that could be learned from the entire design process.

After two years of cooperative work with the teacher, the Fossilization Web-LE was "completed" and implemented in a classroom in January and February 2003 to investigate the impact of the tool on student learning performance and motivation. General guidelines for designing and implementing an interactive Web-LE are presented below in light of the finding that the data presented in Chapter 5 that the Fossilization Web-LE had indeed solved most of the teacher's instructional problems.

Twenty-seven tenth-grade students participated in this study, spending three class sessions using Fossilization Web-LE to finish cognitive tasks assigned by the teacher. Questionnaire data were collected at the end of the third session to investigate student motivation to use the tool. This motivation questionnaire allowed students to evaluate the tool and their attitudes toward using it. The students' grades were also collected and analyzed to determine their learning performance. Observation and interview data were collected during the sessions and after the three-day study was over.

The motivation questionnaire, observational protocol, interview questions were designed based on Newmann's identification (1992, p.13) of levels of engagement: (1) observable behavioral responses, (2) covert cognitive responses activated during learning, and (3) interest. I carried out statistical analyses and correlation analyses to examine factors that might have influenced student motivation and learning performance. Newmann's levels of engagement helped me scrutinize indicators of motivation that surfaced during the learning process. Student grades, student interviews, and the teacher interview were used to triangulate the data collected from the motivation questionnaire. The results show that students reaped moderate learning and strong motivational benefit through using Fossilization Web-LE. Several minor interface design flaws were found

during the implementation. These problems have since been fixed so that the teacher can use the revised program with future classes.

Discussion

Impact on student motivation

The most significant impact of the Fossilization Web-LE on student motivation was indicated by a rise in student interest. The teacher and I concurred that the students displayed greater interest in the fossilization unit than they had in other units related to earth science.

Alderman (1999) pointed out that making a task interesting is always a good strategy for enhancing student motivation (p. 205). In this study, the Fossilization Web-LE offered a new experience to students. Apparently, this tool successfully enhanced situational interest as suggested by several researchers (Bergin, 1999; Hidi, 1990; Hidi & Anderson, 1992). These researchers pointed out that situational interest is more important than personal interest in the classroom because the teacher can rarely impact a student's personal interests; more often, educators can only manipulate situational interest (Bergin, 1999).

The strategies for integrating intrinsic motivational factors into software design indeed appeared to increase student interests and engagement. Factors that made the Fossilization Web-LE more enjoyable for students while learning the unit of fossilization included: challenge, control, curiosity, and fantasy. To make a tool challenging requires a clear goal setting based on past student performance. If the challenge matches the skills of students, the flow status described by Csikszentmihalyi (1985) may occur and make students more involved with the assignment. Being in flow is described by

Csikszentmihalyi as being totally engaged in an experience such as learning. For the fossilization assignment, the teacher designed questions with different levels of difficulty and encouraged students to finish their tasks continuously. Although a high level of cognitive processing, requiring students to apply information or draw inferences to solve problems (Alderman, 1999, p.201) was necessary, students still tried hard to finish the assignment within the given time frame. The challenge level of this Web-LE can be judged as appropriate for most of this teacher's students, not too low and not too high.

The control factor refers to empowering students to take responsibility for managing their overall learning progress and direction. Many researchers have provided evidence to demonstrate how giving students a sense of control in their learning progress can enhance engagement (Lepper, 1985; Malone & Leper, 1987; Westrom & Shaban, 1992). In this study, a sense of complete control was given to the students. The teacher did not give any academic instruction before the unit; he only distributed the assignment to the students and set the deadline for turning it in. Students had to manage their time, develop strategies for exploring and analyzing information provided by the tool, synthesize rational conclusions, and select and record the most relevant information to demonstrate how much they had learned from the tool.

Giving students control meant that all of them were allowed to develop their own strategies for advancing their learning progress, and they were required to take responsibility for their academic performance. To maximize their control over their progress, several functions were provided in this tool: the movie control buttons; buttons for accessing the encyclopedia, keywords, and in-depth explanations; functions for monitoring learning progress; and interactive functions enabling students to combine

various conditions for fossilization. These functions and the actual cognitive assignment provided this teacher's students with an appropriate level of control. The control factor appears to be one of the features of this learning environment that enhanced motivation, but its effect on performance was not obvious.

Curiosity is peaked by unusual visual or auditory effects (Westrom & Shaban, 1992) and by presenting incomplete information or ideas that are new to the student (Pintrich & Schunk, 1996). Curiosity encourages students to pursue the unexplored parts of a unit. Therefore, one goal of the Fossilization Web-LE was to increase student desire to acquire as much information from the tool as possible. This tool presents eighteen fossilization scenarios using 3D animations and multimedia sound effects. After finishing one scenario, students were encouraged to explore continuously the rest of the scenarios to compare how different conditions affected the outcomes. Many, if not most, of the students did this, and so it can be concluded that the Web-LE encourages the student's curiosity.

Fantasy is defined as the opportunity to experience something that has no physical reality (Westrom & Shaban, 1992) or that cannot be observed in the real world. Fantasy was proposed by Malone and Lepper (1987) as an important factor in raising student interest. In this study, the Fossilization Web-LE provided students with a fantastical context for exploring conditions for fossilization that are impossible to observe in reality. Before using the tool, the only instructional materials related to fossilization that the teacher could use was the Disney movie *Dinosaur*. However, the film only partially presented to the students what the teacher wanted them to learn. The second strategy that the teacher employed in the past was to ask each student to draw pictures of one specific condition for fossilization. As a result, students still failed to visualize the whole process

of fossilization and only received knowledge about one specific condition. With the Fossilization Web-LE, students could observe fossilization in three different natural environments, each including six burial conditions, and then they could access eighteen realistic 3D animations to help them visualize the similarities and differences among all the scenarios. Most students identified that the fantastical animations provided in this tool as the function that made them feel most excited and interested.

All four factors for improving motivation, challenge, control, curiosity, and fantasy, were applied to the design of Fossilization Web-LE, and the tool had positive impact on student motivation as a result. Most students admitted that compared to other units, motivation toward learning fossilization was relatively lower without using the software; such statements reflected the teacher's statement of his instructional problems. Results collected from the motivation questionnaire and student interviews revealed an important message: student interest toward learning the topic of fossilization was higher when learning with the Fossilization Web-LE.

One of the interesting phenomena caused by the fantastical design of the tool occurred during the instruction. In this tool, some keywords are explained using interactive animations. Once students found one interactive animation, they were seemed eager to examine more keywords to see more interactive animations. Their curiosity was peaked by the visual aspects of the tool.

Some findings about motivation were also significant in influencing the learning outcomes. Student interest and confidence in their ability in science strongly correlated with their performance. For students who were defined as high ability or who had high interest in science, motivation to learn with software was nearly equivalent to their

motivation with traditional lecturing instruction. This is not surprising in that high ability students usually find a way to learn regardless of the pedagogy employed. However, the number of students with high ability or high interest in academic education is usually relatively smaller than the number of students with moderate or low ability and interest in any given classroom. It is interesting to note that the collaborating teacher concluded that the Web-LE had helped the lower end students to achieve beyond his expectations.

Impact on student performance

Students who had better past performance in the class tended to perform better in this unit. They also had relatively higher confidence in their performance on the assignment and believed that they had learned more from this tool. The impact of the Fossilization Web-LE on the learning performance of low performance students was higher than the impact it had on high or moderate ability students. Performance of low ability students was almost equivalent to that of the moderate ability students. Therefore, the results of this study suggest that the Fossilization Web-LE might improve the performance of students with low ability and/or limited interest in science.

In this study, the teacher chose to minimize his influence on the students' learning progress within this specific unit. Without academic instruction about fossilization, students had to explore the tool, investigate information, and analyze conclusions by themselves. Under these circumstances, it was expected that student performance would be lower than usual, and it was. When the students received their grades, the teacher asked them to fix their mistakes using the tool. During this follow-up activity, the teacher confirmed that the students could find accurate solutions this time with only slight difficulty.

Two weeks after implementing the tool in the tenth grade classroom, the teacher used it with ninth graders and reported that they performed better than the tenth graders. The teacher gave a short lecture to the students before they engaged with the tool, and he designed a different set of assessment questions. This process was not documented because the impact of the tool on tenth graders was the focus of this study. However, this follow-up event provided evidence that teacher continued to use Fossilization Web-LE in the classroom, and that he modified the implementation of the tool based on the earlier research.

Overall evaluation

This tool was not designed to improve student grades per se, but to solve the teacher's instructional problems: to help students understand difficult scientific concepts and motivate them to study science with more interest. This Web-LE had to meet the teacher's needs and also appeal to a range of student learning styles in this specific context. Although the contents of the tool need to be expanded (e.g., to include more organisms), the bottom line is that the tool was used successfully in a real life context. It met the teacher's needs, and he plans to use the tool in his classroom in future classes. Not only tenth graders but also ninth graders are capable of using the tool to learn about of fossilization. The students experienced a brand new laptop activity in the classroom after more than two years of using laptops in the school. The tool, the instructional process, and the assessment strategy were all new to these students. Furthermore, all the students in this study agreed that using the tool was a good way to use their laptops.

A question might be raised concerning the return-on-investment (ROI) of this type of development research. After all, both the teacher and the research team invested an

enormous amount of time and energy in designing and refining this Web-LE. Was it worth it? The teacher clearly thought so, and in fact, expressed some disappointment that the project could not continue so that additional materials could be developed. As for me, I am convinced that the lessons learned from this initiative will result in considerable time saved the next time this type of project is undertaken. In addition, given the demonstrated direct impact on the teacher's teaching and the students' learning, it appears to have been a good ROI.

Another issue that might be raised is the decentering of the teacher in this type of unit wherein students are given so much responsibility for their own learning. Although a rise in of motivation and improved learning performance were evident, the results do not in any way suggest that the teacher is unnecessary in the learning process. On the contrary, although the Fossilization Web-LE is a learner-centered instructional tool, the teacher played an important role in the development process and had important influence on their academic achievement. First, this tool was customized to fit the teacher's need to solve specific instructional problems. In the early stages of this project, his major role was to define problems. Second, the teacher was involved in the instructional design and content design process. Third, the teacher developed the assessment strategy to correspond with his understanding of his students' abilities, decided what information the tool should provide, and established the learning goals.

Implications

Guidelines for designing similar web-based learning environments

1. Interact with practitioners to determine solutions to instructional problems.

The teacher has an extremely important role in the development process and it is necessary to interact with him or her continually during the process. The teacher clarifies existing instructional problems. Researchers and designers also can obtain useful resources for identifying problems from the teacher, including course outlines, available instructional materials, past student performance, and homework assignments. The teacher is the expert practitioner who will actually implement the tool in a learning environment, evaluate the content, and decide to what degree the tool solves his or her instructional problems. To understand his or her expectations of the tool, to have a better sense about the instructional content, and to be more fully aware of the context, the development team should cooperate closely with the teacher throughout the development research process.

Constructing acceptable modes of communications with the subject expert is necessary. In the preliminary development phase of the study, the team met with the teacher once a week to show him how much progress we had made since the last meeting. In the later development phase, I met with the teacher twice a week to obtain his evaluative feedbacks about the tool. Frequent meetings enabled me to create a rapport with the teacher and also minimized any unease that students may felt about being investigated since they saw me on their campus quite often.

The major role of the researcher and designer is to consult with the teacher and to deliberate the pros and cons as well as the feasibility of available solutions through computer technology. Analyzing hardware and software requirements is also the responsibility of the researchers and designers. In this study, the teacher was not familiar with technology integration and had excessive expectations about the quality of the tool.

All the instructional materials he had previously used in the classroom had been developed by professional organizations or commercial companies. Therefore, he expected the quality of the animations in Fossilization Web-LE to compete with the Disney movie, *Dinosaur*. It is strongly recommended that the researcher and the designer (often the same person) present to the teacher some products that fall within the scope of team's design ability before development begins; that way, the teacher will have a better sense of what the tool will look like. Explaining the personnel, financial, and technological limitations of the project to the teacher is also important.

Even though the teacher may not understand multimedia design, involving the teacher in the iterative design process can facilitate production. For instance, the teacher can save invaluable development time by participating in frequent reviews focused on identifying mistakes or providing further direction immediately after observing the designers' prototype works.

2.   Know how the tool will be used before designing.

The researcher, designer and teacher should be aware that the tool is not going to be used in an artificial context. Therefore, how to implement the tool in the classroom and assess student performance should be decided upon before design and development begin. This is easier said than done, of course, and the best that can be hoped for is probably a rough implementation plan. Both the program and the implementation plan will evolve throughout the development phases. Presenting content via instructional technology is not a panacea to improve learning outcomes in and of itself; it has to be implemented at the right time, in the right place, to the right learners, with the right objectives, and aligned with right assessment. In-depth communications with the teacher to probe his/her

strategies for implementation and assessment before developing the tool is very important.

At the beginning of development phase of this study, the teacher explained how he intended to use the tool and measure learning performance. He designed several different sets of questions to measure student learning outcomes. Any tasks or questions suggested by the designer or researcher would not necessarily fit the teacher's needs. This may explain why so many otherwise excellent educational software programs have failed to be implemented in classrooms on a large scale (Cuban, 2001). The careful coordination of objectives, content, pedagogy, technological affordances, and assessment strategies requires the input of practitioners such as the teacher with whom I have carried out this development research project.

3.   Design tasks to encourage students to find conclusions based on available data.

In the unit of fossilization, one of the major cognitive goals that that students would learn to synthesize reasons to explain fossil formations under different conditions. This goal involved deductive and inductive reasoning that require critical thinking skills. Therefore, explanatory questions are better for encouraging students to think critically than to questions that require simple information recall. Tasks should also encourage students to investigate most of the available content before drawing conclusions. Moreover, the tool should provide functions that enable students to utilize interactive features to explore information in-depth and in multiple media. In this study, some of the higher order questions required students to compare several scenarios, find similarities and differences among them, draw conclusions, and investigate available information in the tool and the encyclopedia to provide evidence to support their answers.

4.   Focus design strategies on improving concept understanding instead of raising performance.

Many factors can influence a student's academic success in school, including intelligence, environment, aptitude, effort, parents, and teachers. Considering these factors, Pajares and Schunk (2002, p.3) made a sound assumption that self-confidence plays a significant role in their achievement. It is difficult for researchers and educators to change innate abilities or environmental factors outside of school, but we can design various instructional activities to increase student desire to engage with tasks. In this study, computer technology did not seem to significantly impact the learning performance of the students who already had a higher interest in science. They could perform well whether contents were delivered in a Web-based format or through paper-based materials because of their high intrinsic motivation. However, using software to prolong engagement of moderate or low ability students with the assignment may have improved their performance.

The teacher's expectation of the tool was to provide students with the opportunity to observe the concept of fossilization under various conditions that are difficult to replicate in the real world. If the tool successfully integrated elements such as challenge, control, curiosity, and fantasy, it may have improved students' self-efficacy and encouraged them to engage with the assignment. Therefore, more tools of this sort should be designed to help students understand difficult concepts and prolong their engagement in meaningful academic learning time.

Students must be given adequate time for the development of understanding of a new concept. In this study, students demonstrated strong concentration and engagement

while doing the assignments; however, some students did not have enough time to finish it. Students should always have enough time to explore the topic enough to become an expert on a level appropriate for their age and intellectual development (Mistler-Jackson & Songer, 2000).

5.   Integrate motivational elements in all aspects.

Motivational theory should be applied to all aspects of the learning process. One important finding of this study was that most students were self-regulated enough to use the tool to finish the assignment in the classroom and at home. Age might have influenced their self-regulated behavior, and such an approach may not work with younger students. However, according to the student interviews and my observations, these students were able to control their learning progress and search for information they needed; consequently their motivation to do the assignment increased. Furthermore, the level of difficulty on the assignment met the challenge requirement. Having the students take responsibility for their own learning outcomes and providing an interactive tool to explore information matched with the control factor.

Access to this new learning experience and 3D animations met the curiosity and fantasy requirements. However, when using fantasy to enhance the design of a tool, designers should be careful to ensure that inappropriate elements of fantasy do not distract learners or impair their attention to the educational elements (Lepper & Chabay, 1985; Parker & Lepper, 1992). Because learning is a serious enterprise, do not try to design a fun game to "fool" the student into thinking that learning is always fun. This strategy works only in the short term (Lepper & Chabay, 1985), and students will start to be bored if their teacher cannot constantly replicate the fun in the classroom that some

computer games provide. In short, although computer technology makes designing interactive learning environments somewhat easy, awareness of the content, the characteristics of the learners, and the nature of the instructional problems and needs is more important than fancy presentation modes.

6.   Eliminate user frustration with the interface.

Interface design flaws can cause severe problems when students use computer tools in classroom. In the preliminary phase of interface design, designers should adhere to the standards for usability and accessibility. When the prototype is finished, conducting usability testing with representatives of the end users is essential to eliminating potential operational problems in the future. The cognitive load demanded by an interface should be minimized so that students can focus their cognitive processing on the learning tasks inherent in the Web-LE itself.

7.   Consider the characteristics of the learners.

In this study, data gathered from teacher and student interviews suggested that high school students are visually oriented and are attracted to realistic objects. When designing a tool for different learners, it is important to consider how to appeal to their needs (e.g. screen design, color usage, degree of realism). When developing fantasy elements, instructional designers need to be aware that motivation toward learning is different for learners of various ages. Harter (1984) pointed out that intrinsic students motivation to do schoolwork decreases continually from third grade through ninth grade. Therefore, some fantasy elements that attract the attention of elementary students may fail to make upper school students engage with the learning process. On the other hand, realistic simulations may be both appealing and effective.

8.   Collaborate with an instructional technology support personnel.

To ensure the continuous usage of the tool in a classroom environment, content revisions may be required after a certain period of time. The teacher needs to have back up personnel to help him or her revise the tool when the need arises. In this study, all developed materials and source code were given to the instructional technology support personnel at the school, along with explanations for revising the program. Researchers should try to involve the local instructional technologist, technology coordinators, and media specialists when the development phase begins. Ideally, the local instructional technologists should understand how to use the production software the team is using to develop the tool and what skills are required to maintain or revise the tool. Obviously, this may be more difficult in some contexts than others. My research certainly benefited from the presence at this school of a talented technology support team.

9.   Enhance efficiency of development process.

Personnel, budget, and time limitations are the major factors that determine the success of the development process. In this study, all personnel volunteered to participate in the project. The time the larger cognitive tools team, including two professors and several graduate students, spent conducting the instructional design phase of the project was approximately six months. However, when the project moved to the production phase, only three people, including myself, were available for designing graphics, creating animations, and writing code. These are time intensive tasks, and hence due to limited personnel, the production phase lasted fifteen months.

Maintaining constant and frequent communications with the teacher and conducting formative evaluation to improve the quality of the tool also required large investments of

time. Although it will extend the time to completion, it is recommended to collect

formative information from multiple sources to ensure the effectiveness of the tool as

early as possible and to remain in frequent contact with the teacher to receive immediate

feedback. In this study, expert opinions, the teacher's opinions, and student usability

testing results in the pilot study provided productive and meaningful guidance for

keeping the tool on the right track. All of these essential activities could have been done

faster if more personnel had been available.

      10.   Reduce technological frustrations.

      Technology infrastructure is ever changing in the world of Web development.

Researcher and designer must be aware of the available computer equipment (e.g.,

network bandwidth, stability of the network, CPU, and RAM) before implementation. It

is extremely important that the students obtain the proper equipment and necessary

software before instruction. In this study, the suggested equipment for using Fossilization

Web-LE included a Pentium computer (or better) with at least 64 MB memory, a sound

card, speakers or earphones, and an Internet connection. The students' laptops were

sufficient; however, the network in the school was not stable enough, and sometimes the

speed of the connection was slow. Therefore, researcher copied all necessary files onto

the students' laptops to reduce the frustration of the network problems that were

encountered. Fast laptops are also important because a slow machine yields slow

execution and can easily cause distractions for students while using the tool. Today's

high school students have a low tolerance for long downloads or other delays.

Future Research Directions

Several roles were involved in conducting this development study: researcher, designer, evaluator, and K-12 teacher (subject expert). I played multiple roles at times, e.g., designer, programmer, graphic artist, and researcher, but I was fortunate to have a cadre of faculty and graduate students to work with me through various stages of the project. To conduct a similar development research projects, strong relationships between Instructional Technology programs and K-12 schools should be established. Many K-12 teachers become graduate students in Instructional Technology programs, and they are excellent potential resources that a researcher can use to define instructional problems and potential solutions through computer technology. A university can provide the necessary hardware and software for tool development, while K-12 teachers can provide a real context for implementing the tool and learning how to customize a tool for a specific situation. To conduct similar research in the future, I will continually look for interested K-12 teachers who are pursuing degrees in Instructional Technology programs. The days when instructional technologists could develop instructional innovations in the university laboratory and then toss them over the walls of the schools are over. We must work in tandem through a process of development research.

The teacher engaged in my study plans to revise the contents of Fossilization Web-LE with the instructional technology specialists in his school and continually use the tool in the classroom. The longitudinal impact of implementing the type of cognitive tool in his classroom should be investigated. This teacher has long been known for his dedication to students, e.g., he takes a group of students to Montana every summer to seek dinosaur fossils. It would be an interesting research project to investigate how this

teacher's teaching evolves now that he has made his first major investment in developing educational software. In addition, it would be worthwhile to explore how this teacher might incorporate other assignments into this unit, e.g., the construction of physical models of fossils.

The teacher decided to implement the tool on site in the classroom; as a result, he did not use the Web technology in the instructional process to any great extent. The teacher did not need the asynchronous discussion board that we designed for students to contribute to discussion, share knowledge, and provide answers to the assignment. They could simply talk to each other and to the teacher in person. How to implement this Web-LE as an asynchronous technology in K-12 schools should be investigated in the future. I plan to make the Web-LE freely available to other teachers, and encourage other researchers to adopt this tool for further research.

The following are suggested questions for further research:

1. What effects will the use of Fossilization Web-LE have on later interest in the subject outside the computer context?

2. Does student motivation decrease in other units that do not include technology after being exposed to technological enhancement in the fossils unit?

3. Do any novelty effects of the Web-LE persist after students become accustomed to using this type of tool?

4. What are the effects of students working in pairs or small teams in this type of Web-LE?

5. What is required for teachers not involved in the development of this Web-LE to implement it successfully?

6. How does the instructional effectiveness of this type of Web-LE compare with the effectiveness of other strategies for using the Web in science education such as WebQuests (Dodge, 2001)?

Chapter Summary

The goals of this development research were twofold: the teacher needed a workable tool in his classroom to solve the instructional problems, and after implementation and evaluation, the teacher was satisfied with the effectiveness of the tool and planned to use the tool in his classroom. Thus the first goal was met. As the researcher, I also desired to employ the development research process to establish some general guidelines for designing an instructional tool in this type of context. Although levels of student performance improved slightly and only for certain types of students, levels of student motivation to learn the unit of fossilization with the tool were observed to be enhanced greatly. Students were fond of the new learning experience, regarded the tool as a good laptop activity, and hoped to use similar tools in the classroom in the future. In achieving the second goal, I have been able to draw from this experience a number of important design and implementation principles that I will surely employ in my future research efforts, and hopefully that others can use as well.

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APPENDICES

Appendix A: Parent Consent Form

Parental Consent Form for Participation Research

I give my consent for my child _____ to participate in the research titled, "An Investigation of a Web-Based Learning Environment Designed to Enhance the Motivation and Achievement of Students in Learning Difficult Mental Models in High School Science," which is being conducted by Shiang-Kwei Wang (706-354-6875) and Dr. Janette R. Hill (706-542-3810), Instructional Technology Department, University of Georgia. I understand that this participation is entirely voluntary; I or my child can withdraw consent at any time without penalty and have the results of the participation, to the extent that it can be identified as my child's, returned to me, removed from the research records, or destroyed.

1. The reason for the study is to help the researchers examine the software design to make sure it is appropriate for my child to employ in the classroom.
2. The benefits that my child may expect from the research are: exposure to a new tool for learning about fossilization, and have chances for them to interact with computer to simulate various fossilization and observe the result.
3. The procedures are as follows: my child will spend about 2 class periods (100 minutes) to use a web-based fossilization learning tool, and spend about 20 minutes to complete a taped interview with researcher.
4. No discomforts or stresses are foreseen.
5. No risks are foreseen. My child's participation is voluntary. I understand that my child will be given alternative, equivalent exercises if I or my child do not consent to participantion. This choice will not effect the grade of my child.
6. The results of this participation will be confidential, and will not be released in any individually identifiable form without the prior consent of my self and my child, unless otherwise required by law. The audio tapes will be used for transcribing interview and will be erased in one year.
7. The researchers will answer any further questions about the research, now or during the course of the project, and can be reached by phone at 706-354-6875.

I understand the study procedures described above. My questions have been answered to my satisfaction, and I agree to allow my child to take part in this study. I have been given a copy of this form to keep.

_____   _____   _____
Name of Researcher   **Signature**   **Date**
Telephone: _____
Email: _____

_____   _____   _____
Name of Parent or Guardian   **Signature**   **Date**

Additional questions or problems regarding your child's rights as a research participant should be addressed to Chris A. Joseph, Ph.D. Human Subjects Office, University of Georgia, 606A Boyd Graduate Studies Research Center, Athens, Georgia 30602-7411; Telephone (706) 542-3199; E-Mail Address IRB@uga.edu

Appendix B: Student Consent Form

Research Assent Form

I agree to participate in the research titled, "An Investigation of a Web-Based Learning Environment Designed to Enhance the Motivation and Achievement of Students in Learning Difficult Mental Models in High School Science," which is being conducted by Shiang-Kwei Wang (706-354-6875) and Dr. Janette R. Hill (706-542-3810), Instructional Technology Department, University of Georgia. I understand that this participation is entirely voluntary; I can withdraw consent at any time without penalty and have the results of the participation (up to the date of withdrawing), to the extent that it can be identified as mine, returned to me, removed from the research records, or destroyed.

1. The reason for the study is to help us examine the software design to make sure it is appropriate for students to employ in the classroom.
2. The benefits that I may expect from the research are: exposure to a new tool for learning about fossilization, and have chances for them to interact with computer to simulate various fossilization and observe the result.
3. The procedures are as follows: I will spend about 2 class periods (100 minutes) to use a web-based fossilization learning tool, and spend about 20 minutes to complete a taped interview with researcher.
4. No discomforts or stresses are foreseen.
5. No risks are foreseen. My participation is voluntary. I understand that I will be given alternative, equivalent exercises if I do not consent to participantion. This choice will not effect my grade.
6. The results of this participation will be confidential, and will not be released in any individually identifiable form without the prior consent of myself, unless otherwise required by law. The audio tapes will be used for transcribing interview and will be erased in one year.
7. The researchers will answer any further questions about the research, now or during the course of the project, and can be reached by phone at 706-354-6875.

I understand that I am agreeing by my signature on this form to take part in this research project and understand that I will receive a signed copy of this consent form for my records.

_____   _____
    _____

_____   _____   _____
Name of Researcher   **Signature**   **Date**
Telephone: _____   **Email:** _____

_____   _____   _____
Name of Participant   **Signature**   **Date**

Additional questions or problems regarding your rights as a research participant should be addressed to Chris A. Joseph, Ph.D. Human Subjects Office, University of Georgia, 606A Boyd Graduate Studies Research Center, Athens, Georgia 30602-7411; Telephone (706) 542-3199; E-Mail Address IRB@uga.edu

Appendix C: Teacher Interview Protocol in the Pilot Study

Teacher Interview Protocol

Name: _____   Interviewer: _____   Date: _____

1. Please describe how you have traditionally taught fossilization.

2. Have you used software to teach fossilization? If so, what?

3. What is the instructional goal you could meet through the use of this software?

4. Please describe your thoughts of the software after observing students' use of the software.

5. Please describe the components that you feel are most helpful for learning fossilization.

6. What overall suggestions do you have for improving the software?

7. How would you use this software to teach fossilization?

Appendix D: Student Interview Protocol

Student Interview Protocol

Name: _____   Interviewer: _____   Date: _____

General background information:	1. Have you ever used other software to learn science before?
	2. How do you think about the fossilization software when you used it in the classroom?
	3. How did you use the fossilization software to do your assignment?
Behavioral responses (Engagement):	4. How long did you spent on the assignment? Usually how long would you spend time on Mr. Kridler's assignments?
	5. Was the assignment difficult for you?
	6a. (If yes) What would you do when you encounter a difficult question? 6b. (If no) Was the assignment easy, or did the software provide enough information to do assignment?
Cognitive process	7. What grade did you receive for the assignment? How does the grade compare to other grades on similar assignments you've gotten in science? If they are different, why do you think so?
	8. Were you satisfied with the quality of information you received about fossilization through this software?
	9. How does the amount and quality of learning about fossilization compare to other topics you've learned about in science last year?
	10. Tell me what did you learn about the unit of fossilization.

Interests:	11. Which part of the fossilization software is the most useful for you?
	12. What were some of the exciting things that happened when you use the software?
	13. How would you rank the fossilization unit in comparison with all other units in terms of motivation in science last year? Why were you motivated differently more interested in this unit?
	13a. (If not) Can you think of any school activity that you might be very excited about?
	14.Have you heard other students say about the fossilization software?
	15. Do you hope [your teacher] uses more similar software in his classroom to help you learning science?
Control:	16. How do you think about the "my path" function?
	17. How do you think about the encyclopedia? Did you use them to do your assignment?
Evaluation:	18. Did you encounter any difficulties when using the software?
	19. What overall suggestions do you have for improving the software?

Appendix E: Observational Protocol

Observational Protocol

Name:_____ Observer: _____ Date: _____

Activities	Note
Input name	
Interests (Curiosity and enthusiasm)	
Choose "view" to explore data	
Select keyword and observe inside animation	
Click the objects on the screen and select keywords	
Connect to online encyclopedia	
Cognitive processes (concentration)	
Use "my path" to check learning progress	
Watch each movie from beginning to the end	
Use movie control buttons to control movie (pause and rewind)	
Review the same movie more than once	
Behavioral responses (signs of attention or time on the software)	
Chat with others about the software	
Numbers of selected path	
Distracted by other activities (e.g. browse web-site, receive e-mail)	
Other events?	

Appendix F: Motivation Questionnaire

Fossilization software survey

Directions: Please complete the following statements about the fossilization software. Please answer truthfully and to the best of your ability. Your name will not be used and your answers will not be available to anyone else beyond the research.

	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
The fossilization software was helpful for doing my assignment.					
This software provided me enough information to do assignment.					
I performed well in this assignment.					
I am satisfied with the quality of information that I received about fossilization through this software.					
Compare to your teacher's other assignments, I spent more time on the fossilization assignment.					
I like science more than other subjects.					
Using the software to learn science is exciting.					
My motivation on learning fossilization is greater than learning other units.					
I hope teachers will use more similar software in my classroom.					
Knowing what I was supposed to do when using the software was easy.					
Finding the button I wanted to press was easy.					
Figuring out the path I already completed was easy.					
The screen design was appealing.					
I understand the different conditions of fossilization after using the software.					
I think the fossilization tool is helpful to learn about fossilization.					

What overall suggestions do you have for improving the software?

_____

_____

Appendix G: Teacher Interview Protocol

Teacher Interview Protocol

Name: _____   Interviewer: _____   Date: _____

1. What is your expectation of this software?

2. How did they perform in this assignment? Are you satisfied with their performance?

3. Is there any gap between your expectation and their performance?

4. What is the instructional goal you could meet through the use of this software?

5. How would you describe students' motivation of using this software?

6. Please describe your thoughts of the software after observing students' use of the software.

7. Please describe the components of this software that you feel are most helpful for learning fossilization.

8. What overall suggestions do you have for improving the software?

9. Does the software raise other instructional problems in your classroom?

10. How would you use this software to teach fossilization in the future?

11. Any suggestions to other teachers who have similar instructional problems and want to use the software in his classroom?

Cognitive Learning Tool

Cognitive Learning Tool – The Process of Fossilization

Your main task is to determine which of the 3 specific ecological Biomes is most likely to produce the best fossil, given the described circumstances, and then determine which of the six scenarios described in each would most likely give you the most complete skeletal specimen. On the way to determining these conclusions, there are many specific questions for your to answer that will evaluate your understanding of the processes you are observing and their overall relationships to geologic history, as we presently understand it. Answer each question clearly and completely. Brevity is not appropriate.

1. **Why do you suppose that your teacher chose such a large dinosaur instead of a much smaller one?**

2. **Seasons are not mentioned in this study. If they had been included, which of the four seasons, if in fact all four were indeed experienced, would most probably have provided the most opportunities for fossilization of this animal? Discuss your reasons for your choice.**

3. **In each of the six scenarios, there are TWO outstanding situational and, or physical conditions that preclude good fossilization. What are they?**

a.)

b.)

4. **In most of the scenarios, we do not get an entier skeleton preserved. In the spaces provided below, give FOUR possible explanations for why this is so.**

   a.)

   b.)

   c.)

   d.)

5. **Which of the THREE major Biomes provides us with the best opportunities for the most complete fossilis? _____.**

6. **Explain completely why you chose this Biome.**

7. **Within this Biome, there are several types of fossilization scenarios that differ from each other in the manner in which the animal is killed and buried. Which scenario provides the most complete fossil? _____.**

8. **Describe your reasons for this choice. Be very precise and write sufficiently to clarify each reason.**

9. **When you examine the scenarios, which part of the tool is designed to enable you to "get to the meat" of the problem the most quickly and comparatively? _____.**

10. **Go to the encyclopedia page. Examine exfoliation as a process. If a dinosaur skeleton, not yet completely permineralized, was exposed on the surface of the Badlands of Montana for a few years, how could the process of exfoliation reduce the scientific value of the specimen? Discuss your answer fully.**

11. **Go to the encyclopedic page. Examine the process of acdification, resulting from volcanic activity. How would repeated volcanic activity affect a skeleton that was under only a few feet of debris?**

12. Go to the encyclopedic page. Scroll down to radio-dating. Complete the graph by answering the two question symbols, figuring how many fruits would be left after the next two half-life periods. (do not round your answer to the nearest whole number.)

_____and _____.

13. When you ponder the complete list of circumstances required for good fossilization, it should come as no surprise to you that fully articulated skeletons should be quite uncommon compared to the disconnected and badly weathered fragments that are most often encountered, even in the best of circumstances. Why is this so?

14. There is built-in BIAS in our sampling processes and within the fossil record itself. These Biases paint an incomplete and often error-filled picture of what the ancient world really looked like and how it might have interacted, organism to environment and visa-versa. Discuss the causes of our Biases fully, HERE IS WHERE YOU CAN REALLY SHINE AND EARN SOME EXTRA CREDIT!