Web-Based Learning Environment: A Theory-Based Design Process for Development and Evaluation

Chang S. Nam
University of Arkansas
Fayetteville, AR, USA

Tonya L. Smith-Jackson
Virginia Tech
Blacksburg, VA, USA

cnam@uark.edu

smithjack@vt.edu

Executive Summary

Web-based courses and programs have increasingly been developed by many academic institutions, organizations, and companies worldwide due to their benefits for both learners and educators. However, many of the developmental approaches lack two important considerations needed for implementing Web-based learning applications: (1) integration of the user interface design with instructional design and (2) development of the evaluation framework to improve the overall quality of Web-based learning support environments. This study addressed these two weaknesses while developing a user-centered, Web-based learning support environment for Global Positioning System (GPS) education: Web-based distance and distributed learning (WD^{2}L) environment. The research goals of the study focused on the improvement of the design process and usability of the WD^{2}L environment based on a theory-based Integrated Design Process (IDP) proposed in the study. Results indicated that the proposed IDP was effective in that the study showed (1) the WD^{2}L environment's equivalence to traditional supplemental learning, especially as a Web-based supplemental learning program and (2) users' positive perceptions of WD^{2}L environment resources. The study also confirmed that for an e-learning environment to be successful, various aspects of the learning environment should be considered such as application domain knowledge, conceptual learning theory, instructional design, user interface design, and evaluation about the overall quality of the learning environment.

Keywords: Human-Computer Interaction, Usability Evaluation, Web-Based Distance and Distributed Learning (WD^{2}L), Instructional Design, e-Learning

Introduction

As an increasingly powerful, interactive, and dynamic medium for delivering information, the World Wide Web (Web) in combination with information technology (e.g., LAN, WAN, Internet, etc.) has found many applications. One popular application has been for educational use, such as Web-based, distance, distributed or online learning. The use of the Web as an educational tool has provided learners and educators with a wider range of new and interesting learning experiences and teaching environments, not possible in traditional in-class education (Khan, 1997). Web-based learning environments have been

developed mainly by instructional designers using traditional instructional design models such as the instructional systems design (Dick & Carey, 1996), cognitive flexibility theory (Spiro, Feltovich, Jacobson, & Coulson, 1991), and constructivist learning environment (Jonassen, 1999). However, many of these approaches still lack two important considerations needed for implementing learning applications based on the Web: (1) integration of the user interface design with instructional design, and (2) development of the evaluation framework to improve the overall quality of Web-based learning environments.

First, little attention has been paid to design issues of the human-computer interface, which are critical factors to the success of Web-based instruction (Henke, 1997; Plass, 1998). Learners must be able to easily focus on learning materials without having to make an effort to figure out how to access them (Lohr, 2000). However, current instructional design principles and models do not explicitly address usability issues of the human-computer interface. Second, the rapid growth of Web-based learning applications has generated a need for methods to systematically collect continuous feedback from users to improve learning environments. Unfortunately, few attempts have been made to develop such formative evaluation frameworks for Web-based learning environments whose foci are both the instructional system and user interface system. In addition, few approaches take user interface design issues into account in their evaluation processes. A number of evaluation frameworks that can be used to evaluate the user interfaces have been proposed (e.g., Nielsen, 1993; Rubin, 1994). But, these models are intended for software environments rather than for Web-based learning environments in which user interface systems should be developed to support users' learning activities.

This study addressed these weaknesses while developing a user-centered, Web-based learning support environment for Global Positioning System (GPS) education: a Web-based distance and distributed learning (WD^2L) environment. More specifically, there are two main research goals addressed in this study, and these goals aimed to improve the design process and usability of the WD^2L environment. First, this study offered a systematic approach to the design, development, and evaluation of a user-centered, WD^2L environment for supporting engineering courses. Second, this study evaluated the design process model by assessing the overall quality of the WD^2L environment prototype in terms of 1) students' learning performance and 2) the quality of resources implemented in the WD^2L environment.

We first give an overview of relevant literature that guided the design, development, and evaluation of the WD^2L environment supporting GPS education. The development process will then be briefly summarized. In addition, evaluation processes through the proposed formative evaluation framework will be outlined. Finally, relationships between the design process framework and the effectiveness of the WD^2L environment will be discussed.

Background

Overview of GPS Education

To understand the application domain, a GPS course was analyzed or used as the testbed. As shown in Table 1, there is the educational demand for a new learning environment to effectively support the course while meeting the societal demands on engineers educated in GPS fundamentals.

However, there are also developmental challenges that should be considered. This identified domain knowledge also served as a basis from which to draw practical implications from the literature.

Table 1. Examples of Developmental Challenges

Dimension	Challenging Issues
Context	● Societal demand on engineering students educated in GPS fundamentals ● Development of a new GPS learning support environment ● Redesign of the course relevant for the new learning environment
Delivery Mode	● Delivery of the course independent of geographic location ● Supplemental mode to existing instruction methods
Time Frame	● Learning experiences independent of time ● At own space in own time
Content	● Interdisciplinary subject area ● Implementation of laboratory exercises
Audience	● Diverse educational backgrounds ● Geographically dispersed learners

Learning Theories in Instructional Designs and Models

The overview of the GPS course showed that various developmental situations should be considered to develop a new GPS learning support environment. For an instructional system to be effective, for example, it is important to understand how people learn and to incorporate that knowledge when developing the system. According to underlying philosophical views of learning, design models can be classified into the three main categories: Objectivist Instructional Design Models (OIDMs); Constructivist Instructional Design Models (CIDMs); and Mixed approach to Instructional Design (MID).

Objectivist instructional design models (OIDMs)

According to Moallem (2001, p. 115), objectivist design models emphasize "the conditions which bear on the instructional system in preparation for achieving the intended learning outcomes." Objectivist design models include Dick & Carey's Instructional Systems Design (1996) and Gagne, Briggs and Wager's Principles of Instructional Design (1992), each of which are based on both behaviorist and cognitive approaches to learning. Behaviorism has contributed to traditional models by providing relationships between learning conditions and outcomes (Saettler, 1990). In objectivist design models, behavioral objectives are developed as a means to measure learning success. Cognitive approaches also influenced objectivist instructional models by emphasizing the use of advance organizers, mnemonic devices, and learners' schemas as an organized knowledge structure (Driscoll, 2000). However, there are some problems with objectivist approaches to instructional design. For example, objectivist approaches group learners into standardized categories, thereby promoting conformity and compliance (Reigeluth, 1996). Today, however, organizations want their members to develop their own unique potentials and creativity, which can lead to initiative, diversity and flexibility. Furthermore, objectivist design models do not explicitly address design issues of the user interface in the design process.

Constructivist instructional design models (CIDMs)

The objectivist design models stress a predetermined outcome, as well as an intervention in the learning process that can map a predetermined concept of reality into the learner's mind. However, learning outcomes are not always predictable so that learning should be facilitated by instruction, not controlled (Jonassen, 1991). Instructional design models that take a constructivist view include Spiro et al.'s Cognitive Flexibility Theory (1992), Jonassen's Constructivist Learning Environment (1999), Hannafin, Land, & Oliver's Open Learning Environment (1999), Savery

& Duffy's Problem-Based Learning (1995), Schank & Cleary's goalbased scenarios (1995), and Cognition & Technology Group's microworlds, anchored instruction (1992).

Mixed approach to instructional designs

Unlike objectivist and constructivist design models, the mixed approach to instructional design proposes that an instructional design model reflect all learning theories according to instructional design situations. For example, different instructional design situations such as different learners and learning environments may require different learning theories and thus different instructional design models (Schwier, 1995). Davidson (1998) found that, in practice, a mix of old (objective) and new (constructive) instruction/learning design is increasingly being used. In their 'Continuum of Knowledge Acquisition Model,' Jonassen, McAleese, & Duffy (1993) note that the initial knowledge acquisition is better served by instructional techniques that are based upon traditional instructional design models whereas constructivist learning environments are most effective for advanced knowledge acquisition. However, this approach also does not address the issues involved in user interface design and the overall effectiveness of a Web-based learning environment.

Given common learning activities (e.g., problem solving, inference generating, critical thinking, and laboratory activities) and types of learning domains (e.g., intellectual skills and verbal information) in the GPS course, this study proposes that the instructional design principles provided by the cognitive learning theory would be best suited for redesigning the learning content of the course. For example, providing efficient processing strategies through which students receive, organize, and retrieve knowledge in a meaningful way will facilitate learning activities. For instructional strategies, this study recommends Objectivist Instructional Design Approaches, which combine Cognitivism and Behaviorism. For example, Behaviorism provides relationships between learning conditions and learning outcomes, and such relationships can inform the instructional designer of how the instruction should be designed to achieve successful learning outcomes. To effectively deliver the instruction, on the other hand, cognitive approaches provide various instructional methods, such as the use of advance organizers, mnemonic devices, metaphors, and learners' schemas as an organized knowledge structure. This study also suggests employing constructivist approaches for effective instructional strategies. For example, the constructivist approach states that instruction should promote collaboration with other learners and/or instructors, providing a ground for the implementation of an email system or group discussion board system for educational purposes.

User Interface Design for Learning Environments

For a Web-based supplemental learning environment to be successful, it is also important to effectively facilitate learner interactions with the learning environment. An effective user interface in Web-based learning environments is important, because it determines how easily learners can focus on learning materials without having to make an effort to figure out how to access them (Lohr, 2000). There are a number of design approaches to the user interface, each of which has its own strengths and weaknesses. To review the current user interface design practice, this study borrowed Wallace & Anderson's (1993) classification: the craft approach, enhanced software engineering approach, technologist approach, and cognitive approach.

In the craft approach, interface design is described as a craft activity in which the skill and experience of the interface designer or human factors expert play an important role in the design activity (Dayton, 1991). For successful design, this approach relies on the designer's creativity, heuristics, and development through prototyping. The enhanced software engineering approach claims that formal HCI methods such as task analysis should be introduced into the development life-cycle to support the design process (Shneiderman, 1993). This approach attempts to over-

come the short-comings of structured software engineering methods that ignores issues involved in human-computer interaction and user interface design. The technologist approach claims that designers produce poor quality interfaces because they have to spend more time in performing time-consuming tasks, such as programming an interface, than in doing design activity during development (Cockton, 1988). To allow designers to concentrate on design, the technologist approach attempts to provide automated development tools (e.g., the User Interface Management System) and rapid prototyping tools (e.g., HyperCard and Multimedia Toolkit). The cognitive approach applies psychological knowledge, such as theories of information processing and problem solving to the interface design (Barnard, 1991). This most theoretical approach to interface design is characterized by an attempt to build precise and accurate users' cognitive models that represent their interaction with computers.

In order to design user interfaces that are easy to use and intuitive to anyone, it is important to have good design skills as well as some knowledge of psychology, methodologies and prototyping. Therefore, all four approaches are fundamental to successful design of Web-based learning environments. However, designing a usable interface that is also learner-centered is not trivial. Thus, this study suggests employing a user-centered design process that takes human factors into account. Gould & Lewis (1985) provide three principles of user-centered design: 1) an early focus on users and tasks, 2) empirical measurement of product usage, and 3) iterative design whereby a product is designed, modified, and tested repeatedly. Rubin (1994) also suggests several techniques, methods, and practices that can be used for the user-centered design. Some of the examples include participatory design, focus group research, surveys, design walkthroughs, expert evaluations, and usability testing.

Evaluation of Web-based Supplemental Learning Environments

One of the foci in this study is on formative evaluation. The evaluation of Web-based learning environments is a continuing process throughout the development lifecycle (Belanger & Jordan, 2000). There are several formative evaluation approaches that can be used to identify problem areas or to draw inferences about the overall quality of Web-based learning environments (e.g., Dick & Carey, 1996; Kirkpatrick, 1994; Marshall & Shriver, 1994). Unfortunately, few approaches still take the problems of the user interface design into account during their evaluation process. A number of evaluation frameworks that can be used to evaluate the user interfaces have also been proposed. However, these models were intended for software environments rather than for learning environments such as Web-based learning that requires considering how effectively the user interface system supports users' learning activities. Thus, an evaluation framework is required for Web-based supplemental learning environments, in which the evaluation process, methods, and criteria are provided to systematically evaluate both the instruction and user interface system.

As the evaluation process, Dick & Carey's (1996) evaluation approach may be the best candidate, because this approach allows different types of evaluators (e.g., experts, individual, and group of evaluators) to evaluate various aspects of the web-based learning environment (e.g., individual and group learning activities). As a formative evaluation process, Dick & Carey proposed four different methodologies: 1) subject matter expert review, 2) one-to-one evaluation, 3) small group evaluation, and 4) field trial. Since the focus of this study is on formative evaluation, the first three methods will be reviewed in relation to the evaluation of Web-based learning systems. First, a dry run can be conducted in the Subject Matter Expert Review before the system under development is tested with users. In order for a system to be successful, we must discover overlooked areas or problems. The subject matter experts (SMEs) who exhibit the highest level of expertise in the current topic area fill that requirement. In the One-to-One Evaluation, two or more representative users go through all aspects of the Web-based learning system with an evaluator to iden-

tify and remove prominent errors. Various tools provided to support an instructor in Web-based learning environments can be evaluated with the instructor, such as a course management system (e.g., WebCT or Blackboard). Participants are also asked to evaluate the system in terms of screen design, information structure, and menu structure. In the Small-group evaluation, group learning activities (e.g., group discussion) and multi-user interface system (e.g., Discussion Board) can be evaluated by a group of people representative of the target population.

Development of WD^{2}L Environment

Based on the available literature reviewed in the previous sections, this study suggests that for a WD^{2}L environment to be successful, various aspects of the learning environment should be considered, such as application domain knowledge, conceptual learning theory, instructional design, human-computer interface design, and evaluation plan. Unfortunately, few frameworks are available for the development of WD^{2}L environments to support engineering education. Moreover, they rarely take those factors into account in their design process. This study proposes an *Integrated Design Process* (Figure 1) and a *Design Process Template* (Figure 2), which together will help address various factors involved in the development of the WD^{2}L environment.

Description of the Integrated Design Process (IDP)

As seen in Figure 1, the *Integrated Design Process* (IDP) consists of four design phases - needs analysis, conceptual design, development, and formative evaluation – each of which has its own design processes. The proposed IDP considers two main systems of the WD^{2}L environment (i.e., the instruction and user interface system) from the early Needs Analysis phase.
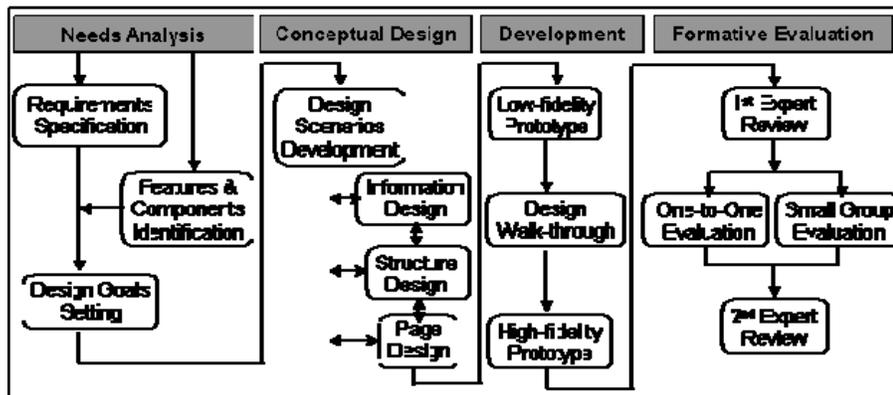

Figure 1. Integrated Design Process (IDP)

This study offered the *Design Process Template* to help implement each step of the design process (Figure 2). There were two main reasons for providing this template. First, the template was intended to provide factors that should be considered in each design process, such as process objectives, inputs, design steps, outputs, methods and tools. Another reason was that information and developmental factors needing to be considered are not constant because of changes in technology, course structure, and users' needs. Although it is not intended to be exhaustive, the template helped to address such issues when developing the WD^{2}L environment prototype.

Phase: Needs Analysis		**Process:** Features & Components Identification
Process Description	This process describes design activities to identify features and components necessary to implement the WD^{2}L environment.	
Process Objectives	• Identify key features conducive to learning and instruction • Specify system components	
Inputs	• Khan's (1997) list of WBI features and components • Requirements specification • Oliver's (2003) list of online tools categorized by functions to be served	
Design Steps	User Interface System Instruction System	
Outputs	• List of key features and conducive components categorized by the functions	
Methods/Tools	• Khan's (1997) and Oliver's (2003) list	

Figure 2. Design Process Template: Features and Components Identification Process

Phase 1: Needs analysis

This first phase, *Needs Analysis*, was concerned with gathering, analyzing, and summarizing information necessary to build the WD^{2}L environment prototype. This phase consisted of three design processes, each of which was performed using its own Design Process Template: *Requirements Specification*, *Features and Components Identification*, and *Design Goals Setting*.

The *Requirements Specification* process provides various design activities involved in capturing abstract, high-level development goals, as well as more specific requirements necessary to develop the WD^{2}L environment. The main objective of the process was to specify user- and system-related requirements while developing a full understanding of the target user group and its tasks. As a result of performing design steps, this process led to the development of the requirements specification document, providing development goals for an effective WD^{2}L environment. The main objective of the *Features and Components Identification* process was to identify key features and corresponding components that constitute an effective WD^{2}L environment. Table 2 shows some examples of key features and component to be implemented.

Table 2. Examples of Key Features and Components for WD^{2}L Environment

Feature	Relationship to WD^{2}L Environment	Component
Interactive	• Allow interactions with students, instructors, and Web resources via various communication channels • Provide interactive feedback on students' performance	Discussion Board
		Practice Sessions
		Quiz
Multimedia	• Support students' various learning styles using a variety of multimedia	Concept Map
		Text to Speech
		Advanced Organizers
Distributed	• Allow downloading and printing the materials from the WD^{2}L environment and any other Web sources	GPS Resources
		GPS Glossary
Collaborative Learning	• Create a medium of collaboration, conversation, discussion, exchange, and communication of ideas	Discussion Board (By Group)

The *Design Goals Setting* process describes the determination of design goals and principles that drive all design decisions throughout the development, which also serve as evaluation criteria for usability testing in the *Formative Evaluation* Phase. Table 3 shows examples of design goals that will govern all design decisions throughout the development of the WD^2L environment.

Table 3. Design Goals for WD^2L Environment Development

System	Design Goal	Description
User Interface System	• Effectiveness	• To increase the accuracy and completeness
	• Efficiency	• To reduce the resources expended
	• Satisfaction	• To ensure users' comfort and acceptability of use
Instructional System	• Clarity	• To make learning materials clear
	• Impact	• To increase users' attitude

As design goals of the instructional system, this study followed Dick and Carey's (1996) evaluation criteria: clarity of instruction and impact on learner. Clarity is a design goal to make sure if what is being presented is clear to individual target learners. Impact is intended to increase an individual learner's attitude. The primary goal of the user interface was to design the interface so the user can easily complete tasks by allowing simple, natural interactions with the WD^2L environment. For example, this study employed Norman's (1987) four principles of good design: visibility, good conceptual model, good mapping, and feedback. Visibility indicates that the use of a device should be as visible as possible to a user by clearly indicating the state of the device, functionality, and the alternatives of action. A good conceptual model refers to consistency in the presentation of user operations and results, which in turn allows the user to predict the relationships between his/her actions and subsequent results (i.e., good mapping principle). Finally, the feedback principle refers to informative feedback that users receive on their actions.

Phase 2: Conceptual design

The *Conceptual Design* phase focused on an explicit construction of concepts about what the WD^2L environment is, what it can do, and how it is intended to be used. This phase consisted of four design processes that translate user requirements into a conceptual user interface and instructional design: *design scenarios development, information design, structure design, and page design*. The output of the *Conceptual Design* phase was an outline of the user interface and instructional system prototype, which was further developed during the *Development* phase.

The *Design Scenarios Development* process describes a set of steps for developing design scenarios that reflect users' key tasks. Several user tasks have identified in this study, including such tasks as uploading assignments on the Web, practicing what has been learned, and participating in discussion. The main objective of the process was to create design scenarios that can be used for the conceptual design of the systems. These scenarios were developed to reveal as much detail as possible about users' learning activities, as well as relevant user interface objects to support their behaviors on the WD^2L environment. Figure 3 presents an example of design scenarios, which shows a set of user activities to study a learning content.
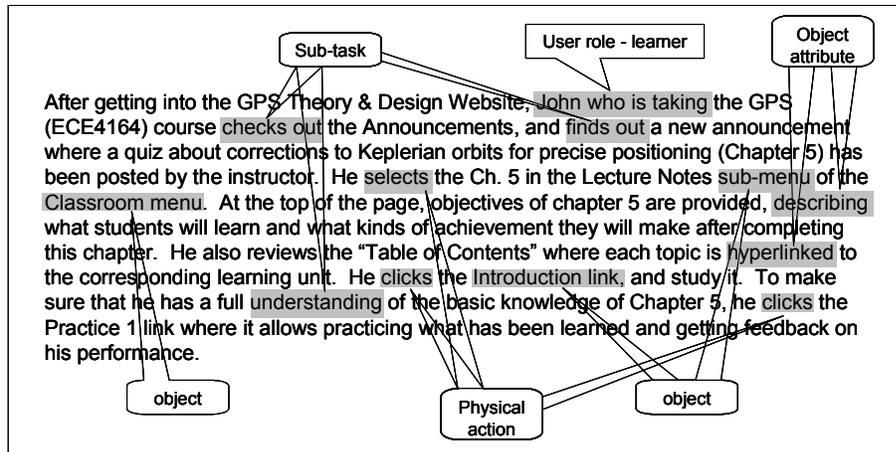
Figure 3. An Example of Design Scenario

The *Information Design* process describes the conceptual design of information content for the instruction and user interface system. The main objective of the process was to identify and outline required content. To outline the learning content, for example, this study applied learning theories as well as their instructional design principles. Table 4 shows an example of how the learning content of the instructional system was conceptually designed to meet user requirements by applying instructional design principles drawn from cognitive approach to learning.

Table 4. An Example of theory-Based Design of Learning Content

Requirement	Design Principle	Learning Theory	Learning Content
• Provide efficient information processing strategies to support complex GPS learning	• Emphasis on structuring, organizing, and sequencing information to facilitate optimal processing	• Cognitivism	• Concept map • Think for a while • Interactive practice sessions

Information content identified for the user interface and instructional system were integrated, resulting in the Content Outline Document as an output of the process. The Content Outline Document describes a list of the content identified for key user tasks in terms of page titles, page elements, and brief descriptions. The Structure Design process describes the main structure of the WD^{2}L environment. The main objective of the process was to specify the presentation and storage structure of the WD^{2}L environment. The structure of information in a Web site is important in that well-structured information allow users to effectively perform necessary tasks or access the required information. The Page Design process described the determination of content layouts or schematics of main pages, displaying rough navigation and the layout of elements that need to appear on a page. The main objective of the process was to specify the content layout and navigational organization of a few key pages. This study adapted the Wireframing process provided by Koto & Cotler (2002) for the Web redesign. To determine content layouts of a page, all page content identified in the previous process were reviewed.

Phase 3: Development

The *Development* phase was aimed to construct a high-fidelity (hi-fi) prototype of the WD^{2}L environment, based on results of the initial user evaluation on low-fidelity (low-fi) prototypes. This phase consisted of three design processes, which translate the conceptual user interface and in-

structural design into the hi-fi prototype of the WD^2L environment: *low-fidelity prototyping, design walk-through, and high-fidelity prototyping*.

The *Low-Fidelity Prototyping* process describes the development of the low-fi prototypes of the WD^2L environment. The main goal of the process was to build a rough interface and instructional system by integrating design ideas developed in the previous processes. The *Design Walk-Through* process was concerned with soliciting initial feedback from users by having them walk through the low-fi prototypes of the WD^2L environment. The goals of the process were 1) to confirm that the proposed design of the WD^2L environment (i.e., the low-fi prototype) is consistent with target users' expectations and skill levels, and 2) to use initial feedback to revise the low-fi prototypes early in the design process before the full functionality is implemented. The *High-Fidelity Prototype* process described the development of the hi-fi WD^2L environment prototype, in which full functionality is completed.

Evaluation of the WD^2L environment

As a formative evaluation process, this study borrowed and modified the first three steps of Dick & Carey's (1996) evaluation approach, Expert Review, One-to-One Evaluation, and Small Group Evaluation, because the fourth step, Field Trial, is more of a summative evaluation step. Instead, this study used the Expert Review (2nd) process in the fourth step again, in which experts finally review the WD^2L environment prototype. Because of the page limit, the Small Group Evaluation process will not be reported.

Expert Review (1st) Process

SMEs reviewed the WD^2L environment prototype to discover overlooked areas or problems and suggested design recommendations to improve it two times: before (*Expert Review (1st)* process) and after (*Expert Review (2nd)* process) usability testing with representative users. Due to the page limit, only the *Expert Review (1st)* process is reported.

Method

Participants: Three SMEs who exhibited a high level of expertise in three main areas were selected; instructional design (34-year-old Ph.D. candidate), user interface design (32-year-old human factors Ph.D. student), and GPS content (27-year-old Master candidate).

Equipment/Apparatus: To review and suggest their recommendations to improve the first version of WD^2L environment prototype, the SMEs were asked primarily to utilize their expertise in their specialties. In addition, to help the SMEs review important aspects of the WD^2L environment prototype, this study developed and provided three types of expert review forms: *User Interface Review Form, Instructional Design Review Form, and Content Review Form*.

Procedures: Three SMEs were given written instructions for the task by asking them to review and provide design comments or recommendations that would help revise the prototype. The user profile specified in the *Requirement Specification Document* was also given to help the SMEs have a better understanding of the target user group. It took about two hours for each expert to complete the evaluation of the WD^2L environment prototype.

Results of the expert review

The overall quality of the user interface system was evaluated by the interface expert. Statistical analysis was not performed as the data was obtained only one time from the SMEs. The Navigation (6.0), Mapping (6.0), Knowledge Space Compatibility (6.0) dimensions were rated highly, while the screen design (3.0) and aesthetics (3.0) dimensions received low points. The instructional design expert evaluated how well components of the instructional strategy were imple-

mented and provided design recommendations for the modification of the instructional system. The overall quality of the instructional design was good (e.g., Design for Target Audience (6.0), Match to Learning Objectives (4.0), and Clear to be Self-Instructional (5.0)). The GPS content expert also reviewed learning units and provided design recommendations for the modification. Learning units received relatively high scores, ranging from 4.8 (Practice Unit – practice 4) to 5.4 (Quiz Review Unit – Quiz 1 Review).

Design changes and discussion

Several design changes were made in response to recommendations suggested by the SMEs, such as redesign of graphic figures used to explain the main concept and provision of more options for editing messages (e.g., font color and size).

One-to-One Evaluation Process

In the *One-to-One Evaluation* process, two evaluation sessions (Evaluation 1 and 2) were conducted with representative users to identify and remove more prominent errors in the second version of the WD^2L environment prototype. Another evaluation was conducted as most of the evaluation criteria were not fully met in the first *One-to-One Evaluation* session. Due to the page limit, the second session only is reported.

Method

Participants: A new pool of four participants participated in the second session of the One-to-One Evaluation. There were 3 male and 1 female participants (Mean hereafter M = 23.0 years, Standard Deviation hereafter SD = 0.82 years). Most participants classified their computer skill level as somewhere between an intermediate and an experienced level.

Experimental Materials and Benchmark Tasks*:* To evaluate main functions of the interface and instructional system, this study developed eight "benchmark" tasks representing users' most common tasks on the WD^2L environment. For the interface system, for example, this study developed four benchmark tasks, which were searching information, uploading assignments, finding GPS resources, and sending email. Another four different benchmark tasks were developed for the instructional system, which were studying the learning content (i.e., Chapter 5), performing practice sessions, reviewing the quiz, and performing prelaboratory activities.

Evaluation Criteria: As evaluation criteria for determining the overall quality of the instructional system, this study used both clarity and impact of instruction. The overall quality of the user interface system was determined in terms of the effectiveness, efficiency, and user satisfaction. To measure user satisfaction with user interfaces, this study employed the Questionnaire for User Interface Satisfaction questions (QUIS^{TM} 7.0) consisting of five categories: initial satisfaction, screen, terminology and system information, learning, and system capabilities.

Procedure: Participants were given written instructions for the task and asked to review the *Site Map* page of the WD^2L environment to familiarize with the prototype. Then, the participants performed eight benchmark tasks representing users' most common tasks on the WD^2L environment, which were presented in a random order. Before doing that, the participants were asked to think aloud throughout the whole session and talk about what they are doing, why they are doing it, and what they expect to happen when they perform an action. After benchmark tasks #4, #5, #7, and #8, evaluation of instruction questionnaires were administered to identify participants' evaluation on the clarity and impact of instruction, respectively. At the end of the evaluation, participants completed the questionnaire.

Results

As shown in Table 5, several measures were employed to investigate the overall quality of the WD^2L environment prototype from users' perspective.

Table 5. A Summary of Usability Specifications: Evaluation 2

Usability Attribute	Measuring Instrument	Value to be Measured	Target Level	Observed Results
Initial Performance	Benchmark Task #1 (Searching Information)	Number of features	4	4.50
		Time on task	15	14.50
		Number of errors	0	0.25
		Frequency of the Help use	≤1	0.00
	Benchmark Task #2 (Uploading Assignments)	Number of features	8	8.00
		Time on task	40	36.25
		Number of errors	0	0
		Frequency of the Help use	≤1	0.25
	Benchmark Task #3 (Finding GPS Resources)	Number of features	4	4.00
		Time on task	30	29.50
		Number of errors	0	0.00
		Frequency of the Help use	≤1	0.75
	Benchmark Task #6 (Sending Email)	Number of features	7	5.50
		Time on task	50	48.00
		Number of errors	0	0.00
		Frequency of the Help use	≤1	0.25
Clarity & Impact of Instruction	Benchmark Task #4 (Studying content)	Clarity of instruction	5.10	5.50
		Impact of instruction	5.10	5.25
	Benchmark Task #5 (Performing Practice)	Clarity of instruction	5.10	5.20
		Impact of instruction	5.10	5.17
	Benchmark Task #7 (Reviewing Quiz)	Clarity of instruction	5.10	5.60
		Impact of instruction	5.10	5.58
	Benchmark Task #8 (Performing Prelaboratory)	Clarity of instruction	5.10	5.17
		Impact of instruction	5.10	5.25
Satisfaction	QUIS 7.0	Initial satisfaction	8.10	8.13
		Screen	8.10	8.19
		System information	8.10	8.13
		System capabilities	8.10	8.15
		Multimedia	8.10	8.17

The fourth column in Table 5 indicates the "*Target Level*" representing the performance goal. Target levels of the number of features measurement and time on task were derived by measuring the fastest steps to complete a benchmark task and times to finish it by the expert user (i.e., the researcher of this study). It took the expert user about 30 seconds to finish the task. Target levels of clarity and impact of instruction measurements were set as 85% from a perfect score (i.e., 5.1 out of 6.0). Ninety percent of a perfect score in the QUIS[TM] (i.e., 8.1 out of 9.0) was determined as target levels of satisfaction measurements. On the other hand, target levels of number of positive/negative remarks were decided a little more arbitrarily, but were intended to be rigorous enough to catch major usability problems ($\leq$ 5).

Effectiveness of the User Interface System: The percent of tasks completed was computed as the ratio of completed tasks to total tasks ($n = 8$), reflecting the overall task performance. Results showed that participants completed all 4 benchmark tasks successfully.

Efficiency of the User Interface System: The efficiency of the user interface system was determined through three metrics: time on task, number of errors, and frequency of help use. As shown in Table 5, participants spent a shorter amount of time completing tasks as compared to the target level. Results also showed that participants did not make mistakes to perform tasks except for the task of finding information (i.e., Benchmark task #1, mean number of error = 0.25).

Clarity and Impact of Instructional system: The degree of clarity of instruction was rated higher than target levels. The content received a mean of 5.50 ($SD = 0.51$), while practice sessions, quiz review, and prelaboratory received mean values of 5.20 ($SD = 0.77$), 5.60 ($SD = 0.60$), and 5.17 ($SD = 0.58$), respectively. The degree of impact of instruction was also rated higher than target levels set as 85% from a perfect score. The content received a mean of 5.25 ($SD = 0.75$), while practice sessions, quiz review, and prelaboratory received mean values of 5.17 ($SD = 0.72$), 5.58 ($SD = 0.67$), and 5.25 ($SD = 0.62$), respectively.

Design Changes and Discussion

Results of the two, *One-to-One Evaluation* sessions showed that almost evaluation criteria were met. However, some changes were still necessary to the third version of the WD^{2}L environment prototype, as reflected by participant design comments.

Effectiveness of Web-Based GPS Learning Environment

The WD^{2}L environment prototype was evaluated as a way of ascertaining the quality of the design process used in the present study. The evaluation was also conducted to identify how users evaluated the quality of resources implemented in WD^{2}L environment prototype.

Research questions

The study sought to answer the following research questions concerning the effectiveness of the Web-based GPS supplemental learning program developed in the present study.

1. Are there any differences in students' learning performance between the Web-based GPS supplemental learning program and traditional supplemental learning?

2. How do users evaluate the quality of resources implemented in the Web-based GPS supplemental learning program?

Experimental design

Procedure: Participants were asked to take a short, essay type of the test (pretest). To learn the content, all participants took the class through a traditional classroom instruction for three separate days. Right after the class, the short essay-type test was repeated (posttest). Participants who

were randomly assigned to the "Web-supplemental" condition (10 students) were instructed to use the WD²L environment as a GPS supplemental learning program to further study. They were told to visit the site at least once a day for 30 minutes. The other half of participants (10 students), who were randomly assigned to the "Traditional" condition, were told to study the learning content (i.e., Chapter 5) further using their normal method (e.g., reading books or asking instructor). After 5 days, all participants took the transfer of knowledge test. The "Web-supplemental" group completed the "Evaluation of Web-based GPS supplemental learning program" questionnaire.

Participants: Twenty students who took the GPS course in Fall of 2003 volunteered in the study. There were 4 female and 16 male participants ($M = 23.13$ years, $SD = 2.9$).

Independent Variables: This study employed Campbell & Stanley's (1966) true experimental design (Figure 4) in that the study included a purposively created control group (participants in the "traditional" condition), common measured outcome (learning performance), and random assignment (participants were randomly assigned into each condition). There was one independent variable manipulated in the study: supplemental learning type. The supplemental learning type condition was manipulated as a 2 level condition: Web-supplemental and traditional conditions. Participants in each condition were pre-tested and post-tested on their recall and assessed on their transfer of knowledge.

R	$O_{Pretest}$	Lecture	$O_{Posttest}$	$X_{Tradition}$	$O_{Transfer}$
R	$O_{Pretest}$	Lecture	$O_{Posttest}$	$X_{Tradition}$	$O_{Transfer}$

Where, R: Randomization; O: Measurement of dependent variable; X: Independent variable

Figure 4. General Experimental Design

Dependent Variables

Recall Test: A recall assessment should be used in order to gauge how much of the presented material the learner can remember (Mayer, 2001). Participants were assessed on their initial knowledge prior to and recall following the lecture. The test question was "What physical effects (including the most important one) produce perturbations on satellite orbits predicted by the basic Kepler orbital theory?" Accuracy was based on the occurrence of acceptable ideas in the participant's responses. To compute a score for a participant, initial knowledge and recall were measured by the participant's ability to remember the following idea units in their pre- and post-test responses: Non-sphericity of the Earth; Tidal forces; Solar radiation; Relativistic effects. Performance was expressed as the number of idea units reported divided by the total possible.

Transfer Test: Transfer test questions were developed on the basis of Mayer & Chandler (2001) and McFeeters (2003). The test sought to measure "meaningful understanding in which participants are required to use the presented information in ways beyond what was presented" (Mayer & Chandler, 2001, p. 393). The transfer test contained the following three questions.

1. Explain what a harmonic correction to a GPS satellite ephemeride is.

2. List and briefly describe at least two gravitational effects that perturb GPS satellite orbits.

3. List and briefly describe at least two non-gravitational effects that perturb GPS satellite orbits.

The teaching assistant graded each question by using a separate rubric. In order for a participant's response to be considered accurate, each rubric included specific ideas from each question that should have been included in the participant's response. The rubric contained four acceptable ideas per question. Each acceptable idea was given a point value. The most specific acceptable idea was given the highest points (3 points). Less specific acceptable ideas were given a lower score (2 points). Vague answers were given the lowest score (1 point). If an answer was considered unacceptable it was given a score of zero. Students received credit for an answer if they expressed either of four categories of ideas provided in the rubrics regardless of writing style or use of terminology. Each participant's transfer performance is expressed as the number of acceptable answers generated divided by a total of 9.

Web-based Learning Program Questionnaire: To investigate how users evaluated the quality of resources implemented in the Web-based GPS supplemental learning program, this study modified and used Felix's (1998) questionnaire for evaluation of Web-based learning program. The questionnaire included 8 dimensions: objectives/directions, content/structure, interactivity, navigation, text, sound, graphics, and interface.

Results

Descriptive Analysis: The collected data included pre- and post-test scores on a one question essay test, a three essay question transfer test, and a 47-item learner preference questionnaire. Mean pretest scores were 0.70 ($SD = 0.37$) for the Web-supplemental group and 0.65 ($SD = 0.29$) for the traditional group. The mean score of post-test for the Web-supplemental group was 0.95 ($SD = 0.15$) and 0.95 ($SD = 0.16$) for the traditional group. Mean transfer scores were 0.57 ($SD = 0.26$) for the Web-supplemental group and 0.63 ($SD = 0.25$) for the traditional group. These differences in mean pretest and post-test scores and no difference in mean transfer scores between the two groups do not indicate statistically significant. Therefore, a series of t-tests were conducted to investigate whether there is nay significant difference in participants' initial knowledge and learning performance.

Validity Test: Although a small sample size was used in the study, t-tests were performed as the data obtained met several assumptions underlying the t-test. For example, we could assume that the variances are approximately equal, given Levene's test results of homogeneity of variance $\alpha = 0.05$ ($p > 0.05$). The Mann-Whitney test, a nonparametric test to compare two groups, was also conducted and showed the same results with t-tests. Therefore, results from t-tests will be reported in the study. The t-test assesses whether the means of two groups are statistically different from each other. To test whether or not the difference between the means is the same, the p-value is compared with a significance level. If it is smaller, the result is significant. That is, if the null hypothesis (i.e., the hypothesis that there is no difference in the means of two groups) were to be rejected at $\alpha = 0.05$, this would be reported as $p < 0.05$.

The result showed no significant differences in participants' initial knowledge between the Web-supplemental group and traditional group: $t(18) = -0.34$, $p = .741$. On the other hand, significant differences were found between pretest and posttest scores for both groups ($t(9) = 2.37$, $p < 0.05$ for the Web-supplemental group; $t(9) = 2.45$, $p < 0.05$ for the traditional group). This result indicates a significant increase in scores after the lecture. However, gain scores (difference between pretest and posttest scores) between the two groups were equal after the exposure to the lecture ($t(18) = 0.31$, $p = 0.761$).

Transfer of knowledge between the two groups: To test the hypothesis that there is no significant difference in students' learning performance between the Web-based GPS supplemental learning and traditional supplemental learning program, a t-test on transfer of knowledge was conducted. It was concluded that there were no significant differences in students' learning per-

formance between the Web-based GPS supplemental learning group and traditional supplemental learning group (t (18) = 0.59, p = .563).

Learner Preference: Students were asked to indicate their preference in which GPS learning materials might be used on the Web. Almost all the participants considered that the best way to use Web materials was as an addition to face-to-face teaching used in their own time (6 out of 8 responses). Participants in the Web-supplemental group were asked to evaluate various aspects of the programs they used for GPS learning. Responses were favorable, ranging from 70% to 90% agreeing that the objectives were clear, the content was logical, the program was interactive and the navigation was easy. Some 60% to 100% rated the quality of the text, graphics, and interface as 6 or above on a scale of 1 to 9 (The first dimension in the text category needs to be reversed since lower ratings represent readability). On the other hand, more than 60% of the participants did not consider voice recordings of learning material useful to their GPS learning

Discussion and Conclusions

This study described an effort to develop a theory-based *Integrated Design Process (IDP)* in order to improve the design process and usability of the WD^{2}L environment as a learning support tool. As expected, the proposed design process was effective in that the study showed (1) the WD^{2}L environment's equivalence to traditional supplemental learning, and (2) users' positive perceptions of WD^{2}L environment resources.

Equivalence to Traditional Supplemental Learning

Mean test scores between the Web-supplemental group and traditional group were not significantly different in the study. This means that the WD^{2}L environment as a Web-based GPS supplemental learning program could work as well as traditional supplemental learning. The Web-supplemental group had a low mean transfer score (60% correctness), but showed a similar mean score of the GPS class when they were tested on that unit, which was one of the most difficult units. The mean transfer score of the Web-supplemental group (M = 0.57, SD = 0.26) was also lower than that of the traditional group (M = 0.62, SD = 0.25). The lower mean transfer score of the Web-supplemental group can be explained by two reasons. First, the amount of time that the Web-supplemental group spent was not long enough to show the main advantage of the Web-based supplemental learning environment: learners could re-study learning materials whenever they chose. The Web-based supplemental learning environment, which provided learners with opportunities for practice, over-learning, and elaborate rehearsal, should have decreased the rate of forgetting more effectively than learners' traditional learning supplementation (e.g., reading a textbook and class notes) over time. Second, the WD^{2}L environment still needs more practice sessions and informative feedback, which can facilitate students' learning. This finding is consistent with a line of studies that found no significant difference in delivery methods, which are referred to as the "The No-Significant-Difference Phenomenon" (Russell, 1999). A lack of a significant difference between the Web-supplemental group and traditional group provides good evidence that the WD^{2}L environment as a Web-based supplemental learning program does not discernibly create any disadvantage for the students who use it (Andrew, 2003). This finding is important because it demonstrated that the WD^{2}L environment may support students' post-study activities just as well as traditional supplemental learning. From the instructors' point of view, the Web-based supplemental learning environment's equivalence to traditional supplemental learning means that there are more channels with which they can support students' learning activities (Chadwick, 1999). This result is also important to students because they can be confident that the WD^{2}L environment would effectively support their various learning activities as a supplemental learning tool.

It is also true that there are many researchers who discredit studies referred to as media comparison studies (e.g., Lockee, Burton, & Cross, 1999; Russell, 1999). They argue that measuring the impact of media on learning is futile in comparison studies. For example, Lockee et al. maintain that media comparison studies are badly flawed because of a lack of randomization in the sample selection, an assumption that grades actually measure student achievement, and no assumption of homogeneity of groups. However, the present study is not a media comparison study and does not exhibit any of these threats to internal validity. This study did not compare face-to-face/campus-based learning and distance-learning programs as mentioned in Lockee et al.'s study, but compared Web-based supplementation to students' traditional supplementation activities. Furthermore, this study used only on-campus students and compared students who were randomly assigned to one of two conditions. A validity test in the study showed that the groups were homogeneous (e.g., no significant differences in participants' initial knowledge between the Web-supplemental group and traditional group).

Positive Perceptions on WD^{2}L Environment Resources

Participants expressed an overall positive attitude toward Web resources implemented in the Web-based GPS supplemental learning environment. This finding is important from users' perspectives, because they wanted to use Web materials as an addition to face-to-face lecturing. To effectively support users' learning, Web resources implemented in the WD^{2}L environment should be easy and intuitive to use. Given the two main findings, the *Integrated Design Process* was an effective framework to develop the Web-based GPS supplemental learning program. From the user interface design point of view, the main reason is that the *Integrated Design Process* supports usability principles by combining human-computer interface design with instructional design. In other words, user interfaces in the WD^{2}L environment were developed to support students' learning activities. Unfortunately, few email systems or discussion board systems provide user interfaces that can fully support engineering students' learning activities. For example, one of the most important learning activities for engineering students was to use special characters for mathematical equations. To write the equation, $\alpha + 2\delta = \beta$, engineering students had to type the equation in texts on many existing email or discussion board systems as alpha + 2*delta = beta. On the other hand, current email and discussion Board systems on the WD^{2}L environment supported such activities by allowing students to use special characters. This capability was implemented, because the *Integrated Design Process* dictated that user interfaces in the WD^{2}L environment should be developed to support students' learning activities. This is further supported in users' positive attitudes toward user interfaces implemented in the WD^{2}L environment, as well as improvement in the overall quality of the user interface system. From a cognitive perspective, the use of symbols or special characters allows effective communication between learners, and also facilitates information processing (Driscoll, 2000; Spiro et al., 1991).

Another possible explanation from the instructional design point of view is that the *Integrated Design Process* supported theory-based design for the instructional system. In order to provide an effective design of learning contents, while meeting user requirements, the *Integrated Design Process* supported applying learning theories as well as their instructional design principles. For example, one of the user requirements related to the instructional system was that since the GPS course involves complex forms of learning, the instructional system should provide learners with efficient information processing strategies through which they receive, organize, and retrieve knowledge in a meaningful way. Cognitive learning approach recommended providing several different ways in which learners can connect new information with existing knowledge. By employing this design principle, for example, the "Think for a while!" section was designed. In this section, learners could think back to what they learned in previous chapters and how their prior knowledge was related to current topics. This was further supported in the early meeting of evaluation criteria for the instructional system (i.e., clarity and impact of instruction), as well as

improvement in the overall quality of the instructional system evaluated by instructional design experts. This clearly suggests that the theory-based design of the instructional system may play an important role in developing effective learning content.

It can be further noted that there are implications for usability studies for educational applications. Since concerns for usability have not been truly addressed when designing and developing educational applications, more usability studies should be conducted (Levi & Conrad, 2000; Pavlik, 2000). Learners in the WD^{2}L environment must be able to easily focus on learning materials without having to make an effort to figure out how to access them (Lohr, 2000). The findings of the study confirmed that the user interface system that supports students' learning activities can fulfill that requirement.

There were several potential limitations to the study, which may hinder generalization of the results. For example,

- The WD^{2}L environment prototype in the study was developed by focusing on only one GPS chapter (i.e., chapter 5) for a small number of the student user group. Replication of the findings using a fully developed WD^{2}L environment for other user groups (e.g., the instructor and system administrator) and a larger number of participants is needed before strong conclusions are warranted. The WD^{2}L environment was also custom built at the time this study was conducted, but results of the study can also be used to improve any course management and delivery systems such as WebCT and Blackboard, which are not designed to fully support students' various learning activities.

- The present study identified students' traditional activities for supplemental learning - reading a book, questioning the instructor, and discussing with classmates – in an informal way (e.g., through conversation with a teaching assistant and students). Had the study identified more information about students' traditional activities for supplemental learning, subjective ratings of the traditional to the Web-based supplemental learning could have been compared.

- The evaluation activity takes place either formatively or summatively (Rubin, 1994). This study focused only on the formative evaluation of the Web-based supplemental learning environment, because the evaluation in Web-based learning environments is a continuing process throughout the development lifecycle (Belanger & Jordan, 2000). A summative evaluation is also needed to fully investigate the effectiveness of the program with a larger sample of participants.

- It is often more valid to evaluate learning and instructional design using action-research methods even during the formative evaluation stage. The external validity of this study could have been enhanced by implementing portions of the prototype in the actual learning environment and, in parallel, conducting formative evaluations. Given the time-cycle of the actual course used in this study, it was difficult to synchronize the research and classroom schedules to apply an action-research approach.

- Given that usability engineering and instructional design are both emerging specialty areas, the integrated framework is constrained by the knowledge domain. Thus, it is expected that the framework that has emerged from this study will require updating in the future on the basis of new theories and empirical evidence relevant to usability and instructional design.

References

Andrew, M. (2003). Should we be using Web-based learning to supplement face-to-face teaching of undergraduates? In *Proceedings of the 6th International Conference on Computer-Based Learning in Science,* (478-488). Cyprus.

Barnard, P. (1991). Bridging between basic theories and the artifacts of human-computer interaction. In J. M. Carroll (Ed.), *Designing interaction: Psychology at the human-computer interface* (pp. 103-127). Cambridge University Press.

Belanger, F., & Jordan, D. H. (2000). *Evaluation and implementation of distance learning: Technologies, tools and techniques*. Hershey, PA: Idea Group.

Campbell, D. T., & Stanley, J. C. (1966). *Experimental and quasi-experimental design for research*. Chicago: Rand McNally.

Chadwick, S. A. (1999). Teaching virtually via the Web: Comparing student performance and attitudes about communication in lecture, virtual Web-based, and Web-supplemented courses. *The Electronic Journal of Communication*, *9*, 1-13.

Cockton, G. (1988). Generative transition networks: A new communications control abstraction. In D. M. Jones, & R. Winder (Eds.), *People and computers IV* (pp. 509-525), Cambridge University Press.

Cognition and Technology Group at Vanderbilt. (1992). The Jasper series as an example of anchored instruction: Theory, program description, and assessment data. *Educational Psychologist*, *27*, 291-315.

Davidson, K. (1998). Education in the internet--linking theory to reality. Retrieved October 3, 2002, from http://www.oise.on.ca/~kdavidson/cons.html

Dayton, T. (1991). Cultivated eclecticism as the normative approach to design. In J. Karat (Ed.), *Taking software design seriously* (pp. 21-44)*.* Academic Press.

Dick, W., & Carey, L. (1996). *The systematic design of instruction*. New York, NY: Harper Collins.

Driscoll, M. P. (2000). *Psychology of learning for instruction* (2nd ed.). Needham Heights, Massachusetts: Allyn & Bacon.

Felix, U. (1998). Evaluation of Web-based language learning program. Retrieved September 5, 2003, from http://www.arts.monash.edu.au/lc/sill/evalqst.htm

Gagne, R. M., Briggs, L. J., & Wagner, W. W. (1992). *Principles of Instructional Design* (4th edition). New York, USA: Harcourt, Brace, Jovanovich.

Gould, J. D., & Lewis, C. (1985). Designing for usability: Key principles and what designers think. *Communications of the ACM*, *2,* 300-311.

Hannafin, M., Land, S., & Oliver, K. (1999). Open learning environments: Foundations, methods, and models. In C. Reigeluth (Ed.), *Instructional Design Theories and Models* (pp. 115-140). Mahwah, NJ: Lawrence Erlbaum Associates.

Henke, H. A. (1997). Evaluating Web-based instruction design. Retrieved September 5, 2001, from http://scis.nova.edu/~henkeh/story1.htm

Jonassen, D. H. (1991). Objectivist vs. constructivist: Do we need a new philosophical paradigm? *Educational Technology Research and Development*, *39*, 5-14.

Jonassen, D. H. (1999). Designing constructivist learning environments. In C. M. Reigeluth (Ed.), *Instructional-design theories and models: A new paradigm of instructional theory* (Vol. II, pp. 215-239). Mahwah, NJ: Lawrence Erlbaum Associates.

Jonassen, D. H., McAleese, T. M. R., & Duffy, T. M. (1993). A Manifesto for a constructivist approach to technology in higher education. In T. M. Duffy, J. Lowyck, & D. H. Jonassen (Eds.), *The design of constructivistic learning environments: Implications for instructional design and the use of technology*. Heidelburg, FRG: Springer-Verlag.

Khan, B. H. (1997) (Ed.). *Web-based instruction*. Englewood Cliffs, NJ: Educational Technology Publications.

Kirkpatrick, D. L. (1994). *Education training programs: The four levels*. San Francisco: Berrett-Kohler.

Koto, K., & Cotler, E. (2002). *Web redesign: Workflow that works*. New Riders.

Levi, M. D., & Conrad, F. G. (2000). Usability testing of World Wide Web. Retrieved March 5, 2003, from http://stats.bls.gov/ore/htm_papers/st960150.htm

Lockee, B. B., Burton, J. K., & Cross, L. H. (1999). No comparison: Distance education finds a new use for "no significant difference." *Educational Technology Research & Development*, *7*, 33-42.

Lohr, L. L. (2000). Designing the instructional interface. *Computers in Human Behavior*, *16*, 161-182.

Marshall, V., & Schriver, R. (1994). Using evaluation to improve performance. *Technical and Skills Training*, *January*, 6-9.

Mayer, R. E. (2001). *Multimedia learning*. New York: Cambridge University Press.

Mayer, R. E., & Chandler, P. (2001). When learning is just a click away: Does simple user interaction foster deeper understanding of multimedia messages? *Journal of Educational Psychology, 93*, 390-397.

McFeeters, F. E. (2003). The effects of individualism vs. collectivism on learner's recall, transfer and attitudes toward collaboration and individualized learning. Unpublished dissertation, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Moallem, M. (2001). Applying constructivist and objectivist learning theories in the design of a Web-based course: Implications for practice. *Educational Technology & Society*, *4*, 113-125.

Nielsen, J. (1993). *Usability engineering*. New York, NY: Academic Press.

Norman, D. A. (1987). Design principles of human-computer interfaces. In R. M. Baeker & W. A. S. Buxton (Eds.), *Readings in human-computer interaction: A multidisciplinary approach* (pp. 492-501). Morgan Kaufman.

Pavlik, P. (2000). Collaboration, sharing and society – Teaching, learning and technical considerations from an analysis of WebCT, BSCW, and Blackboard. Retrieved September 25, 2002, from, http://members.fortunecity.com/pgp5/Collaboration.Learning.and.Society.htm

Plass, J. L. (1998). Design and evaluation of the user interface of foreign language multimedia software: A cognitive approach. *Language Learning & Technology*, *2*, 35-45.

Reigeluth, C. M. (1996). A new paradigm of ISD? *Educational Technology*, *36*, 13-20.

Rubin, J. (1994). *Handbook of usability testing: How to plan, design, and conduct effective tests.* New York, NY: John Wiley & Sons.

Russell, T. L. (1999). *The no significant difference phenomenon*. Chapel Hill, NC: Office of Instructional Telecommunications, North Carolina State University.

Saettler, P. (1990). *The evolution of American educational technology*. Englewood, CO: Libraries Unlimited.

Savery, J. R., & Duffy, T. M. (1995). Problem based learning: An instructional model and its constructivist framework. *Educational Technology*, *35*, 31-38.

Schank, R. C. & Cleary, C., (1995). *Engines for education*. Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Schwier, R. A. (1995). Issues in emerging interactive technologies. In G. J. Anglin (Ed.), *Instructional technology: Past, present, and future* (2nd Ed., pp. 119-127), Englewood, CO: Libraries Unlimited.

Shneiderman, B. (1993). *Designing the user interface: Strategies for effective human-computer interaction* (2nd ed.). Reading, MA: Addison-Wesley.

Spiro, R. J., & Feltovich, P. J., Jacobson, M. J., & Coulson, R. L. (1991). Cognitive flexibility, constructivism, and hypertext: Random access instruction for advanced knowledge acquisition in ill-structured domains. *Educational Technology,* 31, 24-33.

Wallace, M. D., & Andersen, T. J. (1993). Approaches to interface design. *Interacting with computers*, *5*, 259-278.

Biographies

Chang S. Nam is an assistant professor in the Department of Industrial Engineering at the University of Arkansas. He received his Ph.D. in Industrial and Systems Engineering from Virginia Polytechnic Institute and State University in the United States. His research interests include brain-computer interface, cognitive and cultural ergonomics, adaptive and intelligent human-computer interaction, and haptic virtual environments.

Tonya L. Smith-Jackson is an associate professor in the Grado Department of Industrial Engineering at Virginia Tech. She received her Ph.D. in Psychology/Ergonomics from North Carolina State University in Raleigh, NC. Her research interests include cognitive and cultural ergonomics, human-computer interaction, and inclusive design and evaluation of systems.