COGNITIVELY INFORMED SYSTEMS

Utilizing Practical Approaches to Enrich Information Presentation and Transfer

ESHAA M. ALKHALIFA

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Preface

We dance around in a circle and suppose, while the secret sits in the middle and knows. (Frost, 1971)

It is the laborious life of scientific research that requires us to continually presume, then find support for our presumptions, which either stand the test of time or fall prey to falsifying evidence only to be replaced by new ideas and discoveries. It is this scientific track as described by Popper (1963) that has been followed by scientists taking them from the early days of inventions to current-day knowledge, always following a specific track. First the ideas, then testing, followed by the formation of theories, and after a science reaches a stable state of affairs, the fruits of that knowledge are reaped in the form of applications and inventions that people can benefit from.

I do not think there is any thrill that can go through the human heart like that felt by the inventor as he sees some creation of the brain unfolding to success.... Such emotions make a man forget food, sleep, friends, love, everything. (Nikola Tesla, 1856-1943)

Cognitive science as a field has gone through a long period of discovery and knowledge in its various forms and areas of focus. The findings have stabilized over the years to be able to predict and advise on how best to interact with the human mind, even if on a limited scale. This book aims to bring together the contributors whose respect for the human mind has led them to take the fruits of this science into account while laboring to design systems that interact with that form of magnificence.

Consequently, this book comes as an expected step forward along the natural path of research that starts with pure theory and ends with concrete designs, development, and assessment of tools. Yet, it is to date unprecedented as it contains an organization of the efforts put forward by researchers and designers of novel approaches into five main streams that feed into a larger river. These streams are partitioned in a fashion that is adequate to the human cognitive machine.

For the first of these, we may notice that all humans start their interactions with the world by utilizing their various senses for perceiving, storing what they perceive in their memory to recall it at a later date. The second investigates the organization of stored information in human memory and the cues that cause someone to recall them in addition to the symbols and analogies that are formed between concepts and their names or concepts and other concepts. The third studies mental reasoning, which is the path followed from what is given to the cognitive system until it gets to the deductions it can make based upon that and this process, if repeated, may cause an interaction with the outside world. This interaction may be in the form of trial and error with the outside world along the path of discovery learning. The fourth stream identifies the individual differences between cognitive characteristics where some individuals may have certain strengths, weaknesses, preferences, or even feel more comfortable interacting with a particular type of system. The fifth and last stream includes real-life case studies that are tested in actual classrooms.

The chapters of this book are therefore representatives of each of these five streams of research in this field in order to cover all possible directions within cognitively informed systems. However, representing each of the five main branches does not imply that these chapters will exhaust all the relevant questions, but instead only act as suggestions of the vast possibilities that may follow along the five main branches.

The first of the streams represents work on perception, recall of images, the effects of externalization of information, and how that interacts with recall during problem solving.

Teresa Chambel et al. in Chapter II exhibit one such direction by altering the classical display of video for learners and presenting them instead in a hyperlinked fashion. The various movie clips can be navigated and learners are allowed to go and review a particular scene or to seek further details through another such link. The system also allows collaboration within different student groups if they can watch the same movie or reference the same movie clip link. Such work allows researchers to identify how learning from a movie takes place and what parts of the movie may influence learning the most, consequently informing cognitive learning theory of the particularities that are discovered through the application of this approach.

Verhaart and Kinshuk introduce in Chapter III a proposal of how video clips could be stored in memory in multiple representations. Their work complements what is presented in Chapter II by exhibiting the practicality of the approach. In this chapter, the representations are autogenerated and allow the user of the system to retrieve the images in a manner that does not necessitate recall of all details as in using thumbnails to facilitate the retrieval of images. Thumbnails provide the necessary cues to stimulate the recall of a desired object that the searcher forgot parts of its details such as when searching for an image while having forgotten its name.

Chapter IV, on the other hand, as introduced by van Nimwegen et al., has more of an interest in how externalizing rules that have to be followed during problem solving influence what students recall at a later date. This work is extremely informative in that it shows how computer users who follow clear instructions are relieved of the cognitive load imposed by the task they are doing, but at the same time accomplish the task without learning how they did that. Students who were tested several months later revealed that the information presented to them during the problem-solving process affects what goes into their long-term memories from the learning process.

The second of the streams studies the mental representation of concepts, metaphors, and language. The mental representation of concepts is extremely difficult to study even in the field of cognitive science, so one solution is to attempt to organize information in a way that seems most suited to it and to evaluate how that organization aligns itself with human mental representation. Another issue is that of how words are used to “mean” certain concepts or, in a more general view, how analogies or comparisons of different concepts are made. Along this track, three chapters are offered.

In Chapter V, George offers an intuitive organization of a forum that is used for discussions where the links of the forum are places such that they are accessible when a student goes to a relevant lesson. The aim is to show learners how to access what is discussed on that particular topic or relevant topics. The goal is to identify how concepts are related to each other and, in turn, to reflect that by enforcing the links between the various forum contributions to allow a faster, simpler access to students who wish for further feedback or discussion. Here, the main issue is that of relevancy of the learned materials and how it relates to what is discussed.

Tretiakov and Kaschek, conversely, offer a point of view in Chapter VI that is novel in that it offers an interface that may work with various tutorial systems without requiring any alterations to the actual tutorial system. The interface offers the ability to select various metaphors or concept names and to describe them through analogical comparisons. The aim is to explain to students through a means that allows them a deeper understanding of the concepts that would in turn allow them to make deductions based upon the analogies made.

Ardissono and Gena classify users of the system they built into two levels: novice and expert users. In Chapter VII, they describe how they collected historical data on associations between different information needs that frequently occurred together and utilized the results to make suggestions to users of either of the two knowledge levels adaptively through the system. The time it takes users to access their particular informational needs was greatly reduced through utilizing this historical data of associations that are based on previous requests from the system. Here, knowledge is drawn from past usage in the form of cognitive associations and then applied to the design of this system.

The third of the streams is concerned with mental reasoning. Although some may assume that mental reasoning takes place with analogies, the form discussed in Chapter VI presents the analogies and checks whether students access them. It does not investigate the deductions made. However, the following chapters allow students to make choices, and based upon these choices they attempt to analyze the choices that must be allowed for students and how this can be achieved within the limits of current computer systems.

Chapter VIII, as presented by Tattersall et al., presents a system that studies how students choose the path sequences they follow during learning. It then draws a map of their choices and tries to deduce the most successful paths that were followed. This is then used to suggest to students possible future steps while allowing students the full choices of whether to follow these suggestions. Notice that it is unlikely here that all paths will converge to a single one, as learners are known to have cognitive differences, so this study is likely to illuminate how differences may emerge in the sequences of lessons students follow to achieve more efficient learning.

Chapter IX, by contrast, is presented by Lee, to focus on student collaboration during constructivist study. She uses a blackboard setting to promote scaffolding as represented in presenting partial information to students and allowing them to discuss and attempt to arrive at conclusions based upon the information they could gather on their own. Here, there is no imposed structure to the knowledge presented, and instead learners must discover it on their own, and the only structure imposed is that by the scaffolding offered by moderators who participated in shaping the discussions and ensuring they are going in the right direction.

However, Beynon and Roe, in Chapter X, offer a contrary view indicating a serious flaw with current programming issues when it comes to applying constructivist approaches. They give a very detailed presentation of the constructivist approach in addition to explaining the core differences between the current programming paradigm and the basic requirements of constructivism. The difference seems to lie between giving learners a goal to accomplish, where they have to draw a plan of how to reach it, and when they are given an environment and no plan is possible other than discovery while their conclusions emerge spontaneously. An interesting perspective here on cognition is that this may relate to what is currently described as cognitive insight as represented as the moment of discovery.

The fourth stream is concerned with individual differences whether they exist within different cognitive characteristics or whether they exist within genders or whether they exist in the frequency and types of errors students may make.

Chapter XI, as presented by Triantis and Pintelas, describes a multiagent architecture where a mobile agent represented by the user interface interacts directly with the learner and seeks to provide whatever is needed by that learner. This agent is able to accomplish this by interacting with other agents that exist in the background with the aim of requesting tutorials from them according to the learning needs of the student. This approach is similar to providing a representative who provides custom designs to each individual accessing the system, to reduce search time, in addition to providing a user-friendly environment and reducing any anxieties that may exist prior to learning.

Morgan and Trauth, on the other hand, present in Chapter XII a detailed analysis of the digital divide between those who have access to the Internet and those who do not take advantage of the digital world. Their emphasis in this particular chapter is on the differences within each gender rather than between the two genders. Their particular focus is on the words used while running Web searches on search engines. People's individual selections of words that are used to represent the concepts they are searching for may differ and therefore impact their use of these search engines and possibly even impact the use of the Internet as a whole. The choice itself is a cognitive one, which is made based on what that particular individual deems as the most appropriate to describe the concept desired, but this may not correspond to the same choice made by the designers of the various Web sites.

Liu, in Chapter XIII, studies through a Bayesian model the occurrence of guessing in student responses in tests. The study concludes that the level of similarity between the items in the test itself and those presented in the course materials play a crucial role in affecting the amount of successful guesses that students may make. If on the other hand the number of correct answers is fixed in various trials, guessing is yet again affected. This particular chapter identifies, the false positives that may emerge in tests and assists in isolating these especially when evaluating tutoring systems or in student assessments.

The last stream is concerned with a real-world study of the effects of technology on student science achievement. Although the previous chapters are all informative, the whole book and all the ideas proposed have one goal in mind—namely to benefit those who use the systems.

Hilton presents in Chapter XIV a study on 1,194 students in a high school in California. One of the main conclusions made is that the use of technology does affect learning. The main problems exist in how the technology is used, as using it in one way may encourage the amount of learning made while using it in another may hinder learning. This is a clear indicator that care must be taken when designing tutorial system to take into account all cognitive characteristics that may influence learning, because ignoring them may lead to undesired consequences.

The main conclusion that one arrives at is that this book presents practical work that is being done today to bring the findings of a mature science to the world of reality. Various approaches build upon dispersed findings made in perception, reasoning, memory, and so on, to present the world with cognitively informed systems. The book comes as a natural consequence of the evolution of science, and it is not likely to be the last that will be geared toward this particular target. As systems grow more aware of the cognitive state, they are more likely to better serve and be more aligned with what they are built to achieve. The progress continues.

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If the words that are said,
lead you to be impressed,
Then pray thee do not be led,
to believe they show,
Anything that I know,
For God taught me all I said.
(Alkhalifa)

Chapter I

Cognitively Informed Systems: Justifications and Foundations

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Abstract

Cognitively informed systems as introduced by Alkhalifa (2005b) is a perspective that encourages system designers to consider the findings of cognitive science as informative to the design of their systems. This relies on an underlying assumption that the presentation, interaction abilities, as well as the system structure, are likely to achieve more efficient communication if the design is aligned with the expectations of the human cognitive machine. In other words, this perspective deals with issues such as how to best present materials for the perceptual system to isolate the required differences and focus on the correct points in the image, how to offer sufficient interaction to enhance learning, or how to elicit different levels of cognitive engagement with the system. This chapter offers a survey of the main areas of the field and examples are given of how these areas can inform particular aspects of future system design. A case study is also presented as support to this perspective. The main conclusion that

can be drawn is that this new perspective is not only practical but also worthwhile.

Background

Paul Thagard (2004) describes cognitive science as the interdisciplinary study of mind and intelligence. He indicates that it embraces philosophy, psychology, artificial intelligence, neuroscience, linguistics, and anthropology. The first fruits of this science emerged in the mid-1950s when researchers in several different fields, including George Miller, John McCarthy, Marvin Minsky, and Allen Newell, started to place the foundations of theories of mind. They started by founding the field of artificial intelligence and in their endeavor to do so, started to study the workings of the cognitive system, with the attempt of learning how it works and modeling that onto a computer system.

The main foundation of the science is that thinking can be understood in terms of representational structures of the knowledge in the mind, and that computational procedures may describe all the processing required on those structures that is necessary to make deductions (Thagard, 2004).

There are two standard computational approaches that are utilized in modeling any system in cognitive science. The first is described as symbolicism and deals with symbolic processing where each concept is given a symbol to represent it and rules are utilized to make deductions based on the values of these symbols. The second is known as connectionism, where neural networks are used to represent the structure of the system where each neuron acts as a unit that interacts with its inputs to produce its outputs (Willaford, 2004). According to Andy Clark (1993), cognitive science, "sets out to explain the mechanisms implicated in events which are recognizably psychological in nature, such as reasoning, planning, and object recognition."

Consequently, a conclusion that one may arrive at is that this science is rooted in the philosophy of mind and branched out as a science attempting to concentrate and analyze the workings of the human mind and/or brain and to produce computerized models either through symbolic programming or through connectionist modeling. One question that may arise is, Will this theoretical science continue with its current target without any subtrack branching out? In the case of artificial intelligence, expert systems branched out into the world and found themselves a place in modern-day systems in online help, decision support systems, and many such applications. The success of expert systems justifies the target sought by the perspective suggested here in benefiting from the other findings of that science during the early design phases of hypermedia systems. However, in order to achieve that benefit, the main areas of possible contribution have to be isolated, as a novice to the field may be confused by the diverse directions of work that is currently pursued.

Foundations of Cognitively Informed Systems

Cognitively informed systems is a term that represents all computerized systems that carry within their design an assumption or finding made by the science that seeks to comprehend the cognitive system with the intention of offering a clearer channel of communication or interaction with the human user who is likely to access it. The justification for this type of system lies in the fact that interacting with a human being inherently implies that the human will utilize his or her cognitive system during that interaction. As an example from tutoring systems, one may consider that if the topic to be taught is mathematical series, then the designer of the teaching system should be acquainted with concepts such as cognitive load, which is defined as the amount of cognitive processing required to perform an operation. For example, the cognitive load associated with performing an addition of two numbers is less than that required for learning how to add. Information of comparisons between different levels of cognitive load, in addition to the peculiarities of the concept itself, all stem from the field of cognitive science. Unfortunately, although work that is cognitively informed exists, it is dispersed, in most cases ill organized, and rarely subjected to controlled evaluation and assessment. The pioneers include Jonassen (1991), van Jooligan (1999), as well as Albacete and VanLehn (2000a, 2000b).

Jonassen (1991), for example, advocates the constructivist approach to learning where students are given several tools to relieve them from repetitive computation or to externally represent text they are required to recall as is usually done when writing on paper, in order to allow them to focus on the learning task at hand. He adopts the assumption originally proposed by Lajoie and Derry (1993; Lajoie, 1990) that computers fill the role of cognitive extensions by performing tasks to support basic thinking requirements, such as calculating or holding text in memory, which caused them to label computers as "cognitive tools." Jonassen's (1991) central claim is that these tools are offered to students to lower the cognitive load imposed during the learning process, which in turn allows them to learn by experimentation and discovery. However, no experimental evidence was presented to support these claims where students achieved more learning with these designs. By contrast, van Nimwegen et al. in Chapter IV of this book offer counter evidence to show that this reduction does occur but also directly affects what is being learned because students become dependent on the availability of that support.

Wouter van Jooligan (1999) takes the concept assumed by Jonassen a step farther through proposing an environment that allows students to hypothesize and pursue the consequences of their hypotheses. They presented two systems: the first supports the hypothesis formation step by providing several windows that help students form their hypotheses and the second provides a formatted presentation of experiments already tested and their results in a structured manner. They also added intelligent support to the system by providing feedback to students to guide their hypothesis formation approach. This approach supports scaffolding by guiding students toward their target or goal, but yet again the work was lacking a proper comparative evaluation. However, Karen Lee shows in Chapter IX that the discussions do end up much more structured and reflect an increase in knowledge.

Albacete and VanLehn (2000a, 2000b) recognized the cognitive anomaly that exists between the naive students' ill-structured knowledge of conceptual physics and the highly structured knowledge of experts in the field. Consequently their presented system concentrates on teaching students how the various concepts relate to each other. The evaluation of results exhibited no significant differences between the learning outcomes of the control group when compared to the learning outcomes of the experimental group. Albacete and VanLehn (2000b) then utilized alternative means of analysis to highlight various differences in learning between the groups. The first was through measuring the effect size, as done by Bloom (1984), while the second was to compare results to the nationwide score on a standardized test. The third was to consider how much students who have different pretest scores learned when compared to each other. Perhaps the problem that lies here is in the evaluation step of the results rather than the design of the system because results seemed positive in some testing environments and no difference emerged in other testing environments.

Main Areas of Focus in Cognitively Informed Systems

One may notice that the focus here concentrates on specific areas in the design of the computerized system. These include the design of the interface of the system that will interact with the user; they include the logic behind the operations of the system which will comprehend what the user's wishes, report the results desired by the user, or assess various user ability or styles, in addition to the output mechanism, which includes the modes used to display information to the user.

A formalization of the main areas of contribution to qualify a system to be described as a "cognitively informed system" is as follows:

1. *Perception and Recognition:* The aim is to learn from various findings along this track how the perceptual system of the person using the hypermedia is likely to be affected by the presented materials. Questions that may arise include: Is this likely to convey an implication other than that intended by the designer? Or in the case of a medical tutoring system: How can a student's attention be attracted to a particular part of the image or scan of a patient? Several theories exist in this field and the following is just a small sample of some of the findings:

    a. The visual system is very organized and it seems to perceive the world as accurately as possible.
    b. Helmhotz (1821–1894), Bruner (1957), Neisser (1967), and Gregory (1972, 1980) all agree to assume that the stimuli is subjected to a set of hypothesis or postprocessing. This implies that what is perceived is in a sense interpreted and if this interpretation occurs in an erroneous fashion, than errors occur.
    c. There are basically two research assumptions that investigate how a complex item is perceived. Marr and Nishihara (1978) argue that the main axes of an object are utilized to recognize an object. Template theorists argue that the object that is viewed is viewed as a whole, and is then compared to several existing templates in memory to be able to recognize what has been seen. For example, a chair may have a template or form that any newly seen chair can be compared to.

Biederman (1987) follows the feature theorist view in that objects are perceived as a complex object made up of parts. In this case, a chair is broken up into its basic features, what is the shape of the back, what are the shapes of the legs, and so forth.

d. Pattern recognition theories do not regard the context in which the stimulus is presented as influential in the recognition process. They do not regard the interrelationship between the various objects as influential either.
e. Bruce and Young (1986) offer convincing evidence that when people recognize stimuli that is extremely similar to one another as with recognizing faces, then recognizing a familiar face occurs in a different fashion from recognizing an unfamiliar face.
f. Bruce and Young (1986) also found that associating a name with a face is very different from associating information about that person with a face.
g. Gregory (1970, 1980) indicates that many of the classical visual illusions occur because we impose the images we see in the three-dimensional world that we live in onto a two-dimensional image or representation and this causes an error in interpreting it.

These findings are only representatives of what may influence the design of cognitively informed systems. In the field of teaching medicine, for example, it is essential to identify how to highlight the important parts of the image and to ensure that students acquire the ability to recognize them. They will be examining images of high similarity and, as identified by Bruce and Young (1986), may need to carefully review the images they seek to be able to diagnose the problem by making themselves familiar will all of its possible variations. Another issue is to avoid visual illusions that cause the users of the system to be confused by the display.

2. *Attention and Memory:* Once the issues of perception are resolved, one may wonder how to direct the system user's attention to a particular point of focus. Another goal is to encourage recall of whatever is being displayed on the screen. It is not in the systems designer's interest to use a display plan that is highly likely to cause confusion or to lose the attention of the user.

a. Theories of attention focus on limitations in the cognitive capacity to attend to a particular input by explaining possible causes for these limitations through various approaches (Broadbent, 1958; Deutsch & Deutsch, 1963; Treisman, 1964).
b. Hampson (1989) identified that both focused and divided attention are similar in some settings. One of these is when the system offers different modalities because the difference facilitates the division of attention. The reason proposed is that the processes that occur for different modalities are distinct and therefore little interference occurs between them.
c. Wickens (1984) concludes that tasks interfere with each based upon the modality used (visual and auditory), the stages required of processing of each task, and related memory encoding.
d. With respect to memory, a central division has been established between short-term and long-term memory (James, 1890) where the term "short-term memory" was eventually replaced by Baddeley and Hitch (1974) to be "working memory."
e. Atkinson and Shiffrin (1968) indicate that the working-memory model is of relevance to activities such as mental arithmetic (Hitch, 1978), verbal reasoning (Hitch & Baddeley, 1976), and comprehension (Baddeley & Hitch, 1974) in addition to the task of recalling things from memory.
f. One of the basic assumptions is that a learner who is acquiring a skill has to recall the instructions as well as execute them by recalling the given information. For example, someone learning how to drive has to recall how to drive in addition to paying attention to the road and other cars. Once this person acquires the skill of driving, recall is reduced to the road situation because the driving task turns into a motor activity.
g. Craik and Lockhart (1972) proposed a framework for memory based upon a number of different levels of processing, ranging from shallow or physical analysis of a stimulus to deep or semantic analysis. Depth of analysis is defined as the meaning that is extracted from the stimulus.

This is yet another sample that indicates the importance of attention when displaying information on any screen. Multimedia systems find support within this domain as they offer a medium that does allow multiple representations without risking interference. Another issue is that of memory, and here it is dependent on the main goals of the system and what the user is expected to recall following its use.

3. *Mental Representation of Concepts:* Mental representation research concentrates on how information is represented in memory and how different similarities and relationships are stored. For example, if the word "car" is stored as a word, then the visual image of car is stored as an image or word considering the person would describe it as a car. Is the image stored as it was seen or altered to a format that is similar to it?

   a. The first competition was between the two basic approaches to represent knowledge assumed a basis of this science: symbolism versus distributed representations. Neither of the two groups could offer any clear support that either one or the other is redundant (Anderson, 1993; Baddeley, 1986; Marschark, Richman, Yuille, & Hunt, 1987).
   b. The second issue is the difference between written and graphical representations. Kosslyn (1980, 1983) clarifies several basic differences between the two. The first is that linguistic representation is made up of symbols represented in words made up of letters, while pictorial representations have no obvious small components. The second is that linguistic representation has words that stand for things they represent while pictures show what they represent graphically without symbols. The third is that words are organized according to the rules of grammar and graphical representations are not organized according to such rules.
   c. Issues of interference that adversely affects recall rose within this domain as is exemplified by the finding made by Baddeley, Grant, Wight, and Thomson (1975). Subjects were informed of the locations of digits on a matrix verbally while they were visually tracking a light moving along a circular track and they were then asked to reproduce the matrix. Results showed that verbal messages that can be easily visualized are adversely affected, while complex messages that cannot be visualized remained unaffected.

Albacete and VanLehn (2000a) attempted to utilize the findings on the structure of mental representation in physics. They based the teaching strategy of the "conceptual helper" by comparing the unstructured mental representation of students of conceptual physics as compared to the highly structured mental representation of experts. The system, therefore, concentrated on helping students find the "links" that connect the domain concepts to each other. They defined these links as associations that are classically used in semantics to describe a relationship such as that between the concepts "parrot" and "birds" because the first belongs to the category of the second. By doing this, they assumed a symbolic mental representation which is primarily propositional (see, e.g., Collins & Quillian, 1969; Rumelhart & Ortony, 1977).

4. *Natural-Language Comprehension and Generation:* Communication in an educational setting can only be achieved if both parties arrive at a common interpretation of the written text in a hypermedia setting. Here the idea is to give the computer system the ability to communicate with the user through natural language rather than through imposing restrictions such as allowing users to select words from drop-down menus or select names from a list.

    a. Comprehension of text or speech involves the analysis of the grammatical structure of the sentence (syntax), followed by an analysis of the meaning (semantics) and an interpretation of the sentence in order to comprehend the intended meaning. An example is the sentence, "I will buy a toy train; what will you get him?" A possible context for this sentence is that it is said about a boy who is having a birthday party.
    b. Frazier and Rayner (1982) proposed a garden path model which earned its name because it can "lead up the garden path" by ambiguous sentences formed with correct grammar as in, "The horse raced past the barn fell," "When Fred eats, food gets thrown," "Mary gave the child the dog bit a band-aid," and "I convinced her children are noisy." They used this to support the claim that meaning plays no role in determining the initial syntactical or grammatical structure considered by the reader.
    c. There is a general agreement that inferences are drawn during reading. The simplest form is anaphora in which a pronoun or a noun in a text is to identify with a previously mentioned noun or phrase. For

example: "Fred sold John his lawn mower, and then he sold him his garden hose." It requires an inference to deduce that "he" refers to Fred rather than to John.

d. Additionally, there is a great deal of work on story comprehension of which one of the most successful theories was proposed by Kintsch and van Dijk (1978) where they indicated that story processing occurs at two levels: the micro structure where the details of the story are considered at the level of propositions, and the macro structure level where the edited version of the micro structure is formed. The generalization that occurs is of particular interest to learning as some students tend to overlook important details when they generalize learned texts.

e. Text generation by contrast involves generating language in forms as close to "natural languages" as possible and this is subject to various theories. The goals are usually to guide subjects toward self-reflection and defending their own arguments. The setting usually involves an intelligent tutoring system that generates the text according to specific points it notices as in remediation of common errors. In short, this domain is vast, as it incorporates all the findings made in the study of "effective communication" and many findings could be used as a guide.

The primary aim of utilizing these findings is to either generate language or comprehend language in the most efficient fashion, but it can also be to make language more comprehensible to the user of the system. Natural-language generation is no longer a dream and can occur to a limited degree of accuracy, but natural-language comprehension still faces problems.

5. *Reasoning and Deduction:* This area concentrates on the reasoning procedure that humans follow when arriving at any deduction, and there are two basic tracks that are followed: mental models theory and the theory of interpretation.

a. Johnson-Laird and Byrne (1993) indicate that deductive reasoning is a central intellectual ability which is essential: "in order to formulate plans; to evaluate alternative actions; to determine the consequences of assumptions and hypotheses; to interpret and formulate instructions, rules and general principles; to pursue arguments and negotiations; to weigh evidence and to assess data; to decide between competing theories and to solve problems." It is these domains that are affected by attaining an understanding of reasoning.

b. The mental models theory (Johnson-Laird & Byrne, 1991) assumes that models are formed according to preset criteria such that "truth" is reinforced. Students therefore dislike assuming false facts unless they are explicitly stated. In the learning domain this implies that students are likely to accept presented materials at face value rather than question what if an exception emerges whenever instruction does not include concrete examples.

c. The theory of interpretation (Stenning & van Lambalgen, 2004) is based on the assumption that all tasks presented to students in natural language are subject to a number of possible interpretations as dictated by the semantics of the language. Following that, it is quite possible for reasoning to occur in a logical fashion. This allows different learners to associate different interpretations with the same presentation materials if any ambiguities exist and the range of these presentations can be predicted by the logic of the presented materials. An example perhaps is the work done by Suthers, Weiner, Connely, and Paolucci (1995), which attempts to impose a particular "ideal" reasoning structure onto student reasoning.

Although system designers may wonder how this relates to their work as it is a study of human error, the relationship is there. If a site presents a product and then indicates its positive points, then its designer wishes the customer or visitor to make the decision to buy the product. If an explicit negative exists in the promotion, then this may be cue for the customer's cognitive system to decide against buying by raising the possibility of not getting what is expected. Explicit negatives are one of the reasoning to increase doubt in a rule as found by Johnson-Laird and Byrne (1993).

6. *Cognitive Learner Differences:* There are no guarantees that every human is the same in their thought processes and cognitive styles. In fact, differences have emerged between genders and even different types of thinking.

   a. Jonassen and Grabowski (1993) give a detailed account of basic learner differences that are embedded into cognitive learning theory. These include the differences between a visualizing learner who likes to imagine concepts versus the verbalizing learner who likes to learn through verbal communication.

Al Balooshi and Alkhalifa (2002) showed that cognitive differences of being a visualizer or a verbalizer does not necessitate that the person does not learn from the other type of representation. Students of both styles, when presented with a multimedia representation of the two styles, found the "extra" presentation reinforcing their learning rather than interfering with it. Improvements of up to 40% were recorded. Ignorance of these differences may result in an ineffective design of the educational system.

7. *Cognition and Emotion:* Freud (1915, 1943) argued that very threatening or anxiety-provoking material is repressed from gaining access to conscious awareness and in turn cannot be remembered. Based upon this, Gilligan and Bower (1984) indicate that recall is best when the mood of the student at recall matches that at the time of learning. Eysenck (1992) also argued that the main function of anxiety is to detect an environmental threat and as a consequence anxiety may affect how widely focused a student's attention is. Images in a topic such as medicine should be informed of these results.

This list contains all major areas of influence where cognitive science can inform hypermedia system design and evaluation. However, the implementation of this description into practice can only occur through a case study.

Case Study: Multimedia Tutoring System

Cognitive information may be consciously made part of the system design and therefore investigated during the evaluation phase of the system, or it may inherently exist in a classical design without showing any effect until the evaluation of that system isolates the aspects that cause the effect obtained. Several book chapters were offered by Alkhalifa (2005a, 2005b, 2005c, in press; Al Balooshi & Alkhalifa, 2002; Alkhalifa & Al Balooshi, 2003) in order to offer support to the perspective presented here and the means of how the theory can be implemented in actual design.

A concrete example is represented in multimedia educational systems (Alkhalifa, 2005a). The first step was to carefully review all design questions and to consider which aspects of cognitive learning theory may be informative of the desired design features. Once the system was built according to preset criteria, it was subjected to rigorous testing followed by the evaluation stage.

Students were presented with either a classroom lecture in data structures or a classroom lecture followed by the use of multimedia system or the use of the multimedia system alone. Analysis of the results reflected that the system limited their imagination abilities by suggesting examples depicted graphically so that students did not suggest examples other than those displayed. Conversely, the classroom lecture allowed them to imagine various different examples from life. On the other hand, students learned procedures and how things happen from the system more clearly than from a classroom lecture. Here evaluations isolated specific aspects of the results that are of concern to the educator, such as what type of materials is best taught through a particular system, and this could only be done by offering a framework of evaluation that takes into consideration cognitive differences between types of knowledge such as isolating procedural from description knowledge.

Consequently, the work was accomplished in two stages: design and implementation followed by evaluation.

A Cognitively Informed Design of a Multimedia System

Alkhalifa (in press) presented a mapping of the various decisions that a designer may need to take and the corresponding areas that may be of relevance to that decision.

Amount or Complexity of the Media Offered

The decision made here is if more than one media is offered and at what level of complexity. Issues that may be of relevance are as follows:

- Cognitive load
- Limited attention span
- Interference between different mental representations

The decision made was to investigate the effects of two media types in particular, namely, animation and textual representation. The different modalities are not expected to cause any interference except that they do describe the same subject matter. To avoid dividing attention, full control of the animation was given to the student to start it, stop it, and repeat it whenever desired. Cognitive load was considered by allowing the student to take control of the sequence of lessons as well as requiring only minimal interactivity.

How the screen is partitioned amongst the various media or objects displayed

This decision affects the number of objects or windows displayed at the same time and the issues of relevance concerning the person's interactions and attention given to these windows.

- Perception and recognition
- Attention

The screen was partitioned into exactly two parts, the right-hand side had the text and the left-hand side had the animation. Attention need not be divided as the student can start the animation at any time, and colors were uniform for both partitions.

Delivering Information in Parallel through the Multiple Windows

This decision affects the material displayed within the multiple windows and how they affect the user of the system with respect to being complementary or confusing.

- Redundancy could cause interference
- Limited working memory (cognitive-load issues)
- Limited attention span
- Learner difference

The redundancy did exist between the materials, but the representations differed in that one was purely textual and the other was graphical. Differences in cognitive styles also existed and were tested to identify any learning differences between the two types of learners: visualizers and verbalizers.

Use of Colors

This decision affects colors used in the system and how their choice affects the user of the system by attracting attention, for example:

- Affects attention focus
- Perception of edges to promote recall

Most of the animations were as simple as they could be by including only outlines of the object representations to promote recall and attract attention.

Use of Animation

This decision affects the use of animation in the system to simulate changes or transformation.

- Cognitive-load reduction
- Accommodates visualizer/verbalizer learners

Cognitive-load reduction is supposed to occur by actually showing the students the procedure as it takes place in front of them step by step. Yet at the same time, the full procedure was described in a textual form in the adjacent window.

Use of Interactivity

This decision affects the interactivity of the system and the choices it allows users to take to control their use of the system.

- Cognitive-load reduction
- Raises the level of learning objectives

The level of interactivity in this setting was not high. Raising it may cause learners to interact with the animation window and ignore the textual description, so the decision to keep it low was taken.

Aural Media

This decision affects the use of aural cues or reading of materials.

- Speech perception issues such as accent and clarity
- Interference with other media

No aural media was allowed to avoid any external influences.

Verbal Presentation of Material

This decision affects whether textual material appears and natural language issues such as ambiguity and so forth.

- Clarity of communication
- Accommodates verbal/serialist learners

Verbal descriptions were written in very simple English and sentences were as clear as possible, especially since the users of the system speak English as a second language.

Evaluation of Multimedia Systems

The consideration of the presented cognitive areas of relevance will necessitate an adjustment of the classical evaluation framework to assess the effects of the decisions made. A three-dimensional evaluation framework of educational systems may therefore be presented as follows:

1st Dimension: System Architecture

This dimension is concerned with the system's main modules, their programming complexity, as well as their interactions. Evaluation within this dimension should be performed in any or all of the following methods:

- Full description of system modules and complete check of interaction
- Expert survey of the system filled by experts or educators
- Student evaluations to consider their perspective of the system
- Architectural design must be based on cognitive science findings rather than chance
- Everything else concerning the system design such as cost analysis and portability

2nd Dimension: Educational Impact

This dimension is concerned with assessing the benefits that could be gained by students when they use the system. Classically, these are done in pre- and posttests and this is carried on in this framework with more attention given to detail.

- Students grouped according to their mean grade in a quiz.
- Posttests are used to compare one group with system only and another classroom only. A third group attends the classroom lecture with the class group and does a pretest then uses the system before doing a posttest for comparison with the other two.
- Questions in the pre-/posttests must be mapped to each other to test the same types of knowledge, mainly consisting of declarative and procedural knowledge.
- The tests should best be attempted with students who were never exposed to this material previously to assess their learning rate.

3rd Dimension: Affective Measures

This dimension is mainly concerned with student opinions on the user friendliness of the system and allows them to express any shortcomings in the system. This could best be done through a survey where students are allowed to add any comments they wish without restraints.

It should be apparent that this framework could be easily generalized to evaluate any type of hypermedia system by necessitating the inclusion of cognitive science findings in the design and then evaluating their effects in isolation whenever possible to identify the strengths and weaknesses of that system.

Results

First of all, student grades were analyzed using the analysis of variance (ANOVA) test. In order to conduct a significance test, it is necessary to know the sampling distribution of F given the significance level needed to investigate the null hypothesis. It must be also mentioned that the range of variation of averages is given by the standard deviation of the estimated means.

The ANOVA test did indeed show that there is a significant improvement in group two between the first test which was taken after the lecture and the second test which was taken after using the system. However, this was not sufficient to be able to pinpoint the strengths of the system. Therefore, a more detailed analysis was done of student performance in the individual questions of test one and test two. Since the questions were mapped onto each other by design, it was easy to identify significant changes in student grades in a particular question type for students of group two who responded to similar questions before and after the use of the system. For example, a highly significant improvement with $F=58$ and $p<.000$ was observed in the question "Using an example, explain the stack concept and its possible use?" which is an indication that the use of the system did strongly impact the student understanding of the concept of a "stack" in a functional manner.

Another point of view is to examine the scores by using the total average, which is 10.639, which can be approximated to 10.5, which can be used as a border line. The rest of the scores can then be divided around this line. It was noticed that the average score of the third group was not high, yet 10 of scores were above the border line while comparatively 6 scores were above it from the second group and only 6 of group one, which took the class-only option. This shows the results of the third group used the multimedia tutoring system alone and the second group, which had both the classroom lecture and the tutoring system exposure, to be close. It also underlines how much the second group improved their test results after taking the CBI and in the same time showing that the first group had not improved much only with the lecture learning.

These results indicate that the use of the system may introduce a "limiting" effect that follows the initial introduction to the concepts (Al Balooshi & Alkhalifa, 2002). Classroom lectures introduce students to the concepts allowing them all the freedom to select all types of applications, which is in some ways overwhelming. The use of the system, on the other hand, produces a safe haven to test their ideas and strongly pursue the examples they can imagine, which helps them arrive at a solid procedural understanding of the concepts. It goes without saying that such a conclusion would have been impossible to make if the questions were not purposely set in the shown mapped fashion.

Additionally, students of groups two and three who were exposed to the system were asked to fill out an evaluation form composed of a series of questions as proposed by Caffarella (1987). They generally gave ratings of around 4 to 5 on a scale of 0 to 6 with the highest for “The use of graphics, sound, and color contributes to the student’s achievement of the objectives” and “The user can control the sequence of topics within the CBI program,” and the lowest score, which was 3.559, for “The level of difficult is appropriate for you.” Therefore, it seems that the students in general enjoyed learning through the system although they found the level of difficulty of the concepts presented challenging.

In addition to all this, three peer experts filled out evaluation forms to rate the system from an instructor’s point of view and they gave the system an average rating of 5.33 on the same scale of 0 to 6.

Conclusion

The main conclusion made here is that there exists a science that may inform the design of a computer system that interacts with the human’s cognitive system and the suggestion made is to apply the findings to form a clearer channel of communication. The claim that human minds work by representation and computation is an empirical conjecture and therefore may not necessarily be a correct assumption. In fact, John Searle (1992) has claimed that this approach is fundamentally mistaken. Other challenges exist including, for example, that human thought is affected by social interactions or that the mind is dynamic in nature rather than computational. Thagard (1996) indicates that the science exists and is currently expanding to include many different representations and seeks to meet these challenges. Consequently, a conclusion that can be made here is that the question that is posed for cognitively informed systems is not whether the cognitive system is in fact computations, but rather what types of interacts produce which outcomes. When the question is reformulated in this way, the path of cognitively informed system differs significantly from that of cognitive science in that it no longer seeks to fully comprehend what really goes on, so as information about real-world cognitive reactions are monitored and utilized in predicting reactions, thus influencing system design. By this alteration of the research goal, the target becomes practical and assessable.

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Section I

Perception, Memory, and Recall

Chapter II

Hypervideo and Cognition: Designing Video-Based Hypermedia for Individual Learning and Collaborative Knowledge Building

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Abstract

This chapter discusses how advanced digital video technologies, such as hypervideo, can be used to broaden the spectrum of meaningful learning activities. Hypervideo is conceptualized as the true integration of video into nonlinear information structures by means of spatio-temporal links. Based on cognitive-psychological perspectives, the discussion focuses on the way cognitive and socio-cognitive processes relate to the specific characteristics of hyperlinked videos, and how they inform their design. Then, with regard to technology, two approaches are introduced, providing tools for knowledge building and interaction with nonlinear information structures based on dynamic video information. Case studies and research findings are presented and prospects for future research are outlined.

Introduction

New technologies do not only meet existing needs in terms of communication and learning practice, but they can also redefine our educational culture by enabling new learning experiences in resource-rich learning environments (Beichner, 1994). For example, the advent of video technology, including both analog and advanced digital video, has substantially altered some of our traditional paradigms of educational practice in schools and higher education. Film and video technologies can be used to enrich regular lessons and lectures with dynamic visualizations of knowledge that foster a better understanding, to depict concrete real-world problems or cases in authentic ways, or to conduct video projects, a specific kind of media project where students engage in active video production in a motivating and authentic collaborative task (Baake, 1999). However, by itself, video provides a limited support for reflection and it is difficult to relate it to other materials and activities in learning environments.

Hypervideo technology, which refers to the integration of video in hypermedia structures, can provide the additional means to augment video educational capabilities, contributing to learning in several distinct ways: as a presentation medium, it can support self-regulated cognitive processing of dynamic visualizations; as a nonlinear and interactive medium, it allows for interactive learning as well as for reflective and elaborative knowledge building individually or in group (Chambel 2003; Chambel & Guimarães, 2002; Guimarães, Chambel, & Bidarra, 2000; Zahn, Barquero,& Schwan, 2004; Zahn & Finke, 2003; Zahn, Schwan, & Barquero, 2002). These ideas, their underlying assumptions, and the mechanisms for the design and realization of systems that support them in learning contexts will be discussed in more detail in the following sections.

What is Hypervideo?

The term "hypervideo" reflects the idea of true integration of video in hypermedia spaces, where it is not regarded as a mere illustration, but can also be structured through links defined by spatial and temporal dimensions (Chambel, Correia, & Guimarães, 2001; Chambel & Guimarães, 2002). Hypervideo structures may also be defined as a combination of interactive video and hypertext, as they consist of interconnected video scenes that may further be linked with additional information elements, such as text, photos, graphics, audio, or other videos in the hypermedia space (Zahn et al., 2002).

The roots of hypervideo structures lie in the early days of hypertext, when Ted Nelson extended his hypermedia model to include "branching movies" or "hyperfilms" (Nelson, 1974). However, technology has been slow in bringing these ideas to full realization (Chambel et al., 2001; Chambel & Guimarães, 2002). HyperCafe (Sawhney, Balcom, & Smith, 1996) is one of the earliest hypervideos, featuring digital video and revisiting hypermedia concepts in this scenario. Since then, different levels and types of video integration in hypermedia have evolved (Zahn et al., 2002). For example, regarding the media types that are involved in the hypervideo, we might differentiate between:

- *Homogeneous hypervideo*, where video is the only medium involved, consisting of dynamic audiovisual information presented as a continuous stream of moving pictures that can be navigated by the user;
- *Heterogeneous hypervideo* that integrates other media, providing further and related information to the video, or having video illustrate and complement it. For this broader perspective, the name of "video-based hypermedia" or "hyperlinked video" (Chambel & Guimarães, 2002; Zahn & Finke, 2003) is sometimes adopted.

We might also differentiate between different types of hypervideo with regard to their **structure** and **navigational** options:

- Video nodes may be structured in a *network-like* hypervideo, where a substantial number of short video scenes are linked together to be *freely navigated* by the users, as is exemplified in "HyperCafe" (Sawhney et al., 1996).
- A linear film may be divided into single scenes, according to different themes that can be navigated as *thematic paths* in the hypervideo. Depending on the theme specified, different sequences of the film's scenes can be arranged and selected by the users to be viewed in succession. By following different thematic perspectives, viewers are assumed to develop a more flexible mental representation of the structure and content of the film. This concept is exemplified in a well-known hypervideo tutorial for the interpretation of Orson Welles' film *Citizen Kane* described by Spiro and Jehng (1990).

- Another type of hypervideo can be described as a *film supplemented by multimedia "footnotes."* Basically, a "main" film is presented in its original form (i.e., in linear sequence), but contains dynamic hyperlinks attached to visual objects within the video that branch out to additional information elements, such as a text, an image, or another video clip. After having visited the link destination, the users get back to the main video and may continue watching it as before. This type is very similar to hierarchical hypertext.

Hypervideo shares with classical hypertexts the characteristic of being structured in nonlinear ways according to different patterns, offering the users opportunities of taking different "routes" through learning materials and learning processes. This cognitive dimension in the design and use of hypervideo is the main focus of the next sections.

Learning with Hypervideo

An effective design of tools and environments that support learning requires the understanding of human cognition and learning processes. This section presents the main cognitive concepts relevant for discussing video and hypervideo as supporting tools for learning.

Cognitive Modes, Learning Phases, and Learning Styles

Norman (1993) identifies two **Cognitive Modes**: the *experiential mode* relates to a state in which we perceive and react to events in an effortless way, it is about perception and motivation, and good for accretion of facts and tuning of skills; the *reflective mode* relates to comparison and contrast, thought and decision making, essential for restructuring of knowledge. Both are important in human cognition, but they require different kinds of technological support.

In addition to cognitive modes, different *Learning Phases* have been identified for the learning process. The classic learner-centered pedagogy model has three phases:

1. *Conceptualization* of the subject and its domain;
2. *Construction*, where the learner actively engages with the subject, while relating to his/her own knowledge framework;
3. *Dialogue*, where the learner expresses aspects of the emerging understanding and relates this to the understandings of fellow learners and tutors.

Besides different cognitive modes and learning phases in individual learning, people also develop different *Learning Styles*, or cognitive preferences, that determine the ways of learning best suited to them. There are many theories, models, and instruments to determine learning styles, but they are all essentially based on the idea that individuals perceive, organize, or process information differently (Chambel & Guimarães, 2005). Examples of these theories include the VARK Perceptual Learning Styles (Fleming, 1995), distinguishing four styles: visual, aural, read-write, and kinesthetic; the Kolb's Learning Styles Inventory (Kolb, 1984), identifying four styles: reflector, pragmatist, theorist, and activist; and the Howard Gardner's Theory on Multiple Intelligences (Gardner, 1983), identifying eight intelligences: verbal-linguistic, logical-mathematical, visual-spatial, musical-rhythmic, bodily-kinesthetic, interpersonal, intrapersonal, and naturalist.

This differentiation suggests a need for a flexible support of different styles. An ideal learning environment would support all the learning styles, with the flexibility to allow each learner to spend more time on his/her preferred style, and induce the development of skills in nondominant styles.

It is important to note in this context that not only different individuals, but also possible interactions between different individuals in learning groups might be considered. The dialogue phase and some learning styles, like the one underlying the interpersonal intelligence, already refer to this interactive dimension, but learning in groups involves more specific aspects that will be addressed in the next section.

Learning in Groups: Group Learning

Although learning in the long run is always based on individual cognitive processing, it is at the same time situated, process oriented, and related to social activity (Salomon, 1993). Many theorists of educational psychology and pedagogy therefore argue that intelligence is not an individual property but distributed within socio-technical systems (Pea, 1993) and that most learning occurs within a framework of knowledge communication and knowledge-related cooperative and collaborative action (Salomon, 1993; Scardamalia, 2004). Such a framework can be provided, for example, by collaborative problem-solving tasks including collaborative activities such as writing texts or editing hypertext and multimedia (Beichner, 1994; Scardamalia, 2004; Stahl, 2002).

The educational value of such collaborative tasks may be seen on both a motivational and a socio-cognitive level. On the *motivational level*, the experience of solving a complex problem or designing any kind of product in collaboration with others (peers, teachers, etc.) and thereby using a modern and culturally extended technology (computers, software, authoring tools, and video) can promote a feeling of importance (Carver, Lehrer, Connell, & Erickson, 1992) and improve the self-conceptions of learners (Lehrer, 1993). It may also particularly increase feelings of becoming a competent member of a "community of practice" (e.g., Penuel, Korbak, Cole, & Jump, 1999).

On the *socio-cognitive level*, collaborative tasks serve as a setting where individual knowledge interacts with group knowledge. Applying Salomon's (1993) spiral interaction model, we can assume that repeated interactions between individual knowledge and group knowledge during discussions and discourse steadily lead to higher levels of knowledge related to both individual cognition and to the knowledge resources of the group. The basic argument underlying such positive expectations derives from developmental psychology, where individual cognitive development is generally assumed to be facilitated most where it naturally occurs from the very beginning of life, that is, during the social interaction with significant others and during peer interactions (e.g., Vygotsky, 1978). Or in terms of contemporary computer-supported collaborative learning (CSCL) theory, individual knowledge develops best within group knowledge processes involving both socio-cognitive processes and cultural artifacts (Stahl, 2002).

Group knowledge is also referred to as "shared knowledge" or "common ground" (e.g., Baker, Hansen, Joiner, & Traum, 1999). In contrast to individual knowledge, group knowledge must be identified, negotiated upon, and *expressed in the form of shared information* during different phases in collaborative knowledge acquisition. Group knowledge is developed by learners acting collaboratively on shared information such as texts, images, or even dynamic videos or animations. Activity contexts for interactions between learners should be provided for groups to develop this common ground and to express their shared knowledge in a shared information environment.

After having outlined the general arguments in favor of flexible support for learning, we will consider in the next section why and when using dynamic visual materials and video, in particular, might be a good choice.

Video as a Cognitive Tool

There are a number of topics or problems that can hardly be understood without using dynamic visual materials as a referential basis. Imagine, for example, geography students exploring the formation of a thunderstorm (Mayer, 2001), or a group of school children trying to understand Newton's laws in their physics class. In some learning situations, videos or animations are not only a desirable but an important prerequisite for successful learning to take place. From a cognitive perspective, audiovisual materials support learning:

- By *"replacing" real experience*, because of their authenticity and realism, which evoke feelings of "observing real situations" (Schwan, 2000). Concrete real-world problems or cases can be depicted in authentic ways and then related to more abstract knowledge and problem-solving skills. This is illustrated, for example, by the famous "Jasper Woodbury Series," a set of interactive videos developed by the Vanderbilt University in the late 1980s and 1990s for complex mathematics problem solving (Cogntion and Technology Group at Vanderbuilt University, 1997). Here, video is supposed to help to situate knowledge for the purpose of "anchored instruction." It could be shown in an experiment that those groups of students who were asked (a) to pose their own subordinate questions while working with the video and (b) to self-dependently find the relevant information to answer these questions in a video episode, outperformed other groups of students who just viewed the video episode and received general text-based information on problem solving unrelated to the video (Van Haneghan, Barron, Young, Williams, Vye, & Bransford, 1992).
- By *visualizing dynamic processes*, which might not be observable in reality or which are hard to describe verbally (Park & Hopkins, 1993). Empirical findings on learning with video media consistently show that audiovisual presentation formats facilitate the comprehension and transfer of knowledge, especially in those domains where dynamic processes and concrete objects or complex systems need to be observable for a proper

understanding of the topic (for overview, see Wetzel, Radtke, & Stern, 1994; Park & Hopkins, 1993).

- By *combining diverse symbol systems*, such as pictures, texts, and narration, into coherent media messages (Mayer, 2001). The specific qualities of video presentations are supposed to support the construction of rich mental representations and, by dual coding (Paivio, 1986; Mayer, 2001), improve the transfer of knowledge.
- Through the *conducting of "video projects,"* where learners engage in active video production, relying on an idea sometimes described as "learning by design" (Reinmann & Zumbach, 2001) or "project-based learning" (Baake, 1999; Bereiter, 2002). Video is not only used to present information or situate a problem to be solved; creating video artifacts is the problem to be solved.

In accordance with these assumptions, empirical findings have consistently shown that dynamic media facilitate the comprehension and transfer of knowledge in individual learning (Park & Hopkins, 1993; Mayer, 2001). In specific *collaborative scenarios*, video can also be considered supportive for cognitive processing. For reasons similar to those in the case of individual learning, video is helpful when meaningful collaboration depends on visual perceptions of concrete objects, actions, or complex relations; and when knowledge is created within networked groups, where learners do not meet in the same place at the same time and, hence, cannot observe the same things in the same situation. In these cases, video might support mutual understanding by acting as a referential anchor for collaborative activities.

To summarize, video, as dynamic and figurative information combined with verbal audio, forms a powerful means of communicating meaningful scenarios rapidly and efficiently (LiestØl, 1999; Paivio, 1986). It can bring context to topics and enhance the authenticity of a computer-based learning environment, thus fostering what Norman (1993) called an experiential cognitive mode. However, to allow reflection, a system must have a medium that affords adding, modifying and manipulating representations, and performing comparisons. It must also afford time for reflection, elaboration, and comparison processes. Broadcast television and most videos are usually watched in an experiential mode and cannot augment human reflection in this sense (Norman, 1993). According to Eco (1979), the lack of communication and debate is also an important drawback in television teaching capabilities. He claims that learning should take place in a broader context where discussion could happen.

The Role of Hypervideo

Television and video could also be a powerful tool for reflection, if designed in a way that would allow the viewer to select what to watch, to control the pace of the information flow, to stop and make annotations, and to relate to other materials or to other people's points of view (Correia & Chambel, 1999; Norman, 1993; Zahn et al., 2004).

Hypervideo technology can provide this kind of support to the different learning modes, phases, and styles, and integrate an environment that allows the communication and collaboration among learners, teachers, and other experts on the subjects at hand (Chambel & Guimarães, 2002; Correia & Chambel, 1999; Guimarães et al., 2000; Zahn et al., 2002; Zahn & Finke, 2003). Hypervideo might promote learning in its main modes and phases for different individuals by providing and supporting:

1. *Interactive access* to rich audiovisual information, contextualized in video-based hypermedia spaces;
2. *Construction of knowledge* in a sense of relating concepts and expanding on them, using annotations and cognitive maps;
3. *Communication*, allowing the debate of ideas, the exchange and sharing of information and knowledge, or the collaborative elaboration of the previous hypermedia spaces.

By allowing the viewer to watch video in his/her natural experiential mode and by inducing and supporting more active and reflective attitudes through control, comparison, and annotations, hypervideo can support both cognitive modes suggested by Norman (1993). Its ability to integrate heterogeneous media and activities also allows the support of diverse learning styles and the interaction between different learners.

However, all this power is accompanied by potential complexity and may not be used to its best in all cases, especially for learners and authors with little experience and background knowledge. Hence, design guidelines play an essential role in the authoring of effective hypervideo spaces (Chambel & Guimarães, 2002; Zahn et al., 2002).

Design for Learning with Hypervideo

Hypervideo shares with traditional hypermedia the potential of an increased *cognitive load* that might also lead to *disorientation* (Conklin, 1987; Nielsen, 1995). But in the case of hypervideo, this kind of problem might be even more pronounced. Due to its richness, video itself sometimes carries with it the risk of overstraining the cognitive capacities of the learner; and the dynamic nature of nodes and links may put time pressure on the users, when they are required to make navigational decisions (Zahn et al., 2002). The integration of a dynamic medium, like video, with static media, such as text and images, also raises important rhetorical and aesthetic challenges to hypervideo, since they induce different attitudes in the user (Chambel & Guimarães, 2002; LiestØl, 1994; Sawhney et al., 1996). It is important to avoid discontinuity, especially when navigating from a passive video watching to an active text-reading experience.

The effective design of hypervideo spaces may greatly benefit from following guidelines that help to face the extra challenges video brings to the scenario, and from an adequate support from the underlying systems that bring these hyperspaces to life, as exemplified in the next two sections. Many of the mechanisms adopted for hypermedia need to be extended for hypervideo in order to accommodate its increased complexity, and should address the provision of (Chambel & Guimarães, 2002)

- *Control*, to be able to navigate the videos and the hyperspace, for example, extra mechanisms have to be available in order to provide users with information about the existence (where, when, for how long) of links on the video — "link awareness" (Chambel et al., 2001), a more complex issue in hypervideo, since video changes in time;
- *Consistency* and *coherence*, in terms of structure, interface, and navigation to reduce cognitive load (Zahn et al., 2002);
- *Context* for orientation purposes, for example, through the synchronization of video with navigation maps;
- *Familiarity*, for example, through the adoption of metaphors, such as television, books, and traveling; and
- *Continuity*, especially when navigating between dynamic and static media, for a sense of unity and coherence.

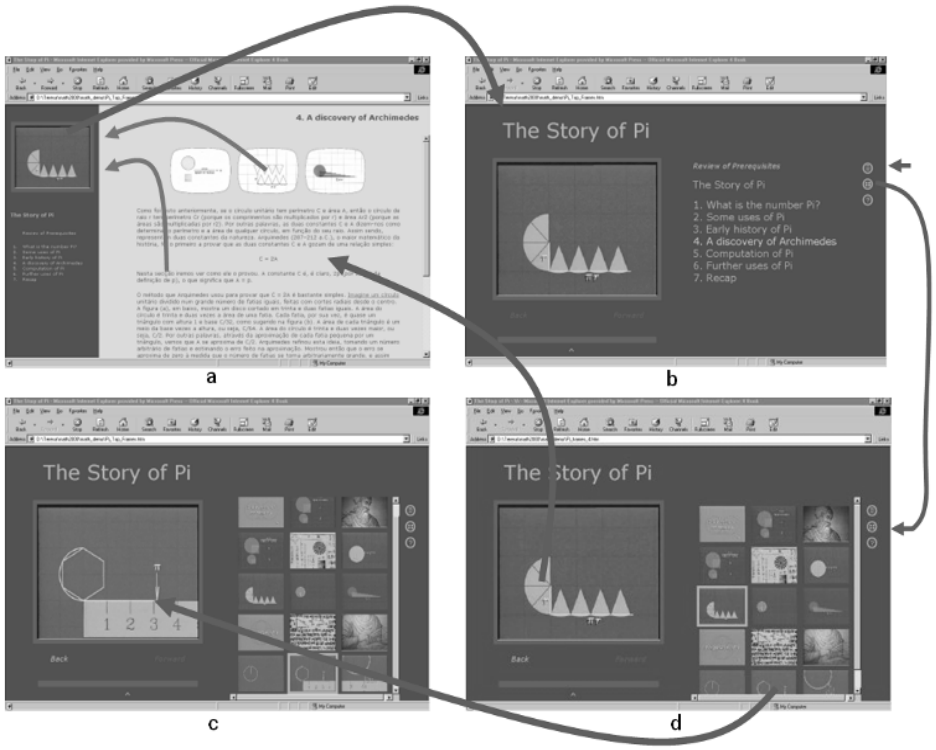
Thus, it is a basic necessity to think carefully about how to adapt technology to the cognitive prerequisites of potential hypervideo users, thereby setting the groundwork for effective and satisfying learning to take place. The design approaches specified in the next sections encompass the following: (1) information is mainly presented by audiovisual media, (2) knowledge can be created collaboratively on the basis of video presentations, by means of both linking information and annotating, and (3) the process of knowledge building is reflected in resulting visualizations in the hypervideo structure.

Hypervideo in HTIMEL

To explore the use of hypervideo in learning environments, we developed the HTIMEL (HyperText Markup Language with Time Extensions) model and language, as an extension to HTML and existing Web tools (Chambel et al., 2001). The temporal dimension was considered to allow the addressing of video in space and time, for the definition of link anchors, and to synchronize media elements. New forms of integration, annotation, and navigation of video in hypermedia were conceived, with a special concern to the support of cognitive processes. These tools were used to create course material, mainly in literature and mathematics, following our ideas about the way video should be integrated and augmented to support learning (Chambel & Guimarães, 2002). Case studies were developed at the University of Lisbon, in collaboration with the Portuguese Open University, in the context of literature distance learning, and with the Center for Mathematics and Fundamental Applications at the University of Lisbon, the California Institute of Technology, and the Technical University of Berlin, for the communication and learning of mathematics.

Figure 1 illustrates one of our case studies. The information is organized around text-based and video-based pages that closely relate to the book and videotapes that were originally used in the course. Through their integration in hypervideo, relations among them could be fully captured, maintaining the original context. In text-centered pages (Figure 1a), video is integrated as an illustration that is played when the hypervideo links defined in the text are followed. While keeping some familiarity with the book metaphor, the user has an augmented experience of text reading.

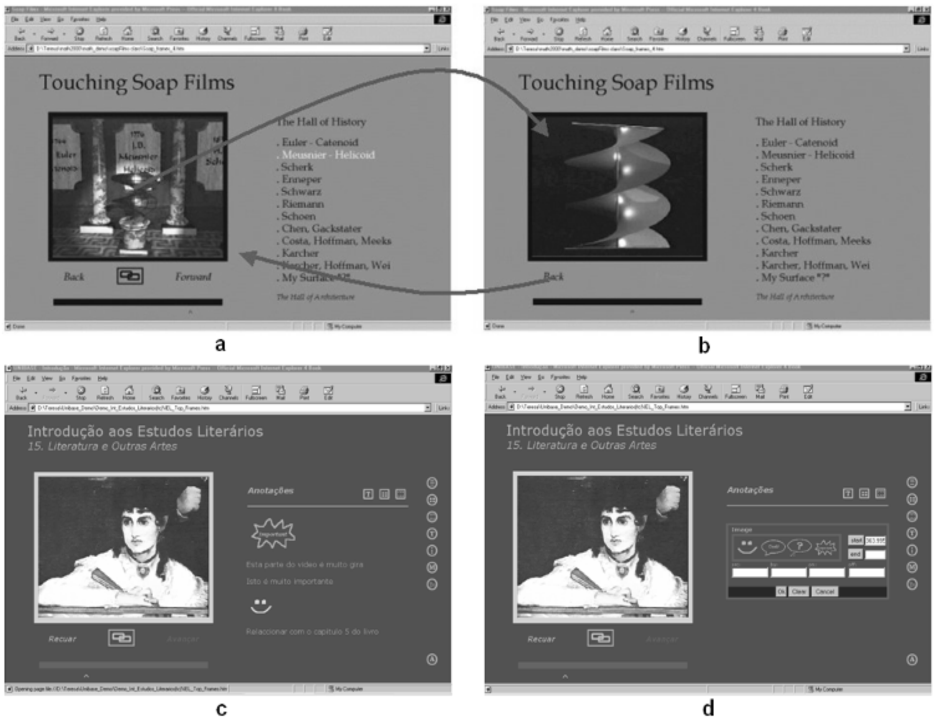
Figure 1. Hypervideo example in HTIMEL



The user may focus on the videos through video-centered pages (Figures 1b, c, d), where the whole video can be played. Indexes, synchronized with the video, make the video structure explicit, provide for user orientation, and can be used to navigate the video, handing control to the user. Different types of indexes act as different views or maps of the video. For example, a table of contents (Figure 1b) represents the video structure, whereas an image map (Figures 1c, d) is a visual summary of the video; a cognitive map represents its knowledge structure (Guimarães et al., 2000), while user annotations (Correia & Chambel, 1999) capture a personal view of the video (Figures 2c, d), and exercise maps (Chambel & Guimarães, 2002) relate activities and quests to video content. In video-centered pages, while keeping some familiarity with the TV/video metaphor, the user has an augmented experience of video watching.

Links can also be defined among different parts of the video, addressed in space and time, allowing the user to navigate it through related information (Figure 2a–b), or among portions of video and text (Figure 1d–a), comple-

Figure 2. HTIMEL (a–b) spatio-temporal link from video to video, and navigation history; (c) annotations map; (d) insertion of an image annotation to video



menting or contextualizing the information conveyed by each of them. Another type of video linking is achieved through video montage. Authors can assemble video segments to make personalized versions of their favorite movies; and a teacher can make available portions of a video, in a particular order, to illustrate concepts in a context where the original video would not be so efficient or concise. Thus, it provides the means to construct hypervideo paths.

Navigation history is recorded and lets the user go backward and forward along visited nodes in the hyperspace (Figure 2b–a). When following from video centered to text-centered pages, video or audio may provide context and smooth the transition from an experiential to a reflective medium. This was adopted when accessing exercises from a video on the Story of Pi. When arriving at the text-centered page, the portion of the video introducing the solid the exercise refers to is played, promoting continuity in navigation.

Navigation can also be made through a timeline, positioned beneath the videos in the presented examples. It provides direct access to any position on the video, in a continuum, and in this sense it contrasts to video indexes that give access to specific positions in a discrete space. HTIMEL timelines also play a part in link awareness, representing the source and/or destination time interval, when the cursor is over any link that involves the video in the context. Besides, while the cursor is over the timeline, all the context changes, reflecting what would happen if the video was to play from that position, providing for context awareness. Other forms of link awareness mechanisms are discussed in (Chambel, 2003; Chambel & Guimarães, 2002). Being developed for the Web, these hypermedia spaces allow an easy integration of communication mechanisms. Students may then create their own versions of hypervideo documents, expand upon the original ones, through annotation, and share them with colleagues and teachers.

From our studies and experiences, we conclude that students are more motivated to watch the videos in this type of hypervideo than in traditional settings, as the process becomes more flexible and engaging; and it is easier to search for information and to capture the videos' messages through the different maps available. Video course material, as rich as it is, is better used in a reflective mode if presented in a way where the content or knowledge structure is made explicit. The full integration of video in hypermedia also allows the capturing of important relations between video and other media, like text, through contextualized explanations and illustrations that promote deeper understandings of the different materials. Different learning styles are also

Figure 3. HTIMEL code for video with a spatio-temporal link

```
<DIV ClassName="HTIMEL_Video" ID="video1"

     activeColor="#EAAB4D" inactiveColor="#993347"
spotColor="#FFFFFF">

  <OBJECT CLASSID="CLSID:05589FA1-C356-11CE-BF01-00AA0055595A">
         <PARAM NAME="FileName" VALUE="E:HPi.mpg">
  </OBJECT>

  <MAP name="map1" orgT1="226" orgT2="230">       <!-- spatio-
temporal link from video-->
    <AREA shape="rect" coords="132, 131, 238, 242"
     ClassName="HTIMEL_link" destT1="1455" dest="video1">
<!-- to video-->
  </MAP>
  ...
</DIV>
```

supported, through the integration of different media and perceptual modalities, interactive, and navigational choices (Chambel & Guimarães, 2002; Guimarães et al., 2000).

From a technical perspective, HTIMEL is an extension of HTML. New elements and attributes were defined, and their functionality is supported by a set of scripts that are generic, reusable, and almost transparent to the author of the hyperdocument. The authoring process is done in a declarative way in HTIMEL. The current prototype is based on Dynamic HTML and uses VBScript language and ActiveMovie technology. Scripts deal with these language extensions, acting as a browser extension, in order to make the declarative authoring possible, without the need for plug-ins or the development of a different browser. Figure 3 exemplifies the definition of a spatio-temporal link from video to video, like the one presented in Figure 2a–b.

The adoption of a declarative format allows the externalization of documents' behavior and provides for maximum portability and reuse of created documents. While programming-based approaches may offer some performance advantages in the short run, a declarative approach provides wider access to quality information with less author effort. It contributes to easier authorship, either using a simple text editor or through automated production. Open and flexible production frameworks that use video and audio processing techniques, for segmentation and indexing, were conceived to automate the authoring of hyperdocuments with markup languages like HTIMEL (Chambel, 2003). The image map presented in Figures 1c and d and the alignment of the video with the text transcriptions of its audio, in text maps, were constructed this way. From both cognitive and technical perspectives, HTIMEL has had good results as a proof of concept approach.

Dynamic Information Spaces (DIS)

To explore the use of hypervideos in collaborative learning scenarios, the Hypervideo System presented in the following paragraphs was developed. Here, hypervideo is conceptualized as a complex dynamic information space (DIS), where learners may add their own materials to selected video objects and make specific annotations, while collaboratively expanding their knowledge on the topic at hand. The general approach is aligned with considerations of cognitive psychology and theories of CSCL (Stahl, 2002).

Thereby, the system provides specific facilities to jointly elaborate on video materials and to change a hypervideo presentation according to the development of knowledge present in any group. Accordingly, a hypervideo document can be changed and extended as a basis to share knowledge and to communicate within a community. The underlying model of the dynamic information space defines three categories of content types (annotated video, additional information, and communication contribution) as separate nodes. Video sequences, which contain sensitive regions, are denoted as annotated videos. Additional information, which is linked to objects in the annotated videos, can be of any kind of multimedia content (text, pictures, graphics, etc.). Communication contributions are the outcome of group conversations and can be linked either to video objects directly or to the associated additional information units.

The Web-based HyperVideo System is based on a client-server architecture. The DIS containing the content of the hypervideo is stored entirely at the server side preventing the users from any form of data inconsistency. The clients are allowed to extract (presentation mode) and to integrate (authoring mode) content to and from the DIS on request. The Web-based graphical user interface basically consists of a special video player that presents visually the spatio-temporal hyperlinks besides the movie sequences within the video display and offers functionalities in order to create new video annotations.

The cross-platform video player itself is written in JAVA using the Java Media Framework for the purpose of manipulative video rendering. Newly created video annotations are immediately transferred from the client to the server in order to be instantly shareable by the community. The system concept allows the adaptation due to different GUI layouts. Thereby different end-device types can be supported. Figure 4 shows the overall system architecture concept of the collaborative hypervideo system, as suggested by Finke and Balfanz (2004).

The human-computer interface concept is based on a view model (see Figure 5). This model allocates for each node type (annotated video, additional information, and communication) a separate view within the graphical user interface. In addition, a fourth view is introduced that enables the disclosure of the hypervideo structure in order to support user orientation within the graphical user interface.

Each view provides its own user interface to access certain parts of the dynamic information space (see Figure 5). By means of these interfaces, a user can initialize so-called system events, for instance, the activation of a hypervideo

Figure 4. DIS: System architecture

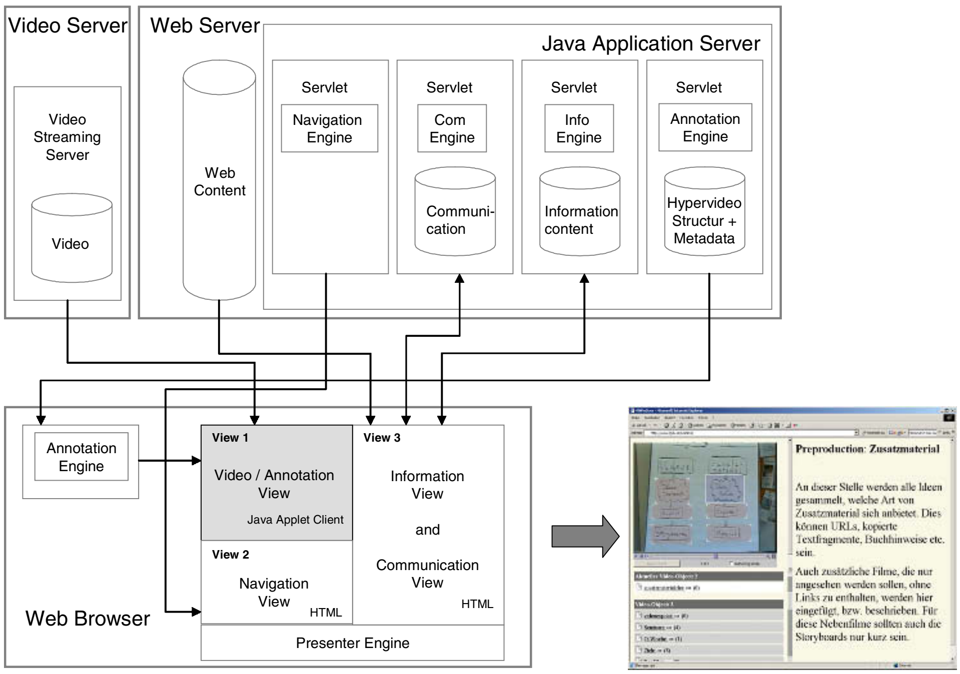
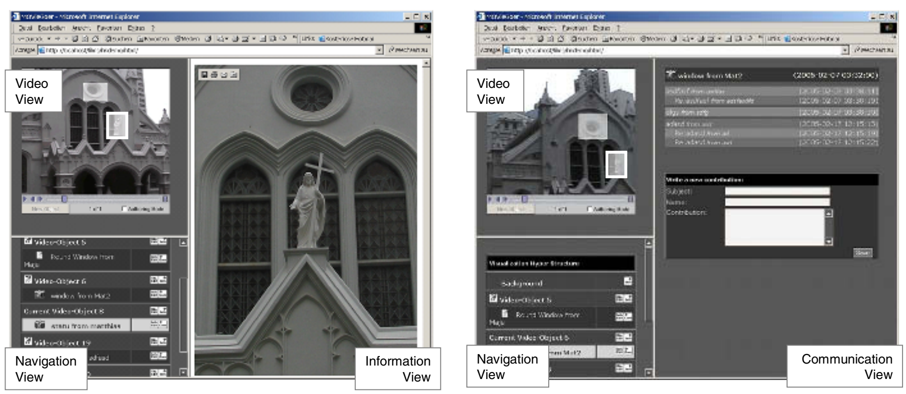


Figure 5. DIS: Examples of the graphical user interface showing the different views



link, by clicking on an object in the video view. Each view offers a number of different facilities:

- *Video view:* The video view presents video sequences containing video annotations. By means of VCR functionalities, a user can control the tempo of the presentation. The existence of a video annotation is announced by the visualization of its sensitive region within the video display. Since it might be disturbing in some learning situations, the user is in charge of initializing the visualization process of sensitive regions. Hypervideo links can be activated by clicking on the corresponding sensitive region with a mouse pointer. Furthermore, the video view is used by the user to generate a sensitive region, which defines the anchor of a hypervideo link;
- *Information view:* Within this view, the information nodes are displayed, which are linked to sensitive regions in the annotated video sequences. The information view offers the definition of hypervideo links. Thereby, more than one information node can be linked to a sensitive region in the video view (multiple link strategy);
- *Communication view:* The communication view presents the group conversation in the form of text-based dialogs. Users can reply on existing conversation or start a new dialogue. Thereby, a dialogue is always related to an object in the video or to a specific information node. This provides us with the opportunity to combine conversations with associated subjects within the hypervideo. The advantage is that a user has a fast access to specific conversations and does not have to go through the entire communication contribution created by the community;
- *Navigation view:* Within this view, the disclosure of the hypervideo structure is presented in order to support user orientation. The arrangement of all node types within the structure is visualized in a text-based manner. Users can browse the navigation view and activate hypervideo links, which will lead to the presentation of the content in the associated views.

The development of the Web-based user interface based on the view model was paralleled with experimental work on learning with hypervideo environments and case studies in the context of university teaching. The experimental research was conducted at the University of Tuebingen in Germany, in cooperation with the Computer Graphics Center at Darmstadt in Germany with an earlier version of this HyperVideo System. Results revealed that hypervideos provide a very successful mode of learning, also positively acknowledged by the satisfaction of the 74 subjects. Results further suggest that slight variations in design options concerning position and number of links to additional information did not significantly influence navigation and successful knowledge acquisition in individual learning, but individual strategies and navigation behavior, including exploration activity, redundancy, and duration of links activated, were significantly and positively correlated with knowledge acquisition (Zahn et al., 2004).

Our current research projects focus on collaborative "learning by design" and include an implementation study with two media psychology courses at the Universities of Muenster in Germany and Linz in Austria (Stahl, Zahn, Schwan, & Finke, in press). In this project, about 30 advanced psychology students collaboratively designed hypervideo structures on "presentation techniques." Results indicate a great general satisfaction with the work of crafting hypervideos with the system.

Conclusion and Perspectives

From a cognitive viewpoint, video can be considered a powerful referential anchor, serving to stimulate and facilitate both individual and collaborative processes of learning and knowledge building, particularly in specific domains such as the natural sciences, which rely heavily on visual phenomena. Video provides context information in an efficient way but has limited advantages to reflective learning. Hypervideo additionally allows more control and the composition of rich and flexible knowledge structures, corresponding to enriched mental models. Learners may also express their internal knowledge structures externally and share and discuss them with other students. Thus, hypervideo provides a better support to reflection and learning, in accordance with learners' individual needs and styles, at different learning phases (Chambel & Guimarães, 2002; Guimarães et al., 2000; Zahn et al., 2002).

From our experiences, we concluded that the ability to integrate video in rich hypermedia spaces enables learners to create rich representations and promotes deeper understandings. It improves both text and video understanding due to the contextualized explanations made possible by the integration of both materials. Important relations with video information can be captured. However, there are some main challenges, including the management of a potentially high cognitive load in processing information based on hypervideo, and usually significant investments involved in the production of multimedia and video-based products. The definition of design guidelines and the development of effective and flexible production frameworks and authoring tools can help to meet these challenges. Some work has been done in this direction (Chambel et al., 2001; Chambel & Guimarães, 2002; Zahn et al., 2002, 2004), but more research needs to be done.

Our directions for future research, either from a cognitive and technical perspective, include new developments in tools and design guidelines for hypervideo in different environments and contexts of use. This process involves the definition and evaluation of new mechanisms to support individual and collaborative learning with video on the Web and also in interactive TV and mobile environments. It also includes the interaction with video augmented books, furthering our previous research on hypervideo and digital talking books. In collaborative learning, for example, a project will investigate the interactions of modern hypervideo technology with individual cognition and teachers' instructions while supporting group discussion. The topic at hand will be "persuasive strategies of TV advertising," for media education in secondary schools, and the learning goals include visual and digital literacy skills. The main focus will be put on students' communication patterns, collaborative hypervideo design processes, and the groups' products. In summary, we intend to explore a broader approach to the support of individual and collaborative learning, inspired by field studies in different learning contexts that might raise specific challenges and require differentiated support.

Our cognitive relation with video is not only experienced in formal learning. Most of the considerations made and the approaches proposed also apply to many other applications, including situations of informal learning and art works. Because video has important communicative, entertaining, and artistic properties, hypervideo can be used to support new forms of expression in new media (Url-nm) in many areas of culture and entertainment, for example, in interactive cinema, electronic literature, and museums. These areas can benefit from many of the mechanisms developed for learning environments, but they may as well raise new challenges that will inspire new methodological and technological developments.

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Chapter III

Assisting Cognitive Recall and Contextual Reuse by Creating a Self-Describing, Shareable Multimedia Object

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Abstract

Digital media elements, or digital assets, are used to illustrate things such as images, sounds, or events. As humans, we use many senses to assist our cognitive processes, and providing multiple representations will enhance our ability to store, recall, and synthesise the knowledge and information contained in the digital asset. This chapter introduces a model for a multimedia object, that allows multiple representations to be managed, and includes a structured metadata file describing the asset that captures the original context. Humans are capable of classifying and describing

millions of such objects, but recalling context and content often blurs over time. Computer systems provide us with a way to store electronic objects, and with a variety of representations and sufficient metadata they can be used to assist cognitive recall.

Introduction

With the large number of digital assets available on the Internet, it has become common practice to use and reuse these elements in many different contexts. A significant problem that occurs is that the original context and associated metadata gets lost. When the digital assets, such as images, sounds, or videos, are created, they have specific properties and they exist in a specific and describable context. Electronic elements have derived properties, such as a type and size, and can be automatically generated. If the element is part of a group, then common properties could be described and would include such things as the author, possibly the location, and maybe some contextual information such as the event. This metadata could be created in a template and automatically added to the description of an element. Annotated information that describes the element can also be attached to the metadata.

Humans are capable of classifying and describing millions of such objects. For example, for image, the scene information may be retained in short- or long-term memory, and for most individuals, the details will blur over time. Computer systems provide us with a way to store electronic objects, and with sufficient metadata, they can be used to aid in classifying, managing, searching, and reusing these objects in a variety of contexts whilst still retaining their original context.

This chapter describes a model that allows a digital asset to be described in its original context, captures ownership details and annotated metadata, and allows for multiple representations. As humans have variable memory capacities, the representation of a digital asset as a multimedia object will assist multiple cognitive processes by providing appropriate metadata and alternative representations.

The proposed metadata model is based on commonly used standards and utilises eXtensible Markup Language (XML). Standards included are the Semantic Web's Resource Definition Framework (RDF), the Dublin Core (used by library systems), and vCard which is used to identify individuals.

Need and Importance of Context: Russian-Finnish Border "Misplaced" Context

Consider the images shown in Figure 1, which were taken on a bus trip to the Russian-Finnish border.

If a presentation were to be constructed by a person who was not on the trip, and was searching for an image from a media repository, it would be more likely that the image on the right would be chosen as the one from the actual Russian-Finnish border. In fact, the image on the right was taken at a tourist stop where a "fake" border was constructed, while the other was taken at the actual border. This is a common problem when sourcing media from a huge repository such as the Internet, where the context of what is being reused is lost.

Problem of Missing Context or Loss of Context

There is significant research being undertaken in the area of deriving context, by major organisations such as IBM and Google (Fallows, 2004). For example, Google (n.d.) provides an image search facility, where keywords are used to locate an appropriate image. The keywords are generated from the context in which the image was found. Unfortunately, this can provide many negative hits, for example, on a page, there can be images of a logo, navigation buttons, unrelated advertising, and so forth.

Figure 1. Photos taken during a visit to Russian-Finnish border

Need for Metadata

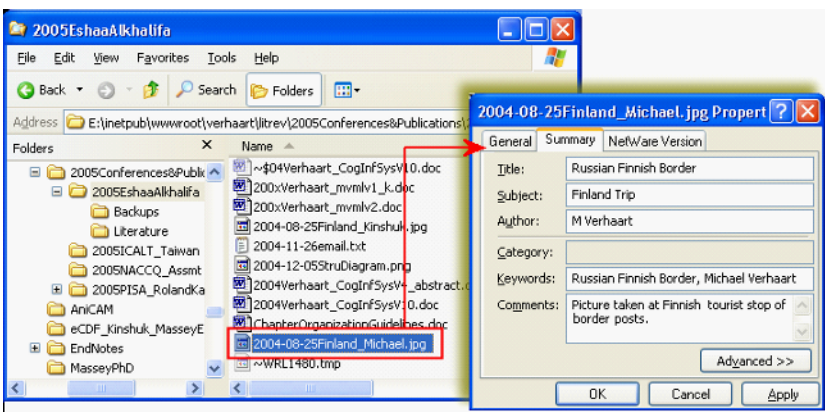
So how can this contextual information be added to a media element? Data that describe the properties of an object are referred to as *metadata*, and are commonly referred to as *data about data*. Many file types have a built-in ability to add information about the element. For example, in Windows Explorer, right clicking on a jpg file, selecting *Properties,* and then *Summary* displays the editable information as shown in Figure 2.

The ability to attach with an object the data about that object gives us the ability to describe the object's context.

Need for Multiple Representations

In the example shown in Figure 2, an image can be represented in two ways: as a photo and as a textual description. The usage will depend on the context, and additional representations may be desirable for appropriate representation in different situations. For example, if a gallery of images is to be displayed, the image needs to be represented as a thumbnail. If the image is to be displayed on screen, then it should be sized accordingly, that is, for a screen display of an image from the Web, download of a 5 MegaPixel digital camera photo (say 2.5 MB) is not necessary; a 1 MegaPixel image (350K) will suffice (CardMedia, 2004).

Figure 2. jpg file metadata



Carrying this further, if a video media element is being displayed, four representations are desirable: a thumbnail, a static image that is representative of the video, the actual video, and a textual description of the video. When a video is displayed on a Web page, the first frame is rendered on the screen. For example, a video of a kiwi bird may start with a clip showing just a bush scene, which progresses to the kiwi. Therefore, the first frame may not assist in identifying the contents of the video and an alternative static image would be desirable. The textual description is used for searching and for providing an alternative representation for those with visual impairment.

Therefore, a desirable feature for working with electronic media is the ability to manage multiple representations. This allows for an appropriate format to be displayed to an end user depending on the required context.

Creating Shareable Digital Assets and the Need to Retain Contextual Information

Commonly, the term *digital asset* is used to describe a media element. This can be an unstructured media element, such as text, an image, an animation, a sound, or a video, or a structured media element, such as a word-processing document (typically contains text and images though it is possible to include animations, sound, and video), a spreadsheet, a database, and so on (AOL Time Warner Group, 2003). The form in which a digital asset is presented should not only retain the appropriate contextual information but also present it in the most appropriate form.

What Contextual Information is Required?

A title is probably the most significant piece of contextual information, followed by the creator of the digital asset. This information can often yield a significant amount of implicit knowledge (Dienes & Perner, 1999); for example, an image of a forest with small upright silver birches may indicate to someone a Finnish landscape. Referencing information, such as the source, publisher, and, on the Web, universal resource locator (URL), would be important for digital assets.

Situational annotations, where the media element is described, are also an important part of the attached contextual information. For example, the image of the Finnish forest described previously would have no specific or contextual meaning to anyone who could not identify the scene information such as the trees in Finland.

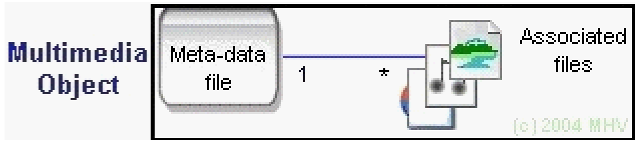
User annotations (annotations made by someone other than the author) also enable contextual information to be attached. Consider the case of a painting by a famous painter such as Picasso. Annotations added by an expert on Picasso's paintings would greatly improve the contextual information of the image's content.

Multiple Representations are Required for Different Contexts

An electronic image may have four basic representations: thumbnail, computer display, printable (most often the original), and textual. Experience of the authors indicates that computer display may even require two types of presentations: one that allows for the image to be displayed on a Web page but fits correctly on a printed page (an image width of 595 pixels), another that enables the image and text to be displayed side by side on the screen in a balanced way (an image of width 295 pixels).

How can a digital asset be represented with multiple files? The first option is to embed multiple files in one single file, for example, the Portable Network Graphic (PNG) format, Adobe's Portable Document Format (PDF) file, and Microsoft's Document file (DOC) format. The second option is to put the files into a wrapper. Many learning object repositories use the ZIP file format to keep the files together. Substantial research in representing multimedia objects is being done by the Motion Picture Experts Group developing MPEG-21 (Bormans & Hill, 2002), and by the organisations and individuals involved in the aceMedia (2004) project. The third option is to keep the files separate and use a naming convention to keep the files together. Microsoft has adopted this in part to save Web pages in Internet Explorer where the main file is saved along with the creation of a folder of the same name containing the included files. A disadvantage of this approach is that files can become separated, while its advantage is that no specialist software is required to view the files. The first option would require considerable design and implementation skills and the widespread adoption of the standard, and the second option is fundamentally

Figure 3. Multimedia Object (MMO) model



an extension of the third, that is the files are placed in a wrapper. Hence, this chapter investigates a model conforming to the third option.

After evaluating several prototypes, a workable model has evolved, which consists of a file that contains the textual metadata for the digital asset and associated files in their original formats. In order to describe this collection of files, the term *MultiMedia Object* (MMO) has been coined (Verhaart, Jamieson, & Kinshuk, 2004), and is illustrated in Figure 3.

To enable the metadata and to describe the information about the associated manifest of files, a markup language has been developed. This language is needed to

- conform to existing standards;
- manage derived information, such as file name, type, and size; and
- manage annotated information, including the contextual information

such as situational data, creator information, bibliographic information, and additional annotation information that may be added later when the digital asset is reused.

Figure 4. MMO showing MVML file and associated files

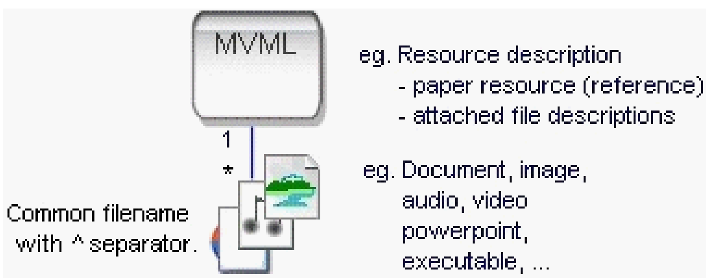
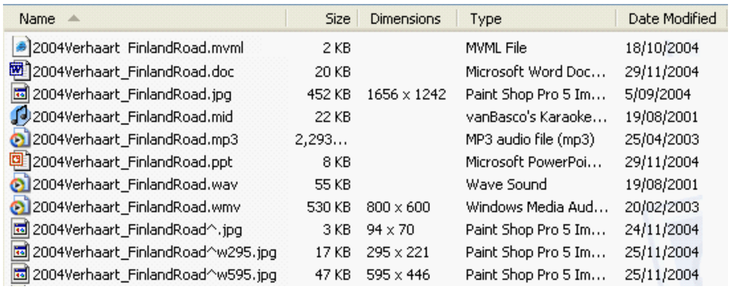


Figure 5. MVML file manifest



Name	Size	Dimensions	Type	Date Modified
2004Verhaart FinlandRoad.mvml	2 KB		MVML File	18/10/2004
2004Verhaart_FinlandRoad.doc	20 KB		Microsoft Word Doc...	29/11/2004
2004Verhaart_FinlandRoad.jpg	452 KB	1656 x 1242	Paint Shop Pro 5 Im...	5/09/2004
2004Verhaart_FinlandRoad.mid	22 KB		vanBasco's Karaoke...	19/08/2001
2004Verhaart_FinlandRoad.mp3	2,293...		MP3 audio file (mp3)	25/04/2003
2004Verhaart_FinlandRoad.ppt	8 KB		Microsoft PowerPoi...	29/11/2004
2004Verhaart_FinlandRoad.wav	55 KB		Wave Sound	19/08/2001
2004Verhaart_FinlandRoad.wmv	530 KB	800 x 600	Windows Media Aud...	20/02/2003
2004Verhaart_FinlandRoad^.jpg	3 KB	94 x 70	Paint Shop Pro 5 Im...	24/11/2004
2004Verhaart_FinlandRoad^w295.jpg	17 KB	295 x 221	Paint Shop Pro 5 Im...	25/11/2004
2004Verhaart_FinlandRoad^w595.jpg	47 KB	595 x 446	Paint Shop Pro 5 Im...	25/11/2004

The term *Media Vocabulary Markup Language* (MVML) is used to describe the metadata language. As the files are to remain in their original form, a way is needed to maintain their grouping. This is achieved by requiring files to be named the same as the core digital asset but with different extensions (e.g., the file could be called 2004Verhaart_FinlandRoad.jpg, and the associated MVML file would be 2004Verhaart_FinlandRoad.mvml). Where multiple files of the same type exist a ^ is used to extend the filename. For example, a thumbnail of the file is called 2004Verhaart_FinlandRoad^.jpg, and an image formatted for the screen 2004Verhaart_FinlandRoad^w595.jpg.

Figure 4 shows a conceptual diagram of an MMO showing the MVML file and associated files.

Figure 5 shows how a single digital asset could be represented by a manifest of related files and the MVML metadata file.

Managing Referencing Information Such as Rights and Copyright

Media elements can come from two sources: the creator or external. The goal of the MMO is to create a shareable object; therefore, whether it has been created or copied, rights and copyright information need to be captured.

Objects can be created in many ways; for example, they may be hand (computer) crafted where an authoring tool (such as a drawing program) or a capturing device (such as a digital camera) is used. The rights and copyright metadata will fundamentally be the same; it would contain the creator's details and copyright notice.

In the case of borrowed objects, this becomes less clear. With the Web as a significant tool for information gathering and rearranging, many media elements lose the rights and copyright information because this information is mostly not stored with the element but is placed on the Web page. The ability to create an associated metadata file with each media element can go some way in keeping the rights and copyright information.

The Need for Standards and to Adopt Existing Standards

In order to make the sharing of media elements possible, a set of standards needs to be developed. For example, if an image from an external Web site is to be used, the associated metadata can be browsed to extract content, context, and rights information.

Libraries have been working with these issues over many years, and Dublin Core (DCMI, 2004) is the most common standard for digital works. The publishing industry has developed the Publishing Requirements for Industry Standard Metadata (PRISM) (Daniel, Hansen, & Pope, 2003).

A major initiative in progress on the Internet is the development of a framework of technologies for the Semantic Web (Ford, 2004; Knorr, 2002; W3C, 2004a). Baker (2002) describes the Semantic Web as one "that will allow machines to easily understand and work with the words and information humans stuff into e-mails, documents and databases. Many time-killing clerical tasks that today require a live person at the keyboard could be automated."

Two important standards that are part of the Semantic Web are the eXtensible Markup Language (XML) (W3C, 2004b) and the Resource Definition Framework (RDF) (Miller, Swick, & Brickley, 2004). XML allows data to be represented in a common and structured way and is a suitable container to describe the metadata. The RDF uniquely identifies a resource, whether electronic or not. Kuchling (2002) states that "RDF is part of a W3C effort called the Semantic Web, aimed at building a web of information that's easy for machines to read."

User Interface Design Considerations

The success of Hypertext Markup Language (HTML) is commonly attributed to the fact that it has a clearly defined and manageable structure. This characteristic is also essential in the design of a user interface for MVML. The three design parameters of creation, viewing, and sharing all need to be carefully considered for acceptable use of MMO.

When designing MMO/MVML creation software, it is important that it can run in stand-alone mode as well as in an Internet mode, as there are many users not connected permanently to the Internet. The application should be capable of autogenerating the standard associated files; for example, when the MVML file for an image is created, a thumbnail should also be created.

Viewing an MMO/MVML file can be generalised but it should be possible to annotate the MMO. The amount of change required in existing media players should be minimal, although at present a Web browser would be the most obvious choice because it can cope with the greatest number of different media types. An advantage of the MMO with its multiple associated files is that cognitive loading can be decreased for each media element. For example, work on exploration space control (Kashihara, Kinshuk, Opperman, Rashev, & Simm, 2000) emphasises the display of optimal amounts of information to be displayed on screen to reduce cognitive overload. A system utilising the MMO would then be able to display an appropriate media object from the manifest and provide a link to the additional related objects in the manifest.

Multimedia Objects (MMOs) and Multimedia Vocabulary Markup Language (MVML)

What Metadata Needs to be Attached to a Digital Asset?

There are two kinds of metadata that need to be attached to a digital asset: derived and annotated (Goldfarb & Prescod, 2002). Derived data can be extracted from the electronic file itself, for example, the name of the file or its physical size. There are many advantages in capturing this information implicitly rather than getting the application to retrieve this information each time it is needed. For example, a thumbnail of an image with a description and its physical size can be quickly displayed to allow the user the choice of accepting the download or not.

Annotated metadata is that which is added by the user. In order for an MMO to have an existence, it must have the mandatory field "title." This is consistent with database schemas where a primary key is defined or in the physical world where a person is given some sort of identifier, for example, a name. An initial list of annotated metadata attributes for an MMO includes title (mandatory), creator, subject keywords, rights, and context (e.g., an image should be described as if the viewer was blind).

Existing Metadata Standards

There are many groups working collaboratively designing common metadata standards. The ability to describe an object in a structured manner is an important way in which objects can be classified and organised. For example, in a database, metadata about a student, employee, or client are used to clearly identify them. Defining standards are essential for developing shareable objects.

There has been much work in defining objects used in learning. McGreal and Roberts (2001) discuss the levels of granularity and define the simplest level as being the information object or *component* (e.g., simple text or a photograph). It can be argued that any object can be used for learning, but it is the authors' contention that in a learning object definition this should be explicit rather than implicit. Learning object specifications that are relevant include IEEE LOM (IEEE LTSC, 2002), DCMES (Dublin Core Metadata Element Set) (DCMI, 2004), and SCORM (Shareable Content Object Reference Model) (ADL, 2004). These standards are then used in metadata schema implementations, such as CanCore (Friesen, Fisher, & Roberts, 2004) or UK-LOM Core (Campbell et al., 2004).

Before deciding which existing metadata standards or implementations can be adapted or modified, core requirements of the MVML-based MMO need to be analysed. The fundamental metadata schemas that need to be considered are Dublin Core, vCard, and the Resource Definition Framework.

Librarians have needed metadata to describe the publications they manage, and the Dublin Core metadata schema has been developed to classify electronic material. "The Dublin Core has been described as the most broadly based metadata specification. It coexists comfortably with the other metadata sets and all its elements are optional and syntax independent. Like the other specifications, it can be tagged in HTML, raw XML or RDF/XML. It consists of only fifteen fields such as Title, Description, Creator, Subject, etc." (McGreal & Roberts, 2001).

This has been significantly extended by the Metadata Encoding and Transmission Standard (METS) (Library of Congress, 2004). METS is a standard for encoding descriptive, administrative, and structural metadata regarding objects within a digital library. It is expressed using XML and includes the Dublin Core standard.

vCard is a specification that is used when authors need to be identified, as in the IEEE Learning Object Metadata Specification (IEEE LTSC, 2002) for identifying a creator (vCard, 1996). It is commonly used in e-mail systems as an electronic business card. The vCard standard was developed prior to the emergence of XML as a common wrapper for describing metadata. Iannella (2001) has developed an XML-based schema for vCard, and it is used in the metadata of the MMO.

As mentioned earlier, the next generation of the World Wide Web is the Semantic Web, and the RDF is a way to uniquely identify a resource, whether electronic or not. Complying with this standard is an important part of the MMO.

MVML a Markup Language to Describe a Digital Asset

As mentioned earlier, the ability to create reusable knowledge depends on developing standards. The core standards adopted in MVML are the Dublin Core, vCard, and the use of XML and RDF.

Figure 6. Driving in Finland

Figure 7. MVML file for MMO driving in Finland

```
<?xml version="1.0"?>
 <rdf:RDF
   xmlns:rdf   = "http://www.w3.org/1999/02/22-rdf-syntax-ns#"
   xmlns:dc   = "http://purl.org/dc/elements/1.1/"
   xmlns:vCard = "http://www.w3.org/2001/vcard-rdf/3.0#"
   xmlns:mvml = "http://is-research.massey.ac.nz/verhaart/1.0" >
```

This section contains meta-metadata used by all files in the manifest, such as a title, creator's name and details (in vCard format), creation date, keyword list (subject), and context.

```
  <rdf:Description rdf:about = "2004Verhaart_FinlandRoad.mvml" >
   <dc:title>Driving on the Right-Hand Side of the Road in Finland</dc:title>
   <mvml:creators>
   <dc:creator rdf:parseType="Resource">
        <vCard:FN> Michael Verhaart</vCard:FN>
        <vCard:N rdf:parseType="Resource">
          <vCard:Family>Verhaart</vCard:Family><vCard:Given>Michael</vCard:Given>
        </vCard:N>
        <vCard:EMAIL rdf:parseType="Resource">
          <rdf:value>mverhaart@eit.ac.nz</rdf:value>
          <rdf:type rdf:resource="http://www.w3.org/2001/vcard-rdf/3.0#internet"/>
        </vCard:EMAIL>
   </dc:creator>
   </mvml:creators>
   <dc:date>2004-12-27</dc:date>
   <dc:source rdf:parseType="Resource">
     <mvml:URI>
       <mvml:root>http://is-research.massey.ac.nz/verhaart/</mvml:root>
       <mvml:path>me_media/2004Finland</mvml:path>
     </mvml:URI>
   </dc:source>
   <dc:subject>Finland, Joensuu, Taxi, Lights</dc:subject>
   <dc:rights>Copyright 2004 M H Verhaart. All Rights Reserved</dc:rights>
   <mvml:context>Finland, Joensuu, Fri. 3 Sept photo through windscreen of taxi to airport. PDA on
dashboard, truck approaching with lights on. Black car with trailer and planks in front. All cars have lights
on during day.</mvml:context>
  </rdf:Description>
```

This section contains a manifest of the associated files with their attributes.

Figure 7. cont.

```
<mvml:manifest>
    <rdf:file rdf:about = "2004Verhaart_FinlandRoad.jpg" >
    <mvml:derived>
      <width>1656</width><height>1242</height><size>462810</size>
    </mvml:derived>
    <mvml:annotated>
      <type>image</type><subtype>basic</subtype><use>original</use>
    </mvml:annotated>
  </rdf:file>
  <rdf: file rdf:about = "2004Verhaart_FinlandRoad^.jpg" >
    <mvml:derived>
      <width>94</width><height>70</height><size>3072</size>
    </mvml:derived>
    <mvml:annotated>
      <type>image</type><subtype>basic</subtype><use>thumbnail</use>
    </mvml:annotated>
  </rdf: file >
  <rdf: file rdf:about = "2004Verhaart_FinlandRoad^w595.jpg" >
    <mvml:derived>
      <width>595</width><height>446</height><size>47791</size>
    </mvml:derived>
    <mvml:annotated>
      <type>image</type><subtype>basic</subtype><use>display</use>
    </mvml:annotated>
  </rdf: file >
</mvml:manifest>
```

This section would contain the annotations.

```
<mvml:annotations>
</mvml:annotations>
</rdf:RDF>
```

Figures 6 and 7 illustrate how an MMO would be represented: an image (Figure 6) and the actual MVML file (Figure 7). The manifest of files was illustrated earlier in Figure 5.

Figure 7 illustrates how the MVML file is structured into the overall metadata (commonly referred to as the meta-metadata) and the manifest. The meta-metadata (in the <rdf:Description> tag) contains the overall description of the MMO, such as the name of the MVML file and author details. The manifest contains a list of the associated files and their properties. The annotations allow users to add comments directly to the MMO.

Derived Metadata

Reviewing Figure 7 reveals that many of the values can be generated by computer software. For example, the date when the MVML file was created (<dc:date>) and the details of the files in the manifest (such as width, height, and size of images). Therefore, it should be possible to create much of the metadata automatically.

The bold parts in Figure 7 illustrate *annotated* metadata, which are those values that relate specifically to the image being coded (title, subject, and context). Other values such as the creator's name could be inherited (as discussed in the following section). This shows that the actual amount of metadata that would need to be entered by the user is actually quite manageable. In MVML, title is a mandatory field, though an interesting observation is that many metadata schemas, such as Dublin Core and LOM, do not have any mandatory fields.

When creating metadata for a group of MMOs, some of the data may be common. For example, if a collection of images were being codified, it is likely that they would all have the same creator. The ability to create a template with this common information would greatly speed up the process of creating the MVML file. This can be referred to as *inherited* metadata.

The MVML Template

A significant problem that exists is that metadata creation requires manual input by an individual or group. Unless there are real benefits, this will not occur (Phillips, 2000). Further, the addition of metadata is often time consuming, with much of the metadata being repeated. In order to facilitate rapid entry of the metadata, a template with an embedded coding language has been developed. This coding language allows the template's author to specify which entries can be automatically created by the system (the derived data), which data need to be added by the user (such as the title), and which data can be inherited from other data entered by the user (such as full name from given and family name).

Figure 8. MVML template: Example of folder generic template

```
<?xml version="1.0"?>
 <rdf:RDF
   xmlns:rdf   = "http://www.w3.org/1999/02/22-rdf-syntax-ns#"
   xmlns:dc    = "http://purl.org/dc/elements/1.1/"
   xmlns:vCard = "http://www.w3.org/2001/vcard-rdf/3.0#"
   xmlns:mvml = "http://is-research.massey.ac.nz/verhaart/1.0" >
```

*The next section shows how the title (a * for mandatory) and derived data, &M(mvml file,) and &D (date)) are defined. The creator's information is already entered.*

```
 <rdf:Description rdf:about = "^&M^" >
  <dc:title>^Title[*]||^</dc:title>
  <mvml:creators>
  <dc:creator rdf:parseType="Resource">
       <vCard:FN> Michael Verhaart</vCard:FN>
       <vCard:N rdf:parseType="Resource">
         <vCard:Family>Verhaart</vCard:Family>
         <vCard:Given>Michael</vCard:Given>
       </vCard:N>
       <vCard:EMAIL rdf:parseType="Resource">
         <rdf:value>mverhaart@eit.ac.nz</rdf:value>
         <rdf:type rdf:resource="http://www.w3.org/2001/vcard-rdf/3.0#internet"/>
       </vCard:EMAIL>
  </dc:creator>
  </mvml:creators>
  <dc:date>^&D^</dc:date>

  <dc:source rdf:parseType="Resource">
    <mvml:URI>
      <mvml:root>http://is-research.massey.ac.nz/verhaart/</mvml:root>
      <mvml:path>me_media/2004Finland</mvml:path>
    </mvml:URI>
  </dc:source>
```

<dc:subject> shows the three-part pattern, the title (Subject), a default value (Finland, ICALT 2004), and a help prompt that would be used for automatic form generation.

Figure 8. cont.

```
<dc:subject>^Subject|Finland, ICALT 2004|Enter keywords separated with a comma^</dc:subject>
<dc:rights>^Copyright|Copyright 2004 M H Verhaart. All Rights Reserved^</dc:rights>
<mvml:context>^Context|Finland Plane (Sat 21 Aug-Sun 22 Aug)Summer School(Mon 23-Aug-Fri 27
Aug)/Conference (Mon 30 Aug - Wed 1 Sep)/ Technology Park(Thu 2 Sep),Plane(Fri 3 Sep-Sun 5 Sep)
2004|Describe the resource as if to a blind person^</mvml:context>
</rdf:Description>
<mvml:manifest>
</mvml:manifest>
<mvml:annotations>
</mvml:annotations>
</rdf:RDF>
```

The MVML template is made up of two parts: the folder generic template (FGT) and the MVML manifest media-specific template. FGT is stored, as the name implies, in the folder with related files. For example, if a collection of images is about a particular country, it would make sense that there would be common metadata. Figure 8 gives an example FGT.

This template illustrates how common metadata is entered, such as creator's name, and how data to be captured is specified. Since an MMO can be made up of many associated media files, a separate *MVML manifest media-specific template* has been created and is kept in a common folder accessible by the entire system. Figure 9 shows a portion of this template for images. Equivalent models have been created for text, animation, audio, video, and application, and further extensions are possible.

Possible Use Cases for MMOs

The ability to add structured metadata that describes a media object in a common and consistent way, irrespective of the media type, will allow many applications to be developed. The separation of the media and their metadata from a specific application will allow resources to be easily shared between applications. The following sections look at possible applications where the MMO/MVML model would be useful.

Figure 9. MVML template: Example of manifest media-specific template

```
<model>
 <type>image</type>
 <subtype>{basic|gif|png|jpg|jpeg|}</subtype>
 <template>
  <rdf: file rdf:about = "^&fn^" >
    <mvml:derived>
     <width>^&dw^</width><height>^&dh^</height>
     <size>^&ds^</size>
    </mvml:derived>
    <mvml:annotated>
      <type>image</type><subtype>^&as^</subtype>
      <use>^choice[original|icon|thumbnail|display|prn]||Use type^</use>
    </mvml:annotated>
  </rdf: file >
 </template>
</model>
```

Content Management Systems

In content management systems (CMS), there is a need to show a representation of the media, be it image, animation, audio, video, or structured media appropriate to the destination device (e.g., screen or printer) or in the correct context (e.g., on a Web page). Reusing images often means redescribing the media and most often the original context and creation information is lost. This is amplified further when media is shared with other people. Figure 10 displays a prototype CMS that has been developed to explore many of these problems. The prototype demonstrates the use of basic structure of MMO.

Business Card and Contacts Organiser

Using MMOs to manage business cards and contacts provides opportunities to assist in the recall of that person. To assist cognition, humans will use multiple references. For example, it is not uncommon for a recall to be triggered when hearing a voice. As the MMO is capable of managing multiple representations of an object, this will enable multiple cognition channels to be stimulated to aid recall. Prototype in Figure 11 displays a business-card reader where the actual business card is scanned, the vCard description attached (in the MVML file),

Figure 10. Displaying a small fragment in a content management system

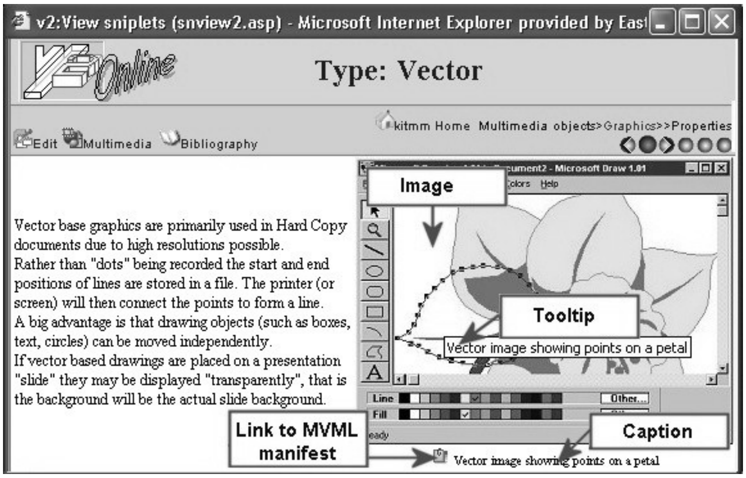
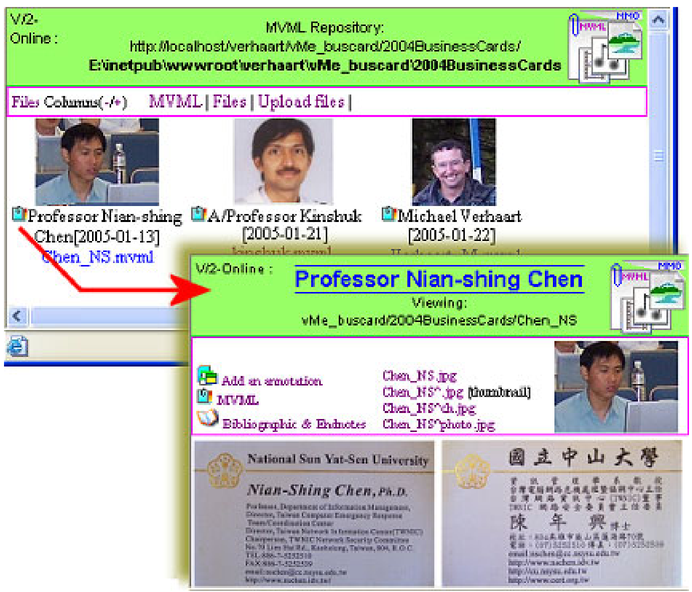


Figure 11. Business-card reader based on MMO/MVML



and other media representations associated, such as a video. Note the occurrence of multiple business cards, where one is in English, the other in Chinese.

Bibliographic Reference Organiser

MMO/MVMLs can be utilised in the management of electronic bibliographic artifacts, such as journal papers, books, and book chapters. While online libraries such as the Association of Computing Machinery (ACM, 2004) provide citation information, most online sources require references to be manually constructed. The MVML mechanism can be used to generate, say, an American Psychological Association (APA) style reference (APA, 2004). For example, if an electronic object (such as a pdf, html, or doc file) is encapsulated in an MMO, the MVML description can be used to automatically create the APA referencing style. Further, the ability of annotation allows comments to be added to the object that will help identify the salient parts relevant to the research context. A prototype has been developed to test the ability to produce an APA citation style by producing an XML file that can be imported into EndNote (n.d.).

Future Directions

There are many opportunities to use MVML-based MMOs and although much of the groundwork has been achieved in defining a workable language and model, there is still much work to be done. This includes evaluating existing metadata implementations to assess whether they will be able to accommodate the requirements of the MVML-based MMO.

The original CMS prototype, based on MMO, is being further developed, and will be used to test the usability and practicability of the approach. Initial work in this area, some of which has been described in the chapter, is encouraging. As the CMS has evolved, it has begun moving in a new direction. In a test environment it is evident that instructors in a blended environment customise the content to suit individual needs rather than use unchanged shareable content. From this, an individualised environment is being developed, where an instructor can place content and solicit feedback in a personal context. This has been coined as “Virtual Me” and is currently a work in progress.

Conclusion

This chapter presents a model that can be used to describe digital assets in such a way that they can retain their original context, be used efficiently in search routines, and be easily shared. The context is attached to the asset via an additional and related file, keeping the original digital asset intact and unaltered. As the file is separated from the objects in the manifest, this will allow for current and future formats to be catered for. Objects can be represented in a variety of formats to allow the appropriate type to be delivered depending on the context it is to be used in.

Cognitive recall is greatly enhanced when multiple representations are presented. For example, an image and an audio clip greatly assist in recalling a contact. Our memories may be triggered in many ways, so multiple representations can greatly assist in reinforcing the acquisition knowledge. Different situations may require different representations. For example, a set of textual steps can be useful in recalling a process but a video of the process is more effective when learning the process.

The variety of possible applications illustrated in this chapter demonstrates how the MVML-based MMO can be used to provide supporting details to assist in cognitive processes. Allowing annotations to be added to the object can assist at the metacognitive level, and indeed can provide a level of dialogue when multiple users are accessing the digital asset.

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Chapter IV

Guidance in the Interface: Effects of Externalizing Information During Problem Solving

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Abstract

How can we design technology that suits human cognitive needs? In this chapter, we review research on the effects of externalizing information on the interface versus requiring people to internalize it. We discuss the advantages and disadvantages of externalizing information. Further, we discuss some of our own research investigating how externalizing or not externalizing information in program interfaces influences problem-solving performance. In general, externalization provides information relevant to immediate task execution visibly or audibly in the interface. Thus, remembering certain task-related knowledge becomes unnecessary, *which relieves working memory. Examples are visual feedback aids such as "graying out" nonapplicable menu items. On the contrary, when certain needed task-related information is not externalized on the interface, it needs to be internalized, stored in working memory and long-term memory. In many task situations, having the user acquire more knowledge of the structure of the task or its underlying rules is desirable. We examined the hypothesis that while externalization will yield better performance during initial learning, internalization will yield a better performance later. We furthermore expected internalization to result in better knowledge, and expected it to provoke less trial-and-error behavior. We conducted an experiment where we compared an interface with certain information externalized versus not externalizing it, and measured performance and knowledge. In a second session 8 months later, we investigated what was left of the participants' knowledge and skills, and presented them with a transfer task. The results showed that requiring internalization can yield advantages over having all information immediately at hand. This shows that using cognitive findings to enhance the effectiveness of software (especially software with specific purposes) can make a valuable contribution to the field of human-computer interaction.*

Introduction

Humans interact with information in the world around them by taking it in, processing it, and outputting reactions. To process information, they use cognitive skills such as thinking, learning, reasoning, recognizing, and recalling, as well as metacognitive skills, which entail thinking about cognition (for instance, planning, strategizing, or choosing between reasoning or calculation types). Cognitive science studies these domains of human thought. Much research in this field is done through the analysis of subject reactions to presented information. This makes cognitive science a source of knowledge that could—and does—guide interface and system designers toward a more effective presentation of information in computer systems. We believe that utilizing cognitive findings to enhance the effectiveness of software can make a valuable contribution. Increasingly humans exchange information with the aid of computers, for instance, in education, entertainment, office tasks, information search, e-mail, and many other domains. Advances in computer and multimedia technology ensure that the format of this information is increasingly diverse using multiple media. Moreover, programs can have hundreds of functions. However, progression becomes difficult with this complexity of choices and representations. Harnessing this complexity to make it manageable for humans gave rise to the domain of "usability." Soon, among other things, the importance of minimizing user memory load became apparent. This resulted in recommendations to simplify the interface, restricting available options to those needed to carry out the task action at hand, and to keep options visible on the interface so users could interact on the basis of recognition rather than recall (Nielsen, 1994). In other words, the aim was just-in-time delivery of just the right information, obviating the need for memorization and extensive search in memory.

Our research does not aim at uncovering more principles that make systems even more usable, intuitive, or appealing. It goes beyond plain usability and focuses on how to shape interfaces that induce a user to learn cognitive and metacognitive skills, and thereby learn about the domain underlying the interface. We would like to find patterns of human behavior occurring with computer use, to find out what kind of *behavior* certain decisions in interface design provoke, not only during interaction, but also after delays and in transfer situations. In this, we feel that one continually has to consider the real purpose of the system. If a system ought to teach material to students or children, or needs to make sure that users do not mindlessly follow interface cues because the task to perform is of a certain crucial nature, then we should know what it is about an interface design that induces people to think and learn. In this chapter, the focus is on *internalization* and *externalization* of information, and how this may lead to different behavior on the user's part. In the following sections, we explain the different terms used in this context. After this, we will look at the pros and cons of externalizing and internalizing information, and some effects of varying interface elements on learning and metacognitive processes. In the next sections we discuss an experiment on users' behavior that two interface styles (internalization and externalization) provoke, and more specifically, the amount of planning and learning from the users' side. In the concluding section, we discuss our findings and lay out our future plans.

Externalization vs. Internalization Information: Related Fields

Visualization of task-specific information, thus minimizing user memory load, is often called "externalizing" the information (Zhang & Norman, 1994). Externalization of information can be contrasted with internalization of information, whereby certain task-related information is less directly available and needs to be internalized (inferred and stored in memory).

Early work of Simon (1975) examining advanced chess skills and strategies to solve the Tower of Hanoi puzzle had noticed the interdependence of "external memory" (perception, cueing recognition memory), and internal memory (recall memory). Norman (1988) argued for the need of a similar analysis for human-computer interaction. Tabachneck-Schijf, Leonardo, and Simon (1997) created a model in which distributed cognition was reified. For an example of distributed cognition, showing the interaction between internal and external memory in creating a Microsoft PowerPoint page, see Tabachneck-Schijf (2004). The question is, how much information should be internalized and how much should be externalized for an optimal task execution? Some research shows that the more information is externalized, the easier executing a task becomes (e.g., Zhang & Norman, 1994). Other research shows that externalizing all needed information seduces the user into mindlessly following the interface cues and learning or planning little (e.g., Mayes, Draper, McGregor, & Oatley, 1988). Yet other research shows that giving users incentives to plan and learn (i.e., internalizing information) pays off in better performance (e.g., O'Hara & Payne, 1999). Internalizing and externalizing information are related to, but not the same as, internal and external memory, internal and external cognition, and plan-based and display-based problem solving. All relate to having information in the head, be it in long-term or in working memory, versus information that is available via (direct) perception. Simon and colleagues refer to *external memory* as all information that *can* be made available for perception (e.g., Greeno & Simon, 1974). In practice, this comes down to all information that, within the task execution, can be made available for direct perception and working memory. Internal memory is all the information within long-term memory that can be made available to working memory.

External cognition is a term coined by Scaife and Rogers (1996) and refers to the interaction between internal and external representations (the latter being "external memory") when performing cognitive tasks (e.g., learning). Scaife and Rogers provide a useful overview on the use of graphical representations in educational environments and outline a theoretical framework. They conceptualize how different kinds of graphical representations (e.g., diagrams, animation, and multimedia) are used during cognitive activities. The framework presents a set of core properties, of which the central one is computational offloading (the extent to which different external representations reduce the amount of cognitive effort required for cognitive activities). This property was also mentioned by Greeno and Simon (1974) and Larkin (1989).

Plan-based and *display-based problem solving* relate to which source is used to draw information from. In plan-based problem solving, one uses detailed problem-solving strategies from (internal) long-term memory. Display-based makes little use of learned knowledge but relies on (external) interface information (Larkin, 1989; O'Hara & Payne, 1999).

Externalizing and *internalizing* information, finally, refer to making information available on external memory versus not making it available on external memory, thus requiring recording it on internal memory. We feel that studying the relationship between internalizing and externalizing information in order to find effects of interface information on behavior and problem solving is an important first step.

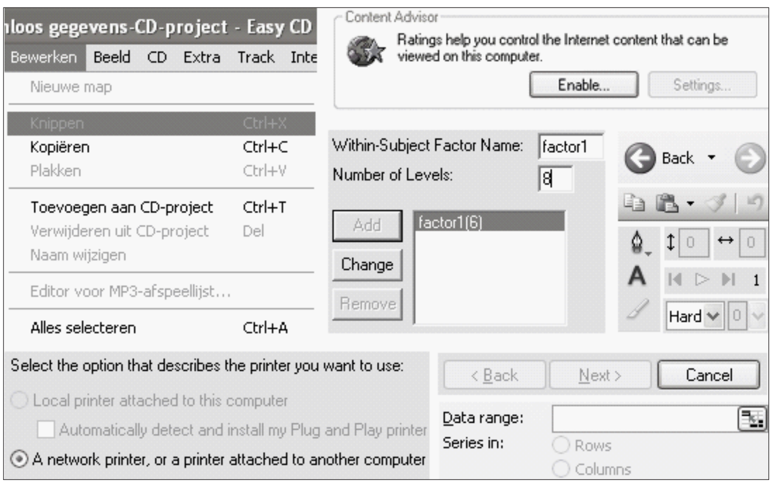
Pros and Cons of Externalizing Information

In many instances, and for many purposes, externalizing information and thereby reducing working memory load is indeed a fine idea. Externalizing interfaces "take the user by the hand," limit choices, and provide feedback. What information should a computer system offer? If one is working with a dynamic visual display on a problem-solving task, problem states are directly visible and elements that are normally stored in working memory can now be read from the display. A way to facilitate reduction of memory load is by visually showing what possible steps can be taken to go from one state to the other in the problem space (for a problem space, see Figure 4). It prevents users from internalizing a great deal of information. Other ways to reduce memory load and support explorative behavior are, for instance, guidelines such as "keep the number of possible operations small," "make the possible operations distinguishable," "make clear what the consequences of every action will be," "make the effects of actions visible once they have been executed," or "make actions easily undoable to make it safe to experiment" (Lewis & Polson, 1990; Van Oostendorp & De Mul, 1999).

Systems such as cash dispensers, automated airline check-in systems, and so forth should be designed in such a way that users can simply and easily follow the interface cues. Other examples are wizards and help options. Graying-out menu items that cannot be used at that moment is also an example of externalizing information. For example, in Word, you cannot select "paste" from the "edit" tab in the menu when nothing is copied or cut first. "Paste" is shown in gray, indicating that the command exists, but that using it is impossible at the moment. In various lists of user interface guidelines similar issues, such as "visibility status" and "visual feedback" are mentioned.

Interfaces that externalize *do* minimize working memory load. For instance, Larkin (1989) considered the role played by differences in external displays in cognitive problem solving, finding that making information visible, enabling "display-based problem solving," helped people recover from interruptions in work. As mentioned, Zhang and Norman (1994) showed that the more information was externalized, the easier solving a problem became.

Figure 1. Examples of externalization by graying-out items



Van Joolingen (1999) studied the idea of learners actively engaging in order to learn about the properties of what is underlying a certain domain. He mentioned the reduction of memory load in the context of research on the role of learner support in discovery learning. Discovery learning assumes that learners take an active role and construct their own knowledge base by interacting with a domain, and inferring rules from the results of these interactions. Active involvement of the learner would result in a better base of knowledge in the learner as opposed to more traditional ways of learning. The question is, of course, how to accomplish this behavior from the users' side. He addressed the issue of supporting discovery learning by means of *cognitive tools*. Cognitive tools were defined as instruments that support cognitive processes by relieving working memory and which can aid the learner to direct the process, to perform a part of it, or to externalize part of processes and memory.

However, externalization of information also appears to have *disadvantages*. There is some evidence that during computer-based problem solving, with most information externalized users simply "follow the yellow brick road." Users search the interface for cues and reliably find them, perform an action that alters the interface, thus enabling another search for cues and so, applying simple perception-based means-ends analysis, eventually complete the task. If the task appears to be completed correctly, then it follows that users will not be triggered to plan, learn, or look for underlying rules or reasons, and also, that people can only carry out a sequence of actions if the interface supplies the needed cues. In a study comparing memory of users for a sequence of actions, researchers found just that (Mayes et al., 1988). Users using a command-style interface (e.g., LaTeX) that requires internalization could recall a sequence, while users using a direct-manipulation interface (e.g., Microsoft Word™) with most cues externalized could not. Also, external cues can easily lead subjects to incorrect actions. Tabachneck (1992) found that when the needed information was externalized on a graph so that simple perception yielded the correct answer, subjects gave the correct answer. However, in different representational formats simple perception yielded an incorrect answer; here subjects also followed the interface cue and gave the *incorrect* answer. In summary, externalizing information does decrease memory load, but drawbacks are that people are likely to perform continual trial-and-error recognition-based search and not learn or plan. Also, the external information may lead to the wrong answer and thus to errors. Task execution via externalized information may also be very resistant to speeding up. We feel that there are many tasks for which, during task execution, *internalization* of information is desirable. Examples are tasks with the purpose to acquire knowledge or skills, be they cognitive or metacognitive; tasks one does often, and consequently speeding up and reducing errors is desirable (such as booking a trip for a travel agent), or tasks where the cost of errors is high (e.g., controlling nuclear power plant or flying an airplane). When looking more specifically at problem-solving tasks, planning and learning are thought to be essential factors. It is therefore desirable to do more research on how interface design, internalizing, and externalizing information can stimulate people to do more internalization. Not externalizing all information may stimulate self-directed search, more active planning, and learning.

Varying Elements and (Meta)Cognitive Processes

O'Hara and Payne (1998) and Trudel and Payne (1996) found that when people are induced to plan, too strong a reliance on external information leads to negative effects regarding planning and transfer of skills. Inducing people to do plan-based problem solving would lead, they hypothesized, to internalization of metacognitive and cognitive knowledge, in turn improving task performance and easier recovery from errors (see also Payne, Howes, & Reader, 2001). O'Hara and Payne's (1998) experiments showed that plan-based activity did lead to shorter solution routes and easier recovery from errors, while a display-based strategy involved more steps because of more (trial-and-error) searching. O'Hara and Payne used an interesting methodology to get people to plan more. In one of two conditions, they made the interface harder to use by imposing delays on operators. They reasoned that subjects plan more when there is something at stake: here, reducing costly delays. A similar observation was made by Svendsen (1991). Using the Towers of Hanoi problem, a high-cost interface yielded improved understanding of problems. In the studies of Payne and colleagues, the amount of information externalized was not varied. We felt that not externalizing all information will similarly stimulate students to self-initiate a search for the missing information to plan and to learn.

In the first session of our experiment, discussed next, we researched whether varying the amount of externalized information would have an effect on performance, planning, and learning while solving a problem. In the second session we assessed what was left after 8 months of what subjects had learned in the first session and whether this still had an effect on task performance. Details follow.

Experiment Session 1

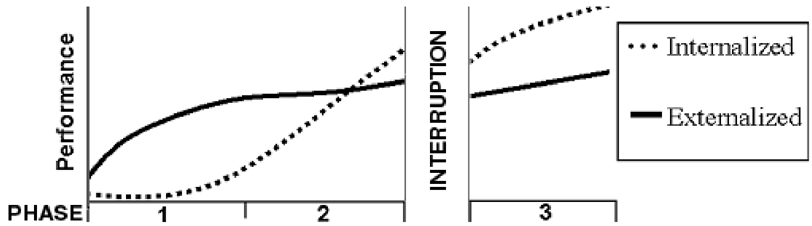
Hypotheses

1. Externalization will initially yield better task performance than internalization. Knowledge is yet to be acquired, so guidance by indicating the legality of moves will help externalization subjects.
2. Internalization yields better task performance later, especially after a severe distraction.

   After a while, subjects will have learned to solve the puzzle. Internalization subjects had no guidance and had to acquire the solving skill by themselves. They will have stored the rules in long-term memory more solidly, and have the needed information more readily available and thus perform better later, especially after an interruption erased working memory. Because of the guiding nature of the interface, externalization subjects will plan and think less than the internalization subjects, therefore work more on the basis of trial and error and consequently display worse performance.
3. Internalization yields better knowledge. Not having externalized information available will motivate a subject to start planning on the basis of self-acquired rules. After the experiment, we expect the explicit knowledge of rules to be memorized better by internalization subjects. There may also be a difference in implicit procedural knowledge, but we expect it to be smaller since both groups will have played the puzzle a similar number of times.

An experiment was conducted in which subjects solved a puzzle on a PC nine times in two conditions: internalized and externalized. In terms of performance, we expect the outcomes to take the following course:

Figure 2. Hypotheses



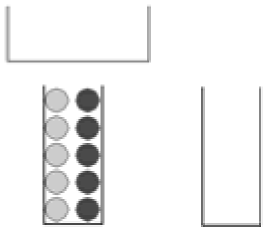
- *Phase 1:* Three trials. Subjects do not have any needed knowledge available yet, externalization offers more interface cues, and will result in better performance.
- *Phase 2:* Three trials. Performance in the two conditions will be equal by this time, because internalization subjects acquired internal knowledge that compensates for the interface cues.
- *Interruption:* This task is sufficiently demanding that all of the working memory is erased.
- *Phase 3:* Three trials, after the interrupting distraction task. Internalization subjects perform better because of better internalized knowledge and a more elaborate plan.

Materials

Our problem-solving task, "Balls & Boxes" (B&B), is an isomorph of the classic puzzle "Missionaries and Cannibals" (M&C). Five missionaries and five cannibals are standing on a riverbank, and all have to reach the other bank by boat. Constraints are that the boat only holds three creatures, and the minimum to sail is one, because the boat cannot move by itself. Furthermore, the cannibals can never outnumber the missionaries at any place (except when there are zero missionaries), or the missionaries will be eaten. Our B&B problem (Figure 3) uses exactly the same problem space (Figure 4), but is more abstract.

We made the puzzle more abstract to reduce the many common knowledge elements in the classic M&C: cannibals eat people, boats cross rivers, boats cannot sail empty, and so forth. Using boxes, blue and yellow balls, and a dish

Figure 3. The Balls & Boxes puzzle



instead, we offer a semantically less rich problem, avoiding the rules to be learned and remembered too easily.

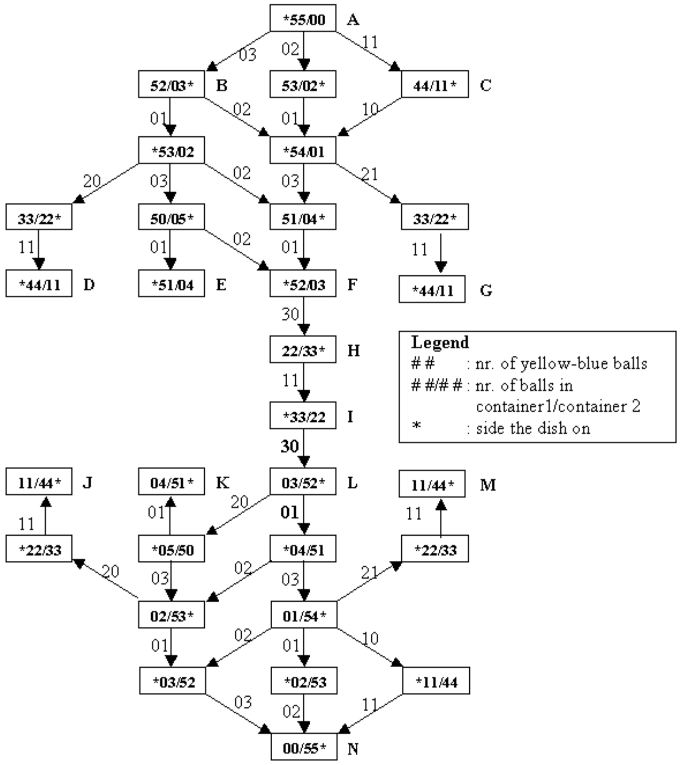
The rules of B&B were as follows:

1. Balls should be transported using the dish.
2. You can transport at most three balls at a time.
3. To move, the dish must contain at least one ball.
4. The dish has to reach the boxes in turn.
5. There can never be more blue than yellow balls in the dish (except when there are zero yellow balls).
6. There can never be more blue than yellow balls left in either of the boxes (except when there are zero yellow balls).

Rules 5 and 6 are the most problematic rules, making no semantic sense whatsoever. In our puzzle, it was possible to consult all the rules, but having access to these does not imply that one knows *how* to solve the problem, and surely not how to solve it in the most efficient manner. Below we depict the formal problem space of the puzzle (Figure 4). The numbers indicate the number of blue and yellow balls in the left and the right box, and the "*" indicates on which side the dish is (see the legend of Figure 4). The shortest path from "A" to "N" takes 11 moves. There are also states of the puzzles that we call "dead-end states," such as states D, E, G, J, K, and M. These states are not on a direct solution path, and force backtracking.

The interface controls of the puzzle were straightforward (Figures 5 and 6). To get balls into or out of the dish, blue or yellow up-arrows or down-arrows had to be clicked. To move the pink dish horizontally, one had to click a pink arrow (left or right). After the dish was moved, the balls automatically dropped into

Figure 4. Problem space of the Balls & Boxes problem



the box. To consult the rules one clicked on the rules tab. The rules screen overlaid the puzzle screen. The puzzle was designed in two versions:

1. *Internalized:* All arrows were always colored (Figure 5) and clickable, providing no information about the legality of moves (performing illegal moves is possible). One could click all buttons at all times; however, illegal moves would be carried out only partially. For instance, if one wanted to transport the dish empty from left to right and clicked the right pink arrow, the empty dish *would* move to the right. Then, an error notification would pop up saying, "This is not possible." By clicking "OK" in the dialogue box, the program would undo the move.
2. *Externalized:* The arrows are colored (and thus clickable) only when an action is legal. The arrows are grayed-out (unclickable, as in Figure 6) when a move is illegal. For instance, in Figure 6, moving the dish empty from left to right is illegal (violating rule 3), externalized by graying-out both pink arrows. It is now only legal to move balls up into the dish.

Figure 5. Internalized version: No information whether an action is possible (no gray-out)

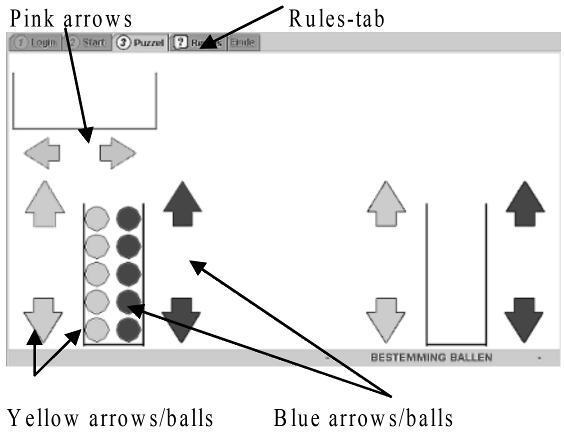
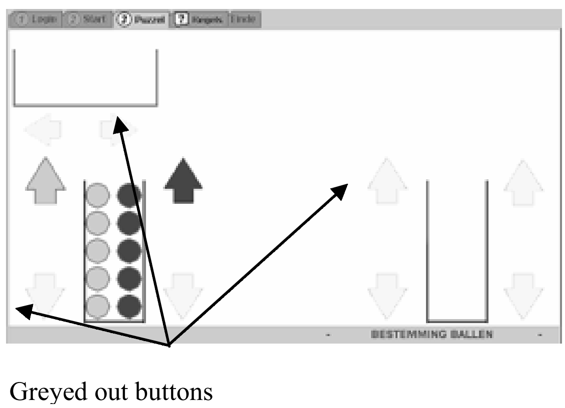


Figure 6. Externalized version: Information whether an action is possible (grayed-out)



Subjects and Design

Thirty subjects of age 19–28 (mean age 21.8), experienced with PCs, were recruited at Utrecht University. Subjects were paid • 5. The puzzle, a Java-applet, ran on a Pentium IV 2.0 GHz PC with a 17" monitor. Our design has one random-assignment between-subjects independent variable: internalization versus externalization. Among the dependent variables were the following:

- *Performance measures (logged)*

    - Number of puzzles subjects solved per phase (maximum three per phase)
    - Speed: time needed to solve the puzzles
    - Reaching dead-end states. These are puzzle states that are off a direct solution path, indicating trial-and-error search (states D, E, G, J, K, and M in Figure 4)

- *Knowledge test:* After the puzzles, we measured implicit and explicit knowledge of the rules and shortest-path solutions of the problem, using a paper questionnaire.
- *Attitudes:* Likert-scale questions concerning perceived amount of planning, feeling lost during interaction, and other such measures.

Procedure

The experiment was conducted in the usability lab at the Center for Content and Knowledge Engineering, Utrecht University. We informed the subjects of the course of the experiment, and gave a brief oral explanation of the interface and a short demonstration. The experiment consisted of nine puzzle trials, divided into three equal phases, and a 10-minute distraction task between phase 2 and 3. The maximum time for each trial was set at 7 minutes. Slightly different starting situations of the puzzle were used to avoid subjects simply repeating actions (states A, B, and C in Figure 4). Also, in the second phase, the playing direction of the puzzle was reversed to right to left. In the third phase, the playing direction was set to left to right again. After the last trial, subjects filled out a knowledge test (score 0–8) consisting of four multiple choice and four open questions with screenshots of puzzle situations. They had to judge and explain whether and why certain actions were possible (implicit knowledge), and recall the rules (explicit knowledge). Subjects also rated how clear the rules were for solving the problem.

Results Experiment, Session 1

Number of Puzzles Solved per Phase

Subjects could attempt to solve three puzzles per phase. A MANOVA (analysis of variance) showed a significant main effect of phase on the average number of puzzles solved, $F(2,56) = 53.74$; $p < .001$ (Figure 7) (*pointer to figure)*. The number of puzzles solved (out of three) improved in later phases, indicating a learning effect. Post-hoc comparisons showed that only the difference between performance in phase 1 and phase 2 was significant ($p < .05$) (Figure 8) (*pointer to figure*). Although the graph suggests an overall better performance for internalization ($M = 6.93$, $SD = 2.05$ vs. $M = 6.33$, $SD = 3.09$), this did not reach significance. There were no interaction effects.

Time Needed for the Puzzle Trials

A MANOVA showed a main effect also for phase on average solving time, $F(2,42) = 35.16$; $p < .001$. The time subjects needed to solve puzzles lessened in later phases, also a learning effect. Post-hoc comparisons showed that all subjects needed significantly more time in phase 1 than in phase 2, and also in phase 2 than phase 3.

Figure 7. Puzzle trials solved per phase, per version

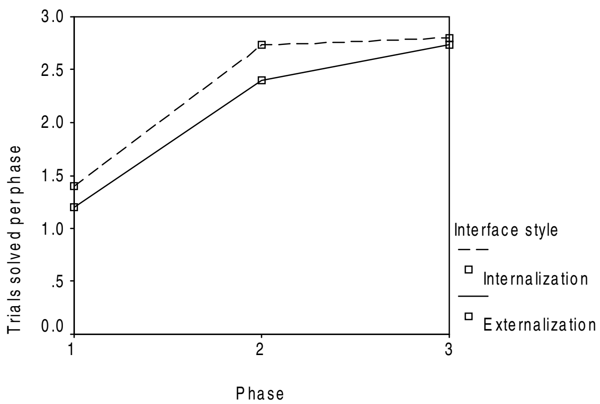
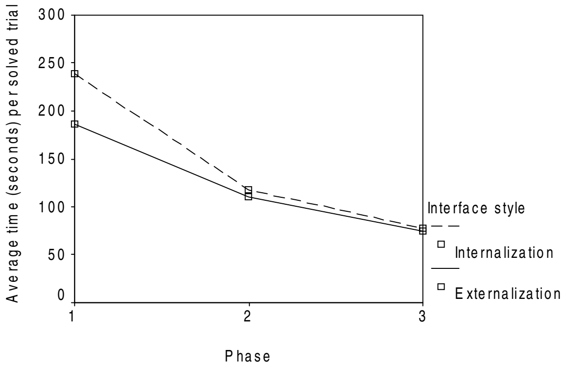


Figure 8. Time needed per solved trial, per version

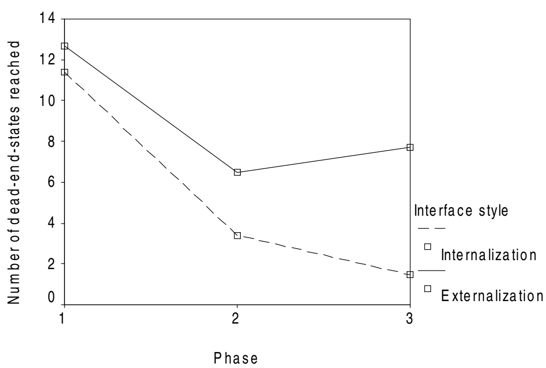


The graph suggests that internalization subjects need some more time on average, but ANOVA showed that this was just a trend ($F(1,21) = 2.79$, $p = 0.11$). Looking closer, it was only in the beginning, in phase 1, that internalization subjects needed more time ($M = 238.77$, $SD = 62.20$) to solve the puzzles than externalization subjects ($M = 186.77$, $SD = 67.08$). This difference was significant, $t(21) = 1.94$, $p = 0.03$ (one-sided). After this first phase, the differences were minuscule and no longer significant.

Dead-End States

Below is the number of times per phase subjects reached dead-end states.

Figure 9. Dead-end states per phase, per version



A MANOVA showed an interesting nearly significant main effect of interface style (Figure 9). Overall, externalization subjects reached more dead-end states ($F(1,28) = 3.58$; $p = 0.06$). In addition, there is a trend for an interaction effect of phase and version ($F(2,56) = 2.11$; $p = 0.13$). Internalization subjects significantly improved from phase 1 to 2 (M = 11.4, SD= 4.70 and M = 3.4, SD = 3.18), $t(14)=5.80$, $p = 0.00$, one sided). This is an improvement of eight states. They also improved from phase 2 to 3 by almost two states, nearly reaching floor level (M = 3.4, SD= 3.18 and M = 1.47, SD = 2.07), $t(14)=1.96$, $p=0.04$, one sided. Externalization subjects improved by 6.2 states from phase 1 to 2 (M = 12.67, SD= 6.91 and M = 6.47, SD = 7.11), $t(14)=2.74$, $p = 0.02$, one sided. But after the interruption, it was different. From phase 2 to 3, they did not further improve. On the contrary, in phase 3 they reached more dead-end states than before, although not significantly so. Here in phase 3 the difference between internalization (M = 1.47, SD = 0.53) and externalization (M = 7.73, SD = 10.64) was significant, t(28)= "2.24, p = 0.04. Externalization subjects reached more than six more dead-end states in phase 3 than internalization subjects.

Knowledge Test

Before measuring knowledge of the rules and states, we confirmed that there was no difference in the number of times subjects in both conditions consulted the rules. The knowledge test that subjects received after the experiment consisted of several procedural knowledge questions and one explicit knowledge question. The Balls & Boxes puzzle contained more than 30 legal states (Figure 4). There were seven procedural implicit knowledge questions about seven of those states (open and multiple choice) in which subjects were visually presented with a puzzle state. They had to judge whether certain moves led to the solution, and explain why. The scores on those seven questions were high for both internalization (M = 6.3, SD = 0.96) and externalization subjects (M = 5.8, SD = 1.20), considering that the maximum score was seven. There was a trend that internalization on average scored higher than externalization on the procedural knowledge questions ($t(28) = 1.17$, $p = 0.12$).

To test the explicit rule knowledge, the possibilities were limited. The puzzle had only few rules, some of which (rules 1 to 4) were extremely easy to grasp and remember. Rules 5 and 6 are more crucial and define the difficulty of the puzzle. They can be merged to just one rule: "Blue balls can never be in the majority at any place, except when there are only blue balls (zero yellow balls)."

Subjects were asked about this rule with a multiple-choice question. All internalization subjects answered this question correctly, whereas of the externalization subjects only 60% answered it correctly. This difference was significant (Phi = -.50, $p < 0.01$). Furthermore, subjects had to estimate the clarity of the rules. They rated the question "the given rules were clear enough to solve the problem" (score range 1–5). Internalization subjects found the rules clearer than the subjects from the externalization condition (M = 4.13, SD = 0.52 and M = 3.53, SD = 1.25), $t(28)=1.72$, $p = .04$ (one-sided).

Summary Experiment Session 1

Our first hypothesis stating that initially externalization yields better performance was only partly supported in terms of the time subjects needed. Internalization subjects did take more time in the first phase. Other measures were in the expected direction, but not significantly so. Unexpectedly, externalization yielded no better performance in terms of puzzles solved in the beginning, as we expected.

The second hypothesis stating that internalization yields better performance in a later stage was partly supported. We saw that the time subjects needed stabilized, and the same was true for the number of trials solved per phase. However, we also looked at performance in a more delicate manner, not in terms of time or correctness, but at *how*, via what route, subjects reached their goal. We introduced the measure "dead-end states" to inform us as to how subjects behaved, in terms of the insight they had, the "smartness" of their route. We assumed that internalization subjects do some smarter, more elaborate planning, while externalization subjects are expected to solve more by trial and error and on the basis of interface cues. It showed that internalization subjects performed better after the interruption and reached those dead-end problem states less often in all three phases (indicating less "lostness"). Furthermore, there was also the trend-like interaction that after the interruption, internalization subjects kept improving, while externalization subjects fell back, reaching more dead-end states than they did before. This confirms our expectation that after the interruption, internalization subjects would continue to work on the basis of the plan-based strategy as they did before. Externalization subjects, on the other hand, perform no better after the interruption. They fell back to depending on the interface, having a less elaborate plan.

The third hypothesis in which we expected that internalization would result in having better knowledge was supported. We also assumed that internalization subjects, who could rely less on interface information, had to build a stronger, more elaborate plan. Though when testing implicit knowledge both groups scored equally high, with a trend advantage for internalization subjects, when asked about explicit knowledge of the crucial rule that defines the difficulty of the puzzle there was a significant difference. All the internalization subjects could correctly answer this question, whereas only 60% of the externalization subjects could—in spite of having the rules readily available for consultation and consulting them as often as internalization subjects. Furthermore, there was also the tendency that internalization subjects rated the clarity of the rules higher. This is intriguing, because in the externalization version of the puzzle subjects had interface feedback *and* were able to consult the rules. Internalization subjects, who *only* had the rules and no interface help found the rules clearer. We carefully interpret the latter two findings as indicators of better understanding in the internalized condition.

Experiment Session 2

We were curious to see how stable this better knowledge provoked by internalization was, and therefore decided to conduct a second session after a delay of 8 months. We invited the same subjects of experiment 1; 14 of the 30 were available. There were two reasons for this rerun. First, to see whether the better knowledge measured in the internalization subjects had endured, we asked subjects to solve B&B five times (experiment 1 showed three to four puzzles suffice for all subjects to be able to solve the puzzle within the allotted time). Second, to see whether the better knowledge might result in better performance on a transfer task, we also confronted subjects with a transfer problem. Transfer problems require subjects to apply acquired skill on a different task of the same nature. To be able to measure differences in performance between the two initial groups (internalization and externalization) on the same material, we presented *all* subjects with the same material this time, one interface style, namely, externalization. Note that the internalization subjects had to make a change in interface style.

Hypotheses

1. Because internalization subjects still have better memory of the rules and solution, they will perform better. We expect the internalization subjects to solve the puzzle faster initially because of their better knowledge of the rules. They will be faster in recollecting knowledge needed to solve the puzzle. After a while, we expect the two groups to perform more or less equally on this puzzle, like in session 1.
2. Internalization subjects will perform better on the transfer tasks. After five times of B&B, we expect the two groups to perform at the same level. But when confronted with transfer tasks (that have similarities but also a few differences), we expect internalization subjects to perform better, again because they possess better knowledge of the rules.

Materials

To test knowledge retention, all subjects first solved the B&B puzzle in the externalized version five times. To test transfer performance, we used another puzzle of the same M&C "family," but with varying characteristics. We first used a quite literal version of M&C, which was further away in terms of transfer.

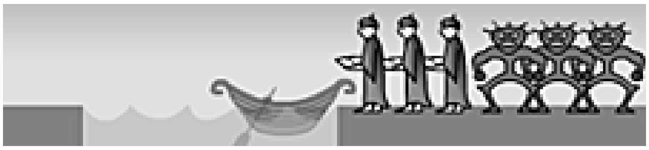
Balls & Boxes

The only difference between this and the previous B&B was that the rules were not consultable anymore, so we could obtain a more pure measure of retention. All subjects received the same externalized version. This meant that attempting illegal moves (moves that violate rules) was not possible, as the externalized interface only allowed legal moves.

Missionaries and Cannibals

The second problem was a transfer task, ironically the original version of the M&C. It was a game that literally shows missionaries, cannibals, a river, and a boat. The solution algorithm to this problem was the same as B&B, but there were some difficulties that did not exist before. The most important one is that

Figure 10. The initial state of the Missionaries & Cannibals puzzle



there were not five of each entity as before, but three, and the playing direction was always from right to left (Figure 10). Although it might seem that one can solve the three-creature problem faster, this is not so—the shortest path to the solution is also 11 moves. Also, unlike in B&B, in this game attempting illegal moves does *not* lead to an error message, but subjects would "die," as in a computer game, and the game would start over. Errors thus had more severe consequences, and subjects needed to exercise caution. Subjects had to solve the problem as many times as they could in 8 minutes.

Subjects and Procedure

Fourteen of the 30 subjects from session 1 were willing to participate a second time. Luckily, seven of them had worked with internalization, and seven with externalization in session 1. We confirmed that these 14 subjects were subjects who performed "normally" (no extreme scores) in session 1. The experiment consisted of two parts:

1. B&B (five times). The maximum time for each trial was set at 7 minutes. Slightly different starting situations of the puzzle were used to avoid subjects simply repeating actions.
2. M&C (8 minutes).

After completing the experiment, subjects received a • 5 reward.

Results Experiment Session 2

- *Balls & Boxes*. Encouraging results were found concerning solving the puzzle correctly again the first time. After not having seen the puzzle for 8 months, it took the internalization subjects only half the time used by the externalization subjects to solve the first B&B puzzle (M = 432 sec, SD = 314 and M = 778 sec, SD = 397). This difference was significant, $t(12) = -1.81$, $p = .05$. There were no further significant differences between the two groups. After the first puzzle, as expected, all subjects solved the remaining four trials of B&B puzzle equally well, just as 8 months ago.
- *Missionaries & Cannibals*. This puzzle was a bit further in transfer. The graphical characteristics of this puzzle differed considerably. Still the algorithm to solve it in itself was the same, but the number of creatures to transport was different, and also the maximum number of creatures allowed in the boat. Although the shortest solution path is the same length as B&B, the problem does have a smaller problem space. The same basic concept had to be applied to a situation that differed at face value, and also underneath. Out of our 14 subjects, 10 managed to solve this puzzle one or more times. Just as in the B&B puzzle, internalization subjects solved it the first time faster (M = 176 seconds, SD = 72.5 vs. M = 302.8, SD = 202.7), though it was just a trend, $t(8) = -1.44$, $p < 0.10$ (one-sided). Moreover, internalization subjects managed to solve the puzzle three times more often (M = 4.83, SD = 1.94) in the 8 minutes than externalization subjects (M = 2.5, SD = 1.73). This was significant, $t(8) = 1.94$, $p < .05$ (one-sided).

Summary Experiment Session 2

Eight months is a long time, but still the interface style subjects received in session 1 appeared to make a difference. Subjects were not told at the first session that they would be asked to play the puzzle again, and when we approached them, we explicitly told them it was not the same experiment they had participated in. Upon being confronted with the puzzle again, the subjects had to recollect the rules and solution strategy from their long-term memory.

The two groups both worked with an externalized version this time and had exactly the same information. We looked at how long it would take subjects to remember how to do this correctly. It showed that in solving the first B&B again, internalization subjects were indeed significantly faster, almost twice as fast, in fact. This is all the more remarkable given that these subjects received, to them, an unfamiliar interface—externalized rather than internalized. After that first success, the performance of both groups equalized. This is coherent with the results from the first session, where stabilization in performance also occurred. The above finding supports our first hypothesis of experiment 2 stating that internalization subjects would still have a better memory of the rules and solutions of the puzzle.

The M&C puzzle that subjects received was the same for everyone. It can be regarded as an internalization version (no direct interface clues were available, all controls were available all the time). Also here there were some interesting results. The subjects that worked with the internalization version of B&B managed to solve this puzzle three times more often than externalization subjects, and this was significant. Furthermore, just like in B&B, internalization subjects needed less time to solve the problem the first time, although this was just a trend. It supports the second hypothesis stating that internalization subjects will perform better on a transfer task. In summary, we demonstrated that the interface style subjects worked with 8 months ago still appeared to be of influence months later, both in solving the same puzzle again as in solving a far transfer puzzle. We take it as encouraging support for the better memory of knowledge provoked by the interface style subjects worked with.

General Discussion on the Two Sessions

We analyzed the influences that externalizing certain information on the interface, thereby making it visible, or not externalizing it has on performance and knowledge acquisition in a problem-solving task. Furthermore, we looked at the long-term effects after 8 months, and at the issue of transfer. Both in session 1 and in session 2, the delayed session, NOT externalizing information led to enduring advantages in performance and knowledge, while externalizing information merely led to a fleeting advantage at the very start of session 1.

According to Zhang (1997), the more information is externalized, the easier performing a task becomes. We hypothesize, however, that being led by the interface also incurs a cost, namely, a lessening of metacognitive activity such as planning, and consequently, less learning. In such situations as where learning is required, transfer is at stake, or the task is prone to interruptions, planning, learning, and in general, getting to know more about the structure of the task at hand are desirable outcomes. Surprisingly, performance measures such as time needed to solve the puzzles and number of correctly solved puzzles were not much influenced by the interface style—if anything, the internalization group was at an advantage. Zhang's (1997) prediction was not confirmed. We feel that the attention of users in the externalization group was immediately taken by the guiding nature of the interface, and as they were not confronted with actual mistakes (one could not make illegal moves, only inefficient legal moves were allowed), they simply kept on solving without feeling a need to figure the problem out more. Subsequently, less active learning took place. This idea of attention taken by an interface fits with Carroll and Rosson's (1987) paradox of the active user—users of computer systems are so consumed with immediate productivity that they are not motivated to take time to learn better ways of accomplishing a task.

Contrary to the externalization group, the internalization group was confronted with errors for which an explanation was not immediately available. These subjects incurred a cost when making errors: a dialog box popped up which they had to click away, and their attempted move was reversed. Though both groups consulted the rules sheets equally often, this cost probably contributed to motivating the internalization subjects to study the rules better in order to avoid incurring the cost. We found that the internalization group possessed better explicit knowledge of the rules and engaged in more planful problem solving. Applying more metacognition to avoid a cost concurs with the findings of O'Hara and Payne (1998, 1999).

During session 2 we found that the effects found in session 1 were still present. Again, only the internalization subjects from months ago showed advantages. This group was both faster in solving the same problem again, and also faster in figuring out the solution to a transfer task. It is remarkable that the influence of working with one interface or the other has effects even after such a long time.

In general, it was surprising for us to see that externalization showed even less advantage than we thought, almost none, to be precise. We expected externalization at least to be of help in the beginning when users were not familiar with the system and the problem. It was, but only in time taken on the first few trials—and this was just a trend that was not confirmed in the number of puzzles solved correctly. This very small and fleeting advantage did not concur with Zhang's (1997) findings. Please note that our type of externalization parallels Zhang's more physical type: both restrict the number of illegal moves that can be made, but do not alter the problem space or give cues as to what the shortest path is through the problem space.

We find the results so far encouraging in that lessening the amount of externalized knowledge apparently can encourage cognitive and metacognitive behavior. Moreover, one can be very precise about which information not to externalize—in other words, this way the information to be learned can be manipulated. Therefore, we feel that the issues of manipulating the amount of externalization in interfaces deserve more attention. In the context of current technology and the widespread use of computer systems in virtually all domains, we are convinced that understanding how the system's users will perceive, reason, and interact with the system can be crucial. The implications of the findings so far and the ones in the future can be valuable for development of applications where active engagement and learning from users is the aim. Examples are systems to teach material to students or children, or situations where it is important that users are not "kept" stupid by the software. In certain situations, users of a system need to understand the underlying structure/rules of the system because the tasks are of a crucial nature. To accomplish this we have to look beyond plain usability and common sense and better scrutinize the interaction between internal memory and cognition on the one hand and external memory and recognition and perception on the other hand. We believe this can, for certain types of systems, enhance the effectiveness in achieving their targets.

Future Trends

There are still many challenges in human-computer interaction and many issues that need to be explored. Understanding how users will react to interface information (on the basis of cognitive findings) is one important issue in attuning software to its purpose, thereby allowing it to achieve its goal. In the future, we will further investigate this issue by exploring behavior in different types of more realistic planning-related tasks. As a more realistic planning task, we think of, for example, spreadsheet or drawing applications where actions are less repetitive, more complex, and could be part of a real job. We are currently designing such an environment.

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Section II

Mental Representation of Concepts, Metaphor, and Language

Chapter V

Bridging the Gap between Human Communications and Distance-Learning Activities

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Abstract

This chapter introduces context-aware computer-mediated communication for distance learning systems. It argues that linking deeply communication to learning activities offers an interesting approach to develop the efficiency of systems in facilitating and increasing discussions between learners. To make this link, the author bases his work on various theories, such as communication theories, situated cognition theory, and activity theory. This theoretical study leads to research issues concerning a contextual forum model. The description of the computing implementation of this model aims at giving researchers some possible uses and *recommendations in dealing with context-sensitive communication tools. Finally, the chapter mentions futures trends and suggests emerging research opportunities within the field of communication services that are able to adapt dynamically to the user's activity.*

Introduction

In a distance-learning context, the emergence of learners' communities has a favourable impact on learning conditions. Indeed, in a socioconstructivist approach (Doise & Mugny, 1984), interactions between learners play a dynamic role to individual learning. However, distance discussion tools are not always really suitable for the emergence of learners' communities. Some works have highlighted that these phenomena are too rare in distance-learning environments (Gommer & Visser, 2001; Hotte & Pierre, 2002).

Forum tools currently used in online educational platforms are mostly unspecific to educational situations (George & Hotte, 2003). The discussion activities are not linked to the learning activities; consequently, this does not encourage the learners to use them for communication. Current distance-learning systems do not respect human communication process that is an "in-context" process (Jakobson, 1960). Our main idea is then to make communication more immediate during learning activities. The aim of this chapter is to describe the conception of forum models and tools that are specific to distance-learning systems. The research question lies in determining how to link discussion activities to learning activities by the mean of well-suited computer tools. On the whole, the work concerns the design of human communication systems that attempt to respect human thought process. We totally agree with the paradigm of "cognitively informed systems," which defines systems that utilize, as a basis for their design, some form of cognitive findings to enhance the effectiveness of the systems in achieving their targets. For the design of our communication system, some results from communication theories, situated cognition theory, and activity theory are used to develop the efficiency of the system in facilitating and increasing discussions between learners. These theoretical considerations guide the system design toward a more effective presentation of discussions.

The chapter concerns the design of forum models and tools which aim at promoting text-based asynchronous discussions during learning activities that are not collaborative a priori. During individual learning activities, to only provide usual communication tools is not always sufficient to create interactions between learners and favour the construction of collective knowledge. Usual communication tools could be appropriate if a collective learning activity is set up, during a project-based learning, for example (George & Leroux, 2001). Nevertheless, in distance education, all learning activities cannot be collaborative, and the approach presented in the chapter aims at encouraging interactions during individual activities that do not commit learners to a forced collaboration.

We propose a forum model, named CONFOR (CONtextual FORum), which is based on two special features: contextual view and structuring. The contextual view of the forum, always visible, allows the learner to focus on pertinent discussions, that is, on messages that correspond to his/her activity. Contextualization is common in annotation systems but not in forum tools. Adding this feature to forums, the intention is to closely link communications to learning activities. To provide this contextual view, the discussions need to be structured. We suggest in this research two means of structuring: according to (1) the content structure of a course and to (2) the cognitive structure of a course.

This chapter starts with a discussion about some theories we rely on. This first part leads to the research issues. Then, two ways to structure contextual forums are detailed before proposing an approach to integrate them. Finally, we give some results of an experiment and we mention lines of future trends.

Theories, Background, and Research Issues

This section presents a literature review to support our position. We conclude this section by stating our research issues.

Theories of Communication

Numerous theories of communication have been developed. The aim of this part is not to make a complete state of the art of these theories but to underline some aspects especially of interesting for the research.

According to the model of Jakobson (1960), all acts of communication, be they written or oral, are contingent on six constituent elements: Addresser, Message, Context, Contact, Code, and Addressee. The "context" element particularly interests us because it defines the frame of the message reference, that is, the ground on which a communication can occur. This referential function emphasizes that communication is always dealing with something contextual. Indeed, "When humans talk with humans, they are able to use implicit situational information, or context, to increase the conversational bandwidth. Unfortunately, this ability to convey ideas does not transfer well to humans interacting with computers" (Abowd & Dey, 1999, p. 1). This notion of context is rarely explicit during mediated communications, except by the addresser of the message. One of our goals is to contextualize communication in e-learning situations, that is, to link discussions to context of discussions.

Situated Action Theory

Works on communication theories can be complete with some other works dealing with situated actions (Lave, 1988; Suchman, 1987). The term "situated action" underlies the idea that each action closely depends on material and social circumstances in which it occurs. Situated action theory introduces an interesting idea: action is not the execution of a ready-conceived plan, but it is the user's adaptation to the context. Applying situated action theory to computer mediated communication, Mantovani (1996) concludes that users are social actors with their own aims and autonomy in situations, and it is technology that must adapt to them. In this sense, "the most effective way of clarifying the meaning of messages is to relate them to a shared context" (Riva, 2001, p. 217).

Thus, by extension, communication is a situated activity (Lambert, 1992). The situated actions theory pointed out the fact that communications should occur during the action, at the time when the user needs it. So if a user can't communicate easily in action, s/he will not do it. Our work aims at facilitating communication in action.

Activity Theory

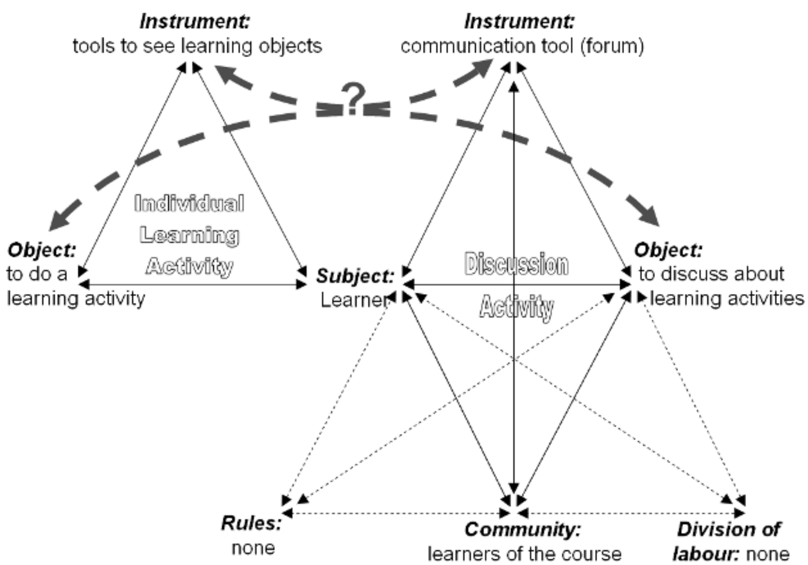
Another theory can throw light on the issues: the activity theory (Leontiev, 1978). This theory, based on the initial ideas of Vygotsky, emphasises how knowledge is "socially constructed." In this way, activities are integrated in a social matrix composed by persons. Basing on this theory, Engeström (1987) has suggested a framework for a collective activity. His popular representation of activity theory adds to the triangle subject-object-artifact (Vygotsky, 1978) another level containing rules, community, and division of labor. Thus, the first relational triangle—the subject who achieves an object by using instruments (e.g., computer tools)—is then widened to show that a subject is not lonely but is a part of a community.

The activity theory is not only useful to describe humans' behaviour during collective activities but also makes it possible to conceptualise collective learning. Thus, these principles can offer a framework to analyse and conceive educational environments (Lewis, 1997; Roschelle, 1998). The next section will come back to the utility of this approach to better understand communication activities during individual learning activities.

Research Issues

We can use the representation of human activity of Engeström (1987) to illustrate the two activities that interest us in this research: individual learning activity and discussion activity (Figure 1).

Figure 1. Linking learning activity and discussion activity through activity theory



We remind the reader that we focus our work on learning activities that are a priori defined to be individual but with possible and desirable communications between learners. Figure 1 shows that, currently in this situation, learning activities and discussion activities are not linked. On the one hand, the learner uses different tools to see learning objects in order to do a particular learning activity (small triangle on the left part of Figure 1). On the other hand, the learner can use communication tools (as forum) to discuss with other learners of the course (big triangle on the right part of Figure 1). In our case, the community does not have imposed communication rules or recommendation to divide the labour. Within this configuration, the only link between learning and discussion activities is the learner. To see the emergence of a community, it supposes that learners have the capacity to link themselves the two activities. We have symbolized by a question mark the point that seems important to us and that is currently missing. It could be seen as a synchronisation point between learning and discussion activities. In other words, we aim at studying communication artefacts as integrated and inseparable components in human learning activity. How to merge the two triangles together?

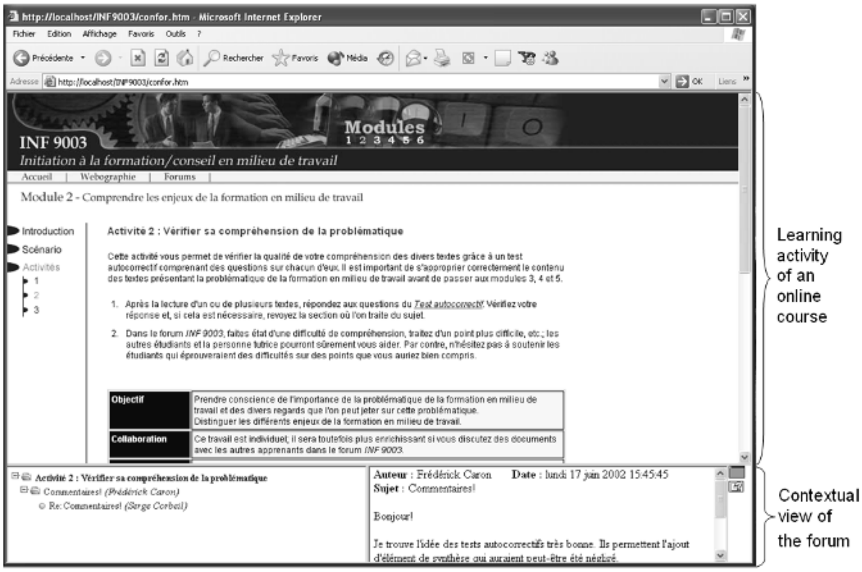
Starting from these considerations, the work consists in finding a solution to deeply integrate communication into distance learners' activities. Learning activities are taken in a broad sense, such as reading an electronic document, doing an exercise, or using a simulation. On the one hand, we want to make communication more **situated** in distance-learning system and, on the other hand, we aim at defining more explicitly the **context** of each discussion.

We focus on one kind of communication tools in distance-learning systems: forums, which are tools for asynchronous communications. The research question lies in determining a model of contextual forum and to develop computer tools based on this model. Currently, we have studied two means to contextualise discussions, which are described in the following section.

Work on Contextual Forum

In this section, we discuss two kinds of contextual forums structuring studied in our work. The first one is based on educational scenarios and the second one is a knowledge-based forum structure. We propose then a solution to integrate these two approaches. Finally, we mention current results of our research on contextual forums.

Figure 2. Screen shot of CONFOR



Contextual Forum Based on Educational Scenarios

In the first approach of forum structuring, each forum thread is linked to an item of the content navigation of an online course. For that, educational content may be sequenced for the learner: "the branching and flow of that content may be described by a predefined set of activities, typically defined at design time" (Dodds, 2003, p. 13). In the model we propose (George & Hotte, 2003) each root message of the forum is a reference to a learning activity. Thus, a reference could be, for example, the title of a course chapter or the number of an exercise. The forum is then hierarchically structured according to learning activities, by reference to the course structure. According to contextualization seen above, the opening of an educational object leads to the opening of a forum partial view corresponding to the activity in progress. With these references, the goal is to focus learners' exchanges on learning objects.

The interface of the CONFOR tool is shown in Figure 2. The upper part of the window contains a learning activity of an online course. Under this course is the contextual view of the forum, which is automatically updated depending on the upper part. For instance, in Figure 2, a learner carries out the activity 2.2 of the module 2 of his/her course and s/he sees, at the same time, the messages of the forum that correspond to this activity (messages under the reference "activity 2.2"). This contextual view of the forum is a part of a unique global forum. This should be noted that this global forum can be displayed in a global view (to see the entire tree of messages). In both views—contextual or global—the left part of the forum displays the list of the message titles and the references names. When the user clicks on a message title, the content of the message is displayed on the right part of CONFOR. The forum can be resized or put in an "always on top" window.

In order to provide the contextual display of the forum, we have to define references in connection with the online course structure. In this model, references contained in the forum are linked to the learning activities structure. So references are dependent on the educational scenario designed by the author of the course. The question is then to determine how to add these references before the course starts. A solution is to give the possibility of manually inserting references. For that, we propose a designer interface in CONFOR allowing this manual definition of references. Each reference is defined by a name and a link. The name will appear in the forum and the link is the reference to the educational object or to the learning activity (e.g., an URL). Moreover, references are linked together in a hierarchical manner. Nevertheless, this manual definition of references can become a hard work if the course is large. For this reason, we also suggest an automatic procedure to add references in the forum. For instance, an automatic import procedure has been done for educational scenarios described with SCORM (Sharable Content Object Reference Model).

Knowledge-Based Contextual Forum

From the previous work, an issue emerges: it would be a good idea to propose a different structuring of forum, by defining references in connection with knowledge dealt in online courses. From a first experiment of CONFOR (cf. the last part of this section), we observed that two messages could be situated in two different threads even though these messages dealt with the same content or with the same knowledge. So the goal became to design a structuring model based on knowledge representation while keeping the contextual view of the forum.

We studied various taxonomies which make it possible to describe knowledge elements approached in learning documents. In particular, taxonomies used by libraries have been examined. Among those, we chose the Dewey Decimal Classification (DDC) because it is flexible, simple to use and allows a classification of knowledge sufficiently fine for our work. The DDC is a knowledge organisation method which is used worldwide. It is universal because it uses numerical indexes to classify documents and, thanks to its international standardized notation, it is alphabet and language independent.

We chose to use the DDC in conjunction with the Learning Object Metadata (LOM) (IEEE, 2002). In online education, the metadata are used to describe courses and learning objects. They include a number of descriptors which are defined according to a standard, so these courses and learning objects are more easily accessible and usable: interoperable, reusable, long lasting, adaptable (Downes, 2001). LOM contains nine categories in order to describe educational resources, but according to our objectives, the ninth category, named "classification," is the category that particularly interests us for contextual forum. This field ensures the classification and indexing of educational objects according to knowledge taxonomies such as the DDC.

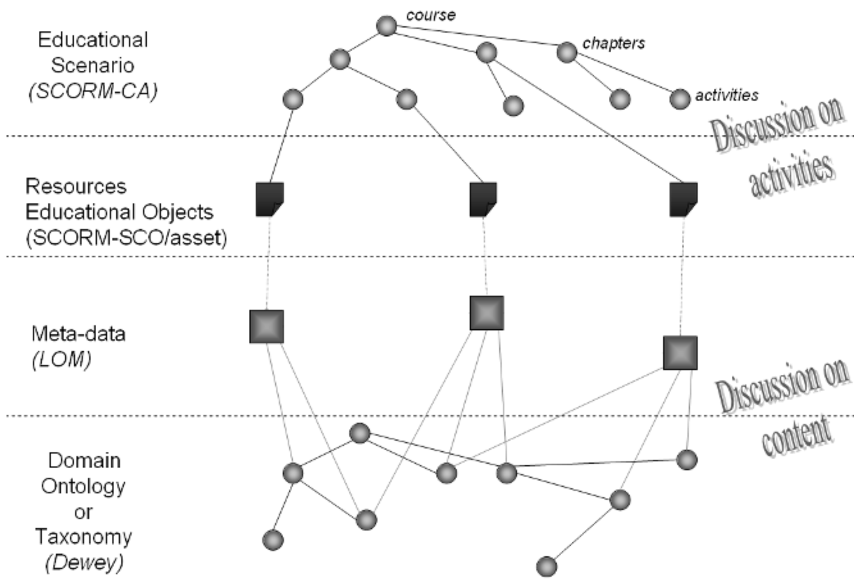
However, providing metadata is not always easy work for some authors of learning objects. From their point of view, this work requiring a literature study, which is not always in their field of competences, is tiresome and nonproductive. We believe that it will be one of the major problems for the development of educational objects. However, we take as a working hypothesis that to use CONFOR, each learning object will be well documented and described with LOM. If this work is not done by authors, information specialists could do it.

Then we suggest a model of knowledge-based forum. In this model, the topics are organised according to a structure defined by the knowledge tackled in a course. With the attribute "classification" of the LOM description of each educational object, the knowledge elements being consulted at a time can be identified. Therefore, a forum function can show in a contextual way all the topics corresponding to these knowledge elements (George, 2004). The learner may then consult, share, and interact with other learners about the knowledge of the course. An advantage of this mechanism is that two students who work on two different learning objects will be able to meet on the same thread to discuss a common knowledge item.

Toward an Integrated Approach of Contextual Forum

Our current research concerns the integration of the two models presented above. Actually, using a singular approach has some limitations. In the first

Figure 3. An integrated model of contextual forum



approach, contextual forum based on educational scenarios, some messages could be situated in different threads even though these messages dealt with the same content. In the second approach, knowledge-based contextual forum, general discussions about learning activities have no place in the knowledge structure.

The idea of integration consists of showing the learners a discussion thread corresponding to the current activity (e.g., to discuss about the organisation inside the course) and also the discussion threads corresponding to knowledge at stake at a time (in order to discuss the content). Figure 2 represents a model that takes into account these two levels of contextual discussions.

In this model, an educational object—or a resource—is referenced as an object of an educational scenario (in the upper part of Figure 3) and this object also deals with several knowledge elements described in its metadata (in the lower part of Figure 3). Knowledge elements could be defined by an ontology of a particular field or by a taxonomy such as Dewey (DDC). Always in this model, each circle is then a discussion topic inside the forum. So when a learner opens an educational object, the contextual forum displays automatically the activity topic and all the knowledge topics linked to the resource.

Current Results

An assessment has been carried out at the Tele-university of Quebec to evaluate the contextual forum. CONFOR was assessed within an introductory course on “training in the workplace” offered to students registered in an undergraduate certificate program in business-oriented computer sciences. The CONFOR version used for this experiment was the first version, with the forum structure only based on educational scenarios. Nevertheless, this experiment provides interesting information.

The experiment lasted 8 months and about 70 students took the course. During the evaluation, two different tutors supervised the students. The goal of the assessment was to study the use of CONFOR. More specifically, we wanted to test the utility and usability of the forum contextual display. For the purposes of the assessment, we used questionnaires, interviews, and regular observations coupled with computer traces analysis. It should be pointed out that the course used to assess CONFOR was newly offered by the Tele-university. For this reason, we will not directly compare the use of CONFOR with that of other forums used at the Tele-university, too many parameters being different.

The questionnaire responses indicate that the students are quite appreciative of the reference-based structure of the forum. Similarly, even if a global view of forum was provided, they favour the forum’s contextual display (4.5 more messages opened in the contextual view than in the global view). Furthermore, the contextual view favours the sending of messages (7.5 more messages sent in the contextual view than in the global view). The results also indicate that CONFOR helps students in finding messages relevant to their activities, that is, messages useful for the learning activity they are engaged in. Finally, students found that the forum fostered the organisation of discussions. Since forums are also an important tool for e-learning tutors, we conducted semistructured interviews with them to obtain information on their use of CONFOR. Tutors found the interface simple and intuitive to use. Concerning utility, tutors appreciated having the forum and the course on the same page. They appreciated the ease of locating new messages, which facilitated their monitoring activities.

At this point, we can thus conclude that contextualisation of discussions for learning activities is appreciated. Users also seem to appreciate the fact that communication and learning are integrated into a single space. Having access to the opinions of others, as they carry out their learning activities, motivates students to locate discussions that help them to understand and to build their knowledge. From this point of view, we can contend that this kind of forum has a positive effect on learning.

Conclusion and Future Trends

There is an increasing need for context-aware services and applications that are able to adapt dynamically to the user's activity. Dey (2000) states that "A system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task" (p. 6). In other words, context-sensitive applications are those that respond to changes in their environment. Some research studies have been done in this direction, for example, in the field of mobile and ubiquitous computing. The general aim is to make information more relevant to the situation in which it is being used. Mechanisms to provide context-sensitive help are common examples.

We introduce in this chapter a new idea that consists of defining a context-driven support communication. Our research aims at proposing specific forum models and tools for online education. The work led to the idea of contextual display of forum messages. We suggest two versions of contextualisation. The first one is based on a forum structuring according to online course structures. Some results of an experiment led us to study another forum structuring, by taking into account the cognitive structure of a course. The result is a discussion tool that displays to the learner an "activity topic" and several "knowledge topics" linked to the learning resource that is open. Currently, the context is limited to the activity in progress and to concepts studied at a time. We wish to extend the notion of context, taking into account more parameters such as a learner's history or learner's goals. Then, we could use this information to better adapt displayed topics to each user. For example, carrying out the same activity, two learners would see different and specific discussions topics according to their past actions and to their personal characteristics.

We can also mention some limits of contextual communication tools. As pointed by Dimitracopoulou and Petrou (2004) and take up by Gao, Baylor, and Shen (2005), "the problem with the systems that contain embedded communication tools is that discussions are usually fragmented by artefacts, which causes learners to lose a holistic view of the discussion and the relationships between different aspects of the artefact" (p. 76). In our case, we try to reduce this effect by also providing a global view of forum discussions. We believe that in developing contextual communication tools, it should be suitable to give several ways to enter and to read the discussions.

Furthermore, we only study at this time a context-sensitive asynchronous system but we want to extend the mechanism to synchronous discussions ("contextual chat"). A future trend will be to no longer see forum or chat tools simply as a communication tools, but also as tools helping to put users in touch with others. These kinds of context-aware communication tools will bring users together depending on their interests, motives, or needs.

Finally, we do not believe in completely generic context-sensitive applications. Context-gathering mechanisms could not be totally generic. In the case presented in this chapter, the context-gathering mechanism is adapted to the e-learning situation even if the global model is generic. We could easily adapt it to a computer-supported cooperative work system, for example, but the sensors would not be the same. Context-driven support communication will be really pertinent only if situations are well defined and if users' activities are circumscribed.

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Chapter VI

Toward Noninvasive Adaptation of Metaphors in Content

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Abstract

Web information systems (WIS) can be considered as media. These media implement a tool language that enables access to content. Accessing that content aids users in achieving their goals. The language in which that content is given nowadays is often natural language or very close to it. Consequently the content involves metaphors. As the Web is open to virtually everyone, the users of WIS are likely to differ from each other with respect to ethnicity, language, gender, age, culture, education, preferences, physical or mental handicaps, and so forth. Consequently users are likely to respond differently to the metaphors occurring in the content. This chapter, therefore, proposes an approach to adapting the employed metaphors to user types for improving the value that the WIS offers to its users. This is expected to result in both increased user *acceptance and number of business transactions. Therefore, an increased return on investment for the WIS is expected as well. We propose a conceptual model for user type and context-aware mapping of concepts in a target domain to concepts in a source domain. The respective mapping is used for modeling metaphors. We formalize that mapping in terms of the Higher-Order Entity-Relationship Modeling (HERM) language and in the Web Ontology Language (OWL). The conceptual model we provide can be used as a basis for hot generation of content representation such that the metaphors occurring in the content are adapted to the types of the users interacting with the WIS. As a step toward implementation, we formulate a high-level architecture that enables us to noninvasively adapt the metaphors in the WIS content to the types of the users. We report our experiences regarding exploration of the feasibility of the architecture. These experiences result from implementing a prototype that shows how metaphors—in a noninvasive manner, that is, without changing its code or content—can be added to the contents of an already-existing WIS. The chapter is completed by presenting the results of formal user evaluation which demonstrate the user acceptance of the respective metaphors.*

Introduction

According to Hirschheim, Klein, and Lyytinen (1995, p. 11), Langefors defined the term "information system" from a functional perspective as "a technologically implemented medium for the purpose of recording, storing, and disseminating linguistic expressions as well as for the supporting of inference making." According to Kaschek, Schewe, Wallace, and Matthews (2004), a Web information system (WIS) is understood as an information system that is integrated in the Web and uses it as a resource. Integration of an information system into the Web makes it open in the sense that virtually everyone can access it. The extent to which system developers know the system users at development time is therefore larger with respect to WIS than it is with respect to information systems in general. User typing and adaptation to users, thus, must be taken more serious in case of WIS than in case of traditional information systems.

We slightly modify a classification of the languages used to interact with a WIS we found in Wallace and Matthews (2002) as "tool language," "domain language," and "metaphor language." These languages are used for explaining to the user the semantics of the WIS functionality, the domain regarding which the WIS can aid in problem solving, and the metaphors used in the WIS user interface or the domain. In any of these three languages metaphors might be used. We target the metaphor use in the domain language, as that is the language in which the content will be expressed. Metaphor use with respect to WIS has been discussed by Nielsen (2000, p. 190). Nielsen assesses the metaphor use in several WIS examples as negative. His assessment, however, does not apply to our work, as he discusses metaphors as tool in WIS interface design, which means that a metaphor is chosen as guideline for both the overall system design and the system interface. Nielsen specifically mentions that such a metaphor might cover a part of the WIS functionality well, but might be poorly cover other parts. That remark does not apply to using metaphors as understanding aid applied to content, as several metaphors can be used easily. It is clear, however, that a sensible use of metaphors must be targeted and is not trivial to achieve. Note that other sources, such as Thalheim and Düsterhöft (2000), recommend using metaphors as design guideline. That makes the findings inconclusive that we know of regarding using metaphors as a design tool.

That inconclusive state of the literature should not make one forget how important metaphors are for modern computing. In a Microsoft Windows-based environment, for example, one makes use of metaphors that are connected to the drag-and-drop style of handling files in case of copying or deleting them. Some of the basic concepts of modern computing such as "file" are or were metaphorical (see Murray Hopper, 1981, p. 16). The functional view definition of the term "information system" insofar as system implementation is concerned is based on a metaphor. A universe of discourse is represented as a particular part of a state of a computer. Such a state is a pattern of electrical current, magnetization, capability to polarize light, or similar. That representation can be manipulated according to rules that may depend on the universe of discourse. After respective manipulations, the pattern part is interpreted in terms of the universe of discourse and notified to the user in terms of suitable linguistic expressions. What actually happens "inside" a computer is beyond of what can be understood by most of the users. However, experts in the fields mentioned understand these processes to such an extent that they can even put in place automated procedures for translating linguistic expressions into the patterns mentioned and vice versa. A broad conceptualization of metaphor as "understanding one domain in terms of another one" here is superposed by a division of labor.

The chapter is organized such that next, we provide more discussion on metaphors. Then, we discuss our conceptual model of a user-type depending mapping of concepts in a source domain into a target domain. After that, we discuss our architecture of a noninvasive add-on for adaptation of metaphors to user types. We then discuss an OWL schema for such an adaptive concept mapping. The paper concludes with a case study, a conclusions section, and our references.

More on Metaphors

While historically metaphor was the topic of literary studies and rhetoric, recently, conceptual metaphors started to play an important role in the fields of cognitive sciences (in particular, cognitive linguistics; see, e.g., Janda, 2000; Evans & Green, 2005) and artificial intelligence (Nehaniv, 1999). In addition, in the second half of the 20th century, metaphors became a standard topic in philosophy of science (Bailer-Jones, 2002). The *Oxford English Dictionary Online* defines metaphor as a "figure of speech in which a name or descriptive word or phrase is transferred to an object or action different from, but analogous to, that to which it is literally applicable; an instance of this, a metaphorical expression." Similarly, more general and a bit more fuzzy defines (O'Grady, Archibald, Aronoff, & Rees-Miller, 2001) metaphor as "the understanding of one concept in terms of another." A more recent text, that is, Kövecses (2002), that is wholly dedicated to metaphors agrees with that and proceeds with defining "[a] conceptual metaphor consists of two conceptual domains, in which one domain is understood in terms of the other. A conceptual domain is any coherent organization of experience.... The conceptual domain from which we draw metaphorical expressions …" (i.e., words or other linguistic expressions) "is called source domain, while the conceptual domain that is understood that way is called target domain" (p. X).

Effective use of metaphors thus constitutes reusing knowledge regarding a particular source domain. Metaphors are known as an effective cognitive tool for improving end-user experience by facilitating the creation of mental models of the system (Comstock & Duane, 1996). For a metaphor to be effective, two conditions need to be met. First, its recipient needs to be capable of identifying the metaphor. Second, the recipient needs to be sufficiently familiar with the source domain, so that s/he can effectively draw from it, using the knowledge and, more importantly, the intuition gained for concepts in the source domain to infer the structure of the target domain. One may utilize everyday life as the source domain. However, it is not uncommon to rely on the user's prior knowledge of a specialist area. For example, for the target domain of economics, it is common to use the following metaphors sourced in the domain of physical sciences: chain reaction (chain reaction of bankruptcies), pendulum (economic cycles as a pendulum), diffusion (technology diffusion), equilibrium (equilibrium of supplies and requests), and so forth.

Metaphors utilizing a source domain unfamiliar to the user are likely to result in confusion or even create misconceptions. For example, the "smiling cat" (maneki-neko) metaphor occasionally used in Japanese e-business WIS is unlikely to be effective for a North American user, who might form an inadequate mental model (e.g., of a "pet shop" rather than of "a small business"). Clearly, to leverage the power of metaphors fully, these need to fit to the targeted recipient's characteristics, such as culture and background knowledge.

Two different approaches might be considered for having effective metaphors in place. First, given the projected audience of a Web-based system the metaphors optimally fitting it might be identified and hard coded as part of the interface provided by the system. This is the approach used in classical human-computer interaction (Carroll, 2003). Second, metaphors may be added to the Web-based system content dynamically at execution time. We focus on the latter approach, as it offers the flexibility required for supporting the increasingly multiage, multibackground, and multicultural WIS user community.

The view on metaphor adopted in this chapter is very close to the one taken by most researchers in the emerging field of cognitive linguistics. In particular, we stress the importance of the conceptual substrate formed by the situational and cultural context in which metaphors are applied. This leads us to the necessity to explicitly take into account the user type and the wider context when using metaphorical expressions in WIS contents. In our view, learning to use a WIS entails the same processes as learning new words and expressions in a language. Cognitive linguists believe that for understanding language structure and dynamics, one should consider the cognitive processes underlying and determining language use (Evans & Green, 2005). That view according to Pena Cervel (2003, p. 27) is adopted from Lakoff and Johnson who in 1980 wrote, "metaphor is typically viewed as characteristic of language alone, a matter of words rather than thought or action.… We have found, on the contrary, that metaphor is pervasive in everyday life.… Our ordinary conceptual system, in terms of which we both think and act, is fundamentally metaphorical in nature.…" The latter point is also made by O'Grady, Archibald, Aronoff, and Rees-Miller (2001, p. 255): "Many people think of metaphor as a literary device reserved for the use of authors and poets. In fact, however, it has a prominent place in the conceptual system shared by all human beings." According to Kuhn (1993, p. 539), "Metaphor plays an essential role in establishing links between scientific language and the world. Those links are not, however, given once and for all.… The earth was like Mars (and was thus a planet) after Copernicus, but the two were in different natural families before."

We have to observe that in some essential aspects, the use of metaphorical expressions in WIS in general and in e-learning WIS in particular is similar to their use in model building in natural sciences. As in case of scientific models (Bailer-Jones, 2002), there are clear quality criteria for WIS in general and in e-learning in particular. The best, the most suitable metaphorical expressions are the ones that would allow users to achieve their goals (such as attaining goals in learning and training) as fast as possible, with the minimal effort. On the other hand, we acknowledge that while in case of scientific models the adequate description of phenomena under study is the only applicable criterion, in case of WIS (and e-learning) apart from achieving immediate goals, secondary considerations, such as brand building or motivating lifelong study, may be of importance. In terms of these secondary considerations, metaphorical expressions applied in WIS could be more akin to the ones applied in poetry than to the ones applied in natural sciences.

The ongoing attempts to build human-like mechanisms (robots) and software agents (e.g., avatars) have led to attempts to formalize the formation and the use of metaphorical expressions, for example, in terms of algebraic structures (Goguen, 1999). However, so far there is no generally established approach to such formalization. In this chapter, we opt to formalize and to implement the metaphor use as a straightforward mapping, thus following very closely the mainstream views established in cognitive linguistics and in philosophy of science. For similar reasons, we do not apply the theory of blends, suggesting that metaphorical expression are formed in "blend domains" formed by mixing source and target domains (Veale, 1999); we do not believe that the additional complexity is justifiable for the purpose of building adaptive WIS interfaces, although it does provide additional insight in certain linguistic phenomena.

Matching Target Domain Concepts to Source Domain Concepts

Following Kaschek, Schewe, Wallace, and Matthews (2004), we conceptualize a WIS such that it creates an information space ant that this space contains information objects some of which might be connected by means of traversable links. According to the *Longman Dictionary of Contemporary English*, the context of something is "the situation, events, or information that are related to …" that "something, and help you to understand it better." In a simplifying view, the context of an information object (i.e., an information chunk on a Web page) is understood as the information objects connected to it. More advanced aspects of context in WIS have been discussed in Bineman-Zdanovicz, Kaschek, Thalheim, and Schewe (2004).

The HERM-diagram in Figure 11 formalizes the requirements for user-type–aware mapping of target domain concepts to source domain concepts. Regarding the HERM concepts and notation, see, for example, Thalheim (2000). We limit ourselves to metaphors obtained by relating a concept in the target domain to a concept in the source domain, and do not consider complex metaphors realized by coordinated use of multiple user interface elements.

The data required for creating a metaphor are tied together by an instance of the relationship type "Grounds." The context in which the target domain concept is situated is taken into account by including the "Target domain concept context" (abbreviated as X) entity type. Obviously, w could include the context concept into making metaphor adaptation depending of the user's virtual location in the information space, that is, the Web page currently visited. However, one could introduce other interpretation of what the target domain context is, the X entity type serving as an extension point for further adapting metaphor mapping. The "Explanation" (E) entity type accounts for an explicit description of how the target concept relates to the source concept used to clarify it. The "User type" (U) is accounting for a group of users with similar culture and background knowledge. For a recent paper on user typing, see, for example, Kaschek, Schewe, Thalheim, Tschiedel, and Kuss (2004).

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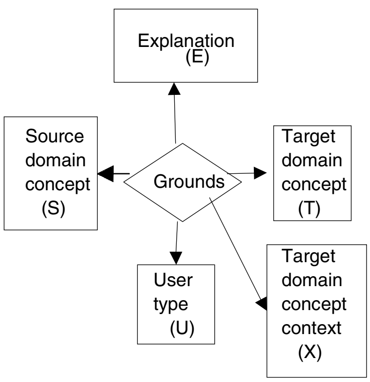
Lookup constraints annotating the diagram are essential for understanding its semantics (see Thalheim, 2000, for a detailed explanation of lookup constraints notation). Here we describe in plain English the restrictions imposed by the lookup constraints in Figure 1:

Figure 1. Matching target domain concepts to source domain concepts



a) $look \quad T, X, U \ , \ S \qquad (0, m)$

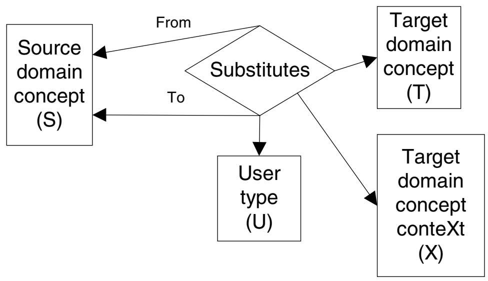
b) $look \quad S, U \ , \ T \qquad (0,1)$

c) $look \quad T, U, S \ , \ E \qquad (0,1)$

d) $look \quad E \ , \ T, U, S \qquad (1,1)$

e) $look \quad T, S \ , \ U \qquad (0, m)$

Figure 2. Substitutability of source domain concepts



$$look \quad T, X, L \;,\; From, To \qquad (0, m)$$

a. For a given user type, target domain concept, in its context, may or may not be representable by a suitable source domain concept (hence, a suitable source domain concept is not always available). Furthermore, more than one suitable source domain concept may be available.
b. For a given user type, a source domain concept may illustrate no more than one target domain concept. Hence, source domain concepts utilized in metaphors can be unambiguously traced back to the target domain concepts they represent.
c. There can be no more than one explanation for a given combination of user type, target domain concept, and source domain concept.
d. Each explanation relates to one, and only one, combination of user type, target domain concept, and source domain concept.
e. A given combination of a target domain concept and a source domain concept may occur several times, with different user types.

Note that the only role of context (of a target domain concept) is to differentiate between source domain concepts matching the target domain concept. We envisage applications that would ignore the context or use it as a refinement step (providing a source domain concept matching the context if one is available, otherwise ignoring the context and attempting a match just to the target domain concept and to the user type). On the other hand, a situation when no "Grounds" instances are available in a given context can be used to indicate the context in which the use of a metaphor is not desirable.

It should be noted that source domain concepts matching a given combination of a target domain concept, its context, and a user type when more than one such concept is available, are not differentiated in Figure 1, and can be substituted for each other. This is reflected in Figure 2, which is not independent, but is a direct consequence of Figure 1 (with lookup constraints taken into account). Substitutable concepts may be differentiated by the system to take into account individual user preferences, although the data model in Figure 1 would have to be enhanced to form a basis for such differentiation.

A given pair of source and target domain concepts can be related to several instances of an Explanation, distinguished by the user type. For example, for a user type involving users very familiar with the source domain, the explanation can be concise. On the other hand, for a user type involving users not familiar with the source domain, the explanation may cover some aspects of the source domain (such an explanation is warranted if the metaphor in question is a very common one, so that it almost constitutes part of the target domain knowledge). Alternatively, for a user type involving users with no knowledge of the source domain, it may be the case that no "Grounds" instances are provided, so that for them, the metaphor is not available, and thus, they are spared from confusion and conceptual overload. Finally, note that Figure 1 allows chaining of metaphors. That enables a source domain concept of a metaphor to be considered as the target domain concept of another metaphor.

An Architecture Enabling Metaphor Adaptation

In human-computer interaction, traditionally metaphors are considered as design tool in the sense that they guide the overall architecture and design. The drawback of this approach is that to add metaphor support to an existing system, it may be necessary to redevelop the system. This may be unfeasible since one might not have the access required. Also, if metaphors form an integral part of a Web-based system, it increases the complexity, and thus increases the costs of both development and maintenance. Here, we propose an alternative, noninvasive approach focusing on WIS content. That approach relies on adding adaptive metaphor support as a separate architectural layer by using the decorator design pattern (Gamma, Helm, Johnson, & Vlissides,

Figure 3. Adding metaphors to base service

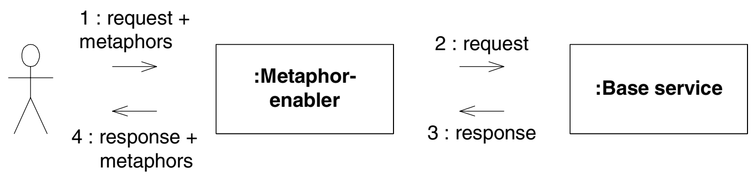
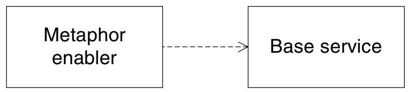


Figure 4. Dependencies in the noninvasive architecture



1995). Henceforth, we occasionally refer to this layer as "metaphor support layer."

In the basic architecture we identify two main components (see Figure 3). We call the component providing the basic user service a "base service component." A "Base service" component could be a legacy system that is usable on its own. Another component, the "Metaphor enabler," intercepts the user's communication with the system providing the base services, and performs data and control transformations outlined in the previous section. The metaphor enabler may need to access session context and user-type information in the base service component or it may provide session and user-type management of its own.

While the metaphor enabler depends on the base service component, the base service component is unaware of the metaphor enabler, as illustrated in Figure 4. Thus, the proposed architecture is a noninvasive approach to adding metaphor support to WIS. The services implemented by the WIS do not need to cooperate in any way to allow metaphor adaptation.

The risks associated with the architecture stem from the fact that the metaphor enabler depends rather strongly on the base service. Depending on the implementation approach taken, changes in the base service may need to be matched by changes in the metaphor enabler. Therefore, care should be taken when deciding on the implementation approach to control the degree of brittleness arising from the dependency.

An OWL Schema for Adaptive Concept Mapping

The Web Ontology Language (OWL) is a language designed to formally describe the meaning of terminology used in Web documents (World Wide Web Consortium, 2004). OWL serves (along with RDF) as an underlying technology of the Semantic Web (World Wide Web Consortium, 2005). It is intended for use when the information contained in documents needs to be processed by applications, as opposed to situations where the content only needs to be presented to humans. Clearly, the purpose of OWL is highly relevant to implementing metaphor mapping in context of the WWW.

An OWL schema implementing the conceptual data model of Figure 1 is provided in the Figure 5. The "Grounds" relationship type is represented by the AdaptiveRepresentationInContext OWL class. All entity types are represented as OWL classes with similar names. Instances of AdaptiveRepresentationInContext are connected to the instances of classes representing the entity types by using the OWL properties formalism. We named properties to ensure readability: an instance of the TargetConcept is represented by an instance of the AdaptiveRepresentationInContext class. AdaptiveRepresentationInContext is given by an instance of SourceConcept, whenUserTypeIs an instance of UserType, and whenConteXtIs an instance of a ConteXt.

One should note, however, that OWL is not sufficiently expressive for formalizing all of the constraints implied by the HERM diagram in Figure 1 including the lookup constraints. Therefore, we chose not to use OWL cardinality constraints, and to assume that the constraints are to be enforced by the application, using a mechanism external to OWL.

An OWL-based implementation would be highly suitable to support a situation in which some of the class and property instances are available over the Internet, with URI serving as object IDs in OWL corresponding to actual physical locations. In particular, we envisage that the vocabulary for concepts (both in target and in source domains), and the vocabulary for user types, could be reused this way. On the other hand, the vocabulary relating to context is likely to be system specific and to have little potential for reuse. As instances of AdaptiveRepresentationInContext and of all OWL properties using AdaptiveRepresentationInContext class as the domain are context dependent, their reuse potential is also limited. A better reuse potential may be realized by

Figure 5. An OWL schema implementing the adaptive concept mapping for metaphor enabling

```
<?xml version="1.0" encoding="UTF-8"?>
<rdf:RDF
      xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
      xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
      xmlns:owl="http://www.w3.org/2002/07/owl#"
      xmlns:xsd="http://www.w3.org/2000/01/XMLSchema#"
      xml:base="http://isrc.massey.ac.nz/adaptifity/metaphors"
>

      <owl:Class rdf:ID="SourceConcept"/>
      <owl:Class rdf:ID="TargetConcept"/>
      <owl:Class rdf:ID="UserType"/>
      <owl:Class rdf:ID="ConteXt"/>
      <owl:Class rdf:ID="Explanation"/>

      <owl:Class rdf:ID="AdaptiveRepresentationInContext"/>

      <owl:ObjectProperty rdf:ID="forTargetConcept">
            <rdfs:domain rdf:resource="#AdaptiveRepresentationInContext"/>
            <rdfs:range rdf:resource="#TargetConcept"/>
      </owl:ObjectProperty>
      <owl:ObjectProperty rdf:ID="givenBy">
            <rdfs:domain rdf:resource="#AdaptiveRepresentationInContext"/>
            <rdfs:range rdf:resource="#SourceConcept"/>
      </owl:ObjectProperty>
      <owl:ObjectProperty rdf:ID="whenUserTypeIs">
            <rdfs:domain rdf:resource="#AdaptiveRepresentationInContext"/>
            <rdfs:range rdf:resource="#UserType"/>
      </owl:ObjectProperty>
      <owl:ObjectProperty rdf:ID="whenConteXtIs">
            <rdfs:domain rdf:resource="#AdaptiveRepresentationInContext"/>
            <rdfs:range rdf:resource="#ConteXt"/>
```

Figure 5.cont.

```
        </owl:ObjectProperty>
        <owl:ObjectProperty rdf:ID="explanation">
              <rdfs:domain rdf:resource="#AdaptiveRepresentationInContext"/>
              <rdfs:range rdf:resource="#Explanation"/>
        </owl:ObjectProperty>

        <owl:ObjectProperty rdf:ID="representedBy">
              <rdfs:inverseOf rdf:resource="#forTargetConcept"/>
        </owl:ObjectProperty>
  </rdf:RDF>
```

refactoring the schema, exposing functional dependencies implied by lookup constraints (b) and (c). We leave it, however, as a topic for further research.

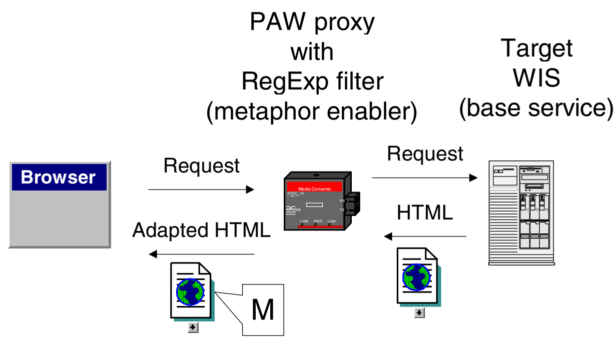
Case Study: Metaphor Enabling an E-Learning System

The purpose of the study we are reporting about in this section is to demonstrate the feasibility of noninvasive metaphor adaptation and to gather experience regarding user acceptance of metaphor adaptation.

Metaphor Enabler

The architecture outlined in Figure 3 was implemented by using the PAW (Proactive Web Filter) open-source filtering HTTP proxy based on the Brazil Framework provided as an open-source project by Sun Microsystems (Brazil Project, 2005; Proactive Web Filter Project, 2005). The PAW proxy offers the capability to plug in custom filters (which have to comply with filter APIs defined as part of the Web application development framework defined by the Brazil Project). At present (in version 2.7), the PAW proxy comes with a RegExp filter, allowing us to match Web page data included in HTTP responses as a string against a set of regular expressions, and to replace matches by

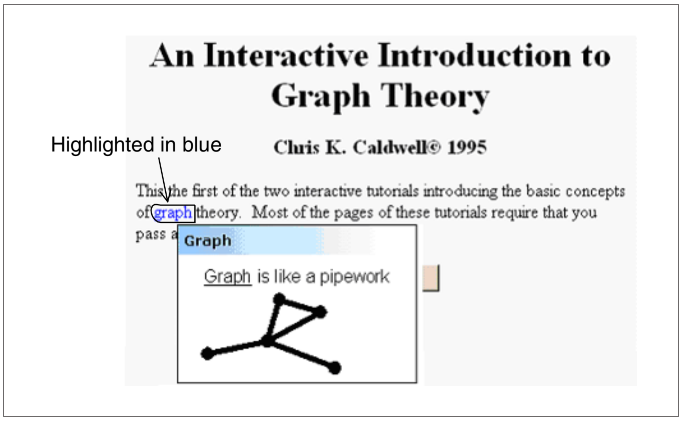
Figure 6. Physical implementation of the architecture outlined in Figure 3



arbitrary strings. To fully implement the conceptual model given in Figure 1, one would have to develop a custom filter, combining the capability to match and replace strings with access to session and context data (such as current user identity and user-type assignment, the URL of the page being retrieved, etc.). For the purposes of initial evaluation, we opted to limit ourselves to relying on the functionality of the already-available RegExp filter, so that the concept mapping was not context sensitive: rules defined for string replacement were defined for all Web pages of the target WIS (the "base service") in a uniform way. While it would be easy to introduce a form of user-type adaptivity by running several instances of the proxy simultaneously, one for each user type, and by instructing users belonging to different user types to use the appropriate proxy settings, the number and the variety of users available for the initial evaluation was not sufficient to validate the value of adaptivity to user types. Hence, we defined the transformations necessary to add metaphor support for a single proxy instance, supporting a single user type, and assuming a uniform context for target domain concepts.

To make sure that the addition of a metaphor support layer does not diminish the user experience under any circumstances (even for users who do not consider the metaphor support to be useful), rather than replacing the occurrences of target domain concepts by source domain concepts, we transformed the Web page HTML in such a way that each target domain concept would became an anchor that, when activated by the user, would display a pop-up showing the corresponding source domain concept (see Figure 7). The RegExp filter was configured to add JavaScript allowing us to achieve this effect on all

Figure 7. A metaphor-enabled Web page, with the source concept (pipe work) shown for the target concept graph, after the user clicked on the source concept highlighted as an anchor by the metaphor support layer



HTML pages served via the PAW proxy. Thus, from a user perspective, the metaphor support layer we introduced was "transparent": users could see through it without taking note of it, if they wished to.

As seen in Figure 7, words corresponding to target domain concepts were highlighted in blue to make them appear similar to HTML links in default HTML styling, but they were not underlined (as HTML links are), so that they could be distinguished from HTML links. By adopting a styling of target domain concepts similar to HTML links, we hoped to suggest to the user that when he/she clicks on the target domain concept, some relevant information (the source domain concept) will appear. We believe that highlighting target domain concepts should not negatively affect the usability of the interface for a user who opts not to use the metaphor support layer (and it could even improve it).

Target WIS Choice and Metaphor Design

As a target WIS for the metaphor support layer evaluation, we chose the Introduction to Graph Theory and Euler Circuits and Paths online tutorials from Graph Theory Tutorials by Chris K. Caldwell (Caldwell, 1995) (in the following, we often refer to them collectively as "the tutorial"). The reasons for this choice were as follows:

- The tutorials are highly interactive and involve static pages, dynamic pages, and HTML forms, thus representing a full-featured WIS.
- The tutorials have a linear structure, which ensured that all test users followed the same path, and had comparable exposure to the WIS information.
- The tutorials include a large number of quizzes, which allowed us to consider the success of the users in learning the subject.
- The topic covered by the tutorials is relevant for the background of the test users we had available.

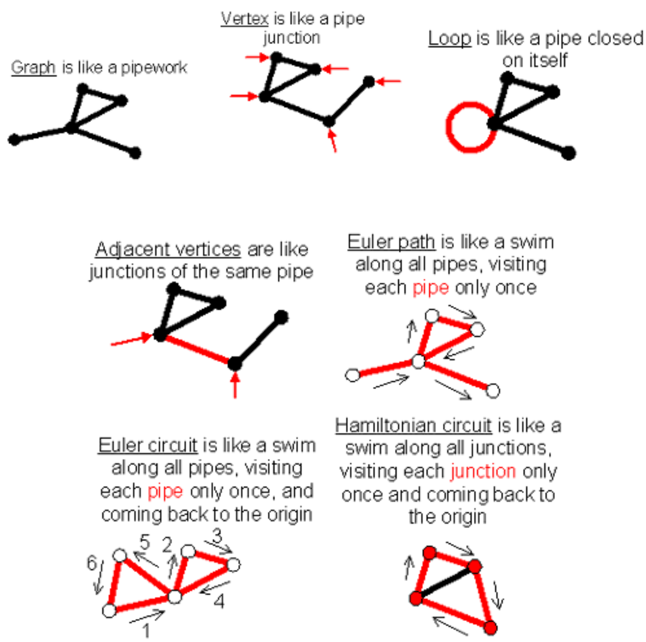
Since the test WIS was devoted to teaching graph theory, the target domain contained various graph theory terms. As the source domain, we chose plumbing with pipes standing for graph edges and pipe junctions for vertices, on the assumption that all of the prospective users have a degree of everyday experience relevant to this domain. We have built a system of metaphors based on this representation of edges and vertices, with movement along edges and vertices interpreted as "swimming" along "pipes." In addition to textual representation, we added the relevant drawings. Care was taken to make sure that each target concept representation would stand on its own, and would not require any further clarification via cross-referencing and so forth. All of the metaphors employed formed a metaphor system organized around the common high-level metaphor (of a pipe work and movement through it). Some of the target concept representations we used are listed in Figure 8.

Evaluation Setup and Results

The evaluation was conducted with 11 users of similar background (most of them postgraduate students employed as graduate assistants not majoring in mathematics). The users were instructed to reconfigure their browsers to use the PAW proxy imposing the metaphor support layer, and to complete the tutorial with as few quiz resubmissions as possible. The tutorial was set up (by its original creator) in such a way that in order to proceed the user needed to answer all questions in each of the intervening quizzes correctly; if a quiz was answered incorrectly, the user was prompted to redo it until all answers were correct (see Figure 9).

There was no time limit, and the users were not asked to maximize the speed with which questions are answered, so the number of quiz resubmissions was

Figure 8. Some of the metaphors used in the evaluation



the only quality criterion (the fewer resubmission, the better, with zero resubmissions corresponding to all questions answered correctly at the first attempt). The evaluation instructions we used can be viewed online at Tretiakov and Kaschek (2005).

All HTTP requests were logged at the proxy. We attributed Web page and metaphor invocations to user sessions via IP addresses, which were stored by the proxy as part of each log entry. As IP addresses in our environment are allocated dynamically, it was not possible to determine the identity of the user, which ensured user anonymity. In addition to completing the tutorial, users were asked to anonymously provide free-form comments on the usefulness of the metaphor layer.

A Python script that was created for that purpose was used to filter out log entries for each session and to represent the session as an animated replay of user interactions with the tutorial and with the metaphor layer.

For each user, the animated replay was visually analyzed to make sure that any spurious or irrelevant interactions are not taken into account. While most users navigated along the tutorial linearly, only once, from beginning to end, some completed only half of the tutorial on the first attempt; later, they resumed from the beginning, and this time, completed it, or almost completed it. For such users, we disregarded the part of the second attempt session duplicating the first attempt, so that all data correspond to the first encounter of the user with the particular part of the system's hyperspace. A detailed summary of the data is given in Table 1.

As is clear from Table 1, we divided all metaphor invocations into two categories: the ones in the context of exploration, and the ones in the context of fulfilling short-term goals. This was achieved as follows: we divided all pages of the tutorial into three categories—exploration page, in which new concepts were introduced; quiz page, showing questions to be answered by the user; and feedback page, providing feedback for quiz submissions (see Figure 9). When a metaphor was invoked from an exploration page for the first time, or from a feedback page after a successful quiz submission, we assumed that it was for the purpose of learning a concept, in the context of exploration, rather than for the purpose of recollecting a definition (a short-term goal). On the other hand, when a metaphor was invoked from a quiz page, or from a feedback page after

Figure 9. The structure of the tutorial

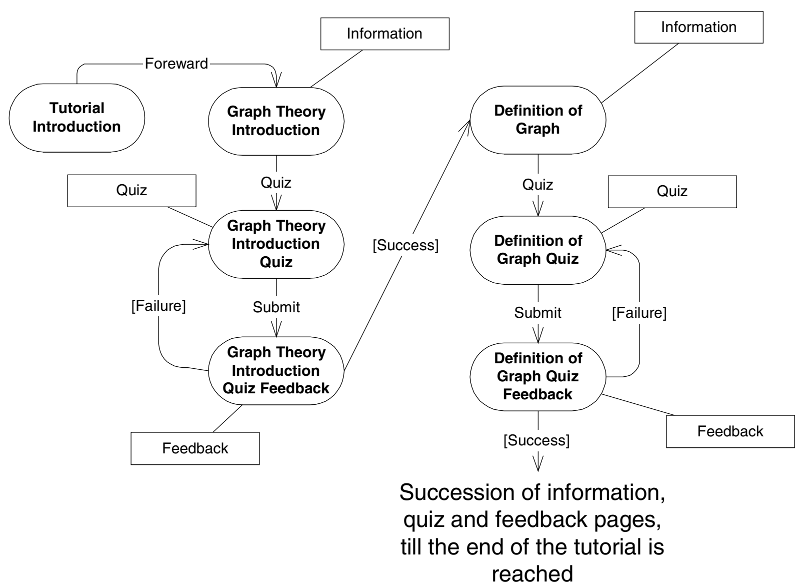


Table 1. User success (measured by the number of quiz resubmissions) and the number of metaphor invocations. For users who did not complete the tutorial, the number of resubmissions is not given (marked n/a).

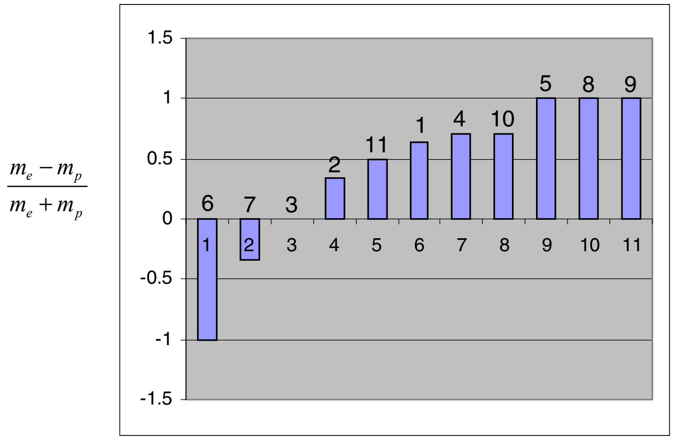
User no.	Number of quiz resubmissions	Metaphor invocations in context of exploration	Metaphor invocations in context of fulfilling short-term goals
1	11	9	2
2	1	2	1
3	1	8	8
4	n/a	6	1
5	9	2	0
6	6	0	4
7	12	4	8
8	8	11	0
9	n/a	4	0
10	8	6	1
11	4	9	3

an unsuccessful submission, we assumed that it was for the purpose of fulfilling an immediate information need prompted by the necessity to solve a problem.

Most of the users made use of the metaphor layer feature, with the mean number of metaphor invocations per user of about 8, which considering that there were 34 pages in the tutorial, constitutes about 1 invocation per 4 pages visited. As one can see from Table 1, the number of metaphor invocations differed significantly from user to user, the standard deviation is estimated as 4.6 (more than half of the mean value of 8).

An unexpected and highly interesting outcome was that the users made heavy use of metaphors in the context of exploration, with almost 70% of invocations falling in that category. There were 45 metaphor instances available on information pages, 29 on quiz pages, and a smaller number of metaphor instances on feedback pages, with the user exposure to metaphors on feedback pages depending on his/her answers in the corresponding quiz. While the specific numbers are difficult to interpret, as the impact obviously depends not just on the number but also on the quality and appropriateness of the metaphors available, the numbers clearly indicate that users, overall, accept the services provided by the metaphor layer, as they invoke them without an imposition.

Figure 10. The difference between the number m_e of metaphor invocations in context of exploration to the number of metaphor invocations in context of solving a problem m_p, normalized by the total number of invocations $m_e + m_p$, separately for each user (with the user number shown at the top of each bar).

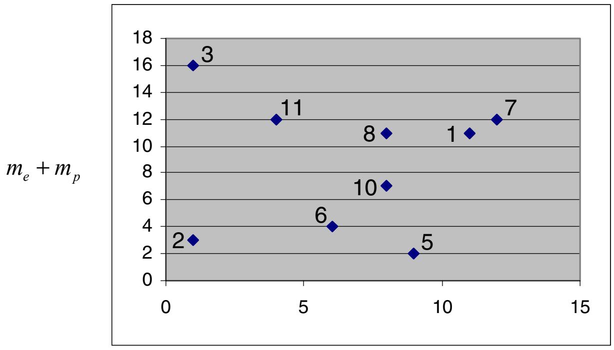


The difference of the number of metaphor invocations in the context of exploration and the number of metaphor invocations in the context of solving a problem, normalized by the total number of invocations, is plotted in Figure 10.

On the other hand, with the relatively small number of users participating in the evaluation, we were not able to observe a clear correlation between metaphor layer usage and user success measured by the number of quiz resubmissions (the smaller, the more successful). As can be seen from Figure 11, there were heavy and poor metaphor users at all levels of that success measure.

Figure 10 appears to suggest that while many of the users favor using the metaphor layer in exploration context, others rely on it in problem-solving context, suggesting that two user types could be defined, with metaphors provided differently to each type depending on the context (e.g., users using metaphors in exploration mode could be provided with richer, more complex source concepts). However, it is a matter for further research to consider how to use the adaptivity to user type in metaphor layer to alter user behavior (e.g.,

Figure 11. The total number of metaphor invocations as a function of the number of quiz resubmissions n_r (the fewer the number of resubmissions, the more successful is the user). Users 4 and 9, who did not finish the tutorial, are not included.



to encourage long-term learning), rather than to just cater for facilitating the existing usage patterns.

Out of the 10 users who did provide free-form comments, nine were very positive both about the metaphor layer and about its implementation in support of the tutorials used in the evaluation. One user was positive about the metaphor layer in general, but for the implementation used in the evaluation did not recognize the choice of the source domain and the choice of source domain concepts as appropriate or useful. An evaluation involving a larger number of users would reveal if there are indeed user types for whom a different choice of the source domain would be more appropriate.

Conclusion

We have introduced a conceptual data model allowing us to adaptively map target domain concepts to source domain concepts, for inclusion in metaphors. The model allows defining a database for a metaphor enabler forming part of a noninvasive architecture that we propose for adaptive metaphor enabling of Web-based systems.

Since our approach is noninvasive, it can be applied to both legacy systems and to systems under development. The architecture suggests decorating a Web-based system with metaphors by adding a separate architectural layer, so that the base service does not need to be changed.

In addition, we explored how Web Ontology Language (OWL) could support a potential implementation by providing an OWL schema matching the conceptual model defined in HERM.

We implemented a limited prototype system and conducted a user evaluation. The results of the evaluation indicate a good user acceptance of the metaphor layer, with users tending to access metaphors in context of learning/exploration, rather than limiting themselves to invocations in support of fulfilling short-term goals.

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Chapter VII

A User-Centered Approach to the Retrieval of Information in an Adaptive Web Site

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Abstract

This chapter describes the user-centered design approach we adopted in the development and evaluation of an adaptive Web site. The development of usable Web sites, offering easy and efficient services to heterogeneous users, is a hot topic and a challenging issue for adaptive hypermedia and human-computer interaction. User-centered design promises to facilitate this task by guiding system designers in making decisions, which take the user's needs in serious account. Within a recent project funded by the Italian Public Administration, we developed a prototype information

system supporting the online search of data about water resources. As the system was targeted to different types of users, including generic citizens and specialized technicians, we adopted a user-centered approach to identify their information needs and interaction requirements. Moreover, we applied query analysis techniques to identify further information needs and speed up the data retrieval activity. In this chapter, we describe the requirements analysis, the system design, and its evaluation.

Introduction

The development of a *Web-based information system* targeted to different types of users challenges the Web designer because heterogeneous requirements, information needs, and operation modes have to be considered. As pointed out by Nielsen (1999) and Norman and Draper (1986), the user's mental model and expectations have to be seriously taken into account to prevent her/him from being frustrated and rejecting the services offered by a Web site. Indeed, this issue is particularly relevant to Web sites offering task-oriented services, because most target users utilize them out of their leisure time, if not at work. Being under pressure, these users demand ease of use as well as efficient support to the execution of activities.

The positive aspect of a technical Web site is, however, the fact that the users can be precisely identified and modeled; moreover, their information needs, representing strong requirements, can be elicited by means of a suitable domain analysis. Therefore, utilities, such as data search and retrieval, can be developed to comply with different goals and backgrounds. Of course, users' involvement and testing have to be carried out also in this case because they support the development of effective and usable services (see Dumas & Redish, 1999; Keppel, 1991).

In our recent work, we faced these issues in the development of ACQUA, a prototype Web-based information system for the Italian Public Administration presenting information about water resources (a demo is available at http://acqua.di.unito.it). During the system design phase, we put in practice traditional *usability* principles and *adaptive hypermedia* best practices and we derived general guidelines for the development of *usable Web-based systems* for technical users (see Brusilovsky, 1996, 2001; Fink, Kobsa, & Nill, 1999; Maybury & Brusilovsky, 2002). The system described in the rest of this chapter is targeted to two main classes of users:

- Generic users, such as the citizen, who want to be informed about the general health state of rivers, lakes, and underground waters.
- Technical users, such as the public administration employees, who retrieve specific pieces of information for analysis purposes.

In this chapter we describe the requirements analysis, the design, and the evaluation of ACQUA, focusing on the *user-centered approach* adopted in the prototype design and development phases. We involved domain experts and end users since the beginning of our work in order to assess the usefulness and suitability of the functionality offered by the system, as well as of its user interface. For further information about the system, see Gena and Ardissono (2004).

The rest of this chapter is organized as follows: Section "Background" provides an overview of the relevant user-centered design research. Section "The ACQUA Project" presents our work. Specifically, Section "Application Requirements" describes the interaction and user interface requirements that emerged during the design phase; Section "Adaptive Features" presents the adaptive features we developed for our system; Section "Association Rules" describes the techniques supporting the personalized information search; Section "Evaluation of ACQUA" presents the results of an evaluation we carried out to test the system functionality with real users; and Section "Comparison with Other Solutions" compares our proposal with some related work. Finally, section "Future Trends" discusses some open technical issues and suggests how to address them, and Section "Conclusion" concludes the chapter.

Background

Several researchers suggested to address usability issues by developing *adaptive systems*. For instance, Benyon (1993) proposed adaptivity as a solution, because a single interface cannot be designed to meet the usability requirements of all the groups of users of a system. However, it is possible to prove that adaptivity enhances the usability of a system only if it can be shown that, without the adaptive capability, the system performs less effectively. Benyon identifies five interdependent activities to be considered when designing an adaptive system:

1. *Functional analysis*, aimed at defining the main functions of the system.
2. *Data analysis*, concerned with understanding and representing the meaning and structure of data in the application domain.
3. *Task knowledge analysis*, focused on the cognitive characteristics required by the system users, such as the user's mental model, cognitive load, and the required search strategy.
4. *User analysis*, aimed at determining the scope of the user population to which the system is targeted. This analysis concerns the identification of the user attributes that are relevant for the application, such as required intellectual capability, cognitive processing ability, and similar. The target population is analyzed and classified according to the aspects of the application derived from the above-mentioned points.
5. *Environment analysis* is aimed at identifying the characteristics of the environment in which the system is going to operate.

Notice that these phases are similar to the steps followed during the requirements analysis phase of a generic software system (Preece, Rogers, Sharp, & Benyon, 1994). Benyon underlined the fact that adaptive systems should benefit more than other systems from a requirements analysis before starting any kind of evaluation, because the development of these systems has to take a high number of features into account. The recognition that an adaptive capability may be desirable leads to an improved system analysis and design. As a demonstration, he reported an example of an adaptive system development, wherein he prototyped and evaluated the system with a number of users. Several user characteristics were examined to determine their effects on the interaction. Then, further task knowledge and functional analysis were carried out.

Also Oppermann (1994) proposed a user-centered perspective and suggested a *design-evaluation-redesign* approach. He noticed that the adaptive features can be considered as the main part of a system and thus have to be evaluated during every development phase. The problem is circular:

- A problem solvable by means of the adaptivity has to be identified.
- The user characteristics related to the problem have to be selected.
- Ways of inferring user characteristics from interaction behavior have to be found.

- Adaptation techniques offering the right adaptive behavior have to be designed.

This process requires a bootstrapping method: first some initial adaptive behavior is implemented, then tested with users, revised, and tested again. The reason is that it is hard to decide which particular adaptations should be associated to specific user actions. Furthermore, the adaptations must be potentially useful to the user. The necessity of an iterative process is due to the fact that the real behavior of users in a given situation is hard to foresee; therefore, some evidence can be shown only by monitoring the users' activity. From the iterative evaluation point of view, the design phases and their evaluation have to be repeated until good results are reached.

Oppermann's iterative process is very similar to the *user-centered system design* approach originally phrased by Gould and Lewis (1983) and extended by Norman and Draper (1986).

Dix, Finlay, Abowd, and Beale (1998) pointed out that the iterative design is also a way to overcome the inherent problems of incomplete requirements specification, as only a subset of the requirements for an interactive system can be determined from the start of the project. The iterative evaluation process requires empirical knowledge about the users' behavior from the first development phases. In the case of an adaptive system, prior knowledge about the real users, the context of use, and domain experts facilitates the selection of the relevant data for the user model, such as personal features, goals, plans, domain knowledge, and context. Deep knowledge about users also offers a broad view of the application goals and prevents the system designer from serious mistakes, especially when dealing with innovative applications.

Petrelli, De Angeli, and Convertino (1999) proposed the user-centered approach to user modeling as a way to move from designer questions to guidelines by making the best use of empirical data; they advocated incremental system design as a way to satisfy large sets of users. They reported that at the early stage of development of a mobile device presenting contextual information to museum visitors, they decided to revise some of their initial assumptions about the user model. Indeed, they made this decision after having analyzed the results of a questionnaire distributed to 250 visitors. For instance, they discarded the former user modeling techniques based on stereotypes (because the sociodemographic and personal data taken in consideration did not characterize the users' behavior in a satisfactory way) in favor of a socially oriented and context-aware perspective. For instance, they noticed that people do not like to visit museums on their own and prefer looking at paintings to interacting with a device.

As discussed by Höök (2000), intelligent user interfaces may violate many usability principles developed for direct manipulation systems. The main problem is that these systems may violate many good principles, such as enabling the user to control the system, making the system predictable (given a certain input, the system always generates the same response), and making the system transparent so that the user understands at least partially how it works. In addition, most adaptive interface developers are more concerned with defining inference strategies than with interface design. For Höök, intelligent user interfaces sometimes require a new way of addressing usability, different from the principles outlined for direct-manipulation systems. Instead of measuring factors such as task completion time, number of errors, or number of revisited nodes, other aspects have to be considered. For instance, "if the system should do information filtering, then we must check whether subjects find the most relevant information with the adaptive system and not necessarily whether they find it fast. This is not to say that the traditional measurements are always wrong—this of course depends upon the task that user and (adaptive) system should solve together" (Höök, 2002, p. 12).

Finally, Palmquist and Kim (2000) investigated the effects of (field independent and field dependent) *cognitive style* and online database search experience on WWW search performance. They concluded that cognitive style significantly influences the performance of novice searchers. In contrast, experienced searchers display a common behavior: they usually do not get lost in Web pages including many links, but they are able to choose useful navigation strategies. Therefore, Palmquist and Kim suggested that novice users should benefit from Web pages that have a simple design and few links providing information necessary to perform analytic search.

The ACQUA Project

Application Requirements

In 2003, the Water Resources Division (*Direzione Risorse Idriche*) of the Piedmont Region and the University of Torino started a project for the development of ACQUA, a Web-based information system presenting data about water resources derived from the monitoring activities on the territory. The goal was to make information available on a Web site that describes the Division and supports a search for data in real time, in order to limit the distribution of information on a one-to-one basis via e-mail messages and paper publications. The technicians of the Division guided us in the system development by specifying application requirements and by sharing with us a repository of e-mail messages they exchanged with users asking for information throughout the years. The repository provided us with evidence about the users' interested in water resources data, the inspected information, and the regularities in the search for data. Most questions were posed by the following:

- Employees of other Public Administrations, such as technicians and researchers, who are often interested in environmental impact studies, construction feasibility studies, and historical data.
- Technicians, such as companies working at the construction of bridges and houses.
- Attorneys, who are typically interested in the examination of data concerning specific regions, for example, as a consequence of an environmental disaster.
- Farmers, who wish to monitor the biochemical state of their fields.
- Students attending secondary school, university, and also doctoral programs. These users collect information for the preparation of reports concerning, for example, historical changes in biological and chemical composition of waters, or the evolution of the capacity and hydrometric levels of rivers, and similar.

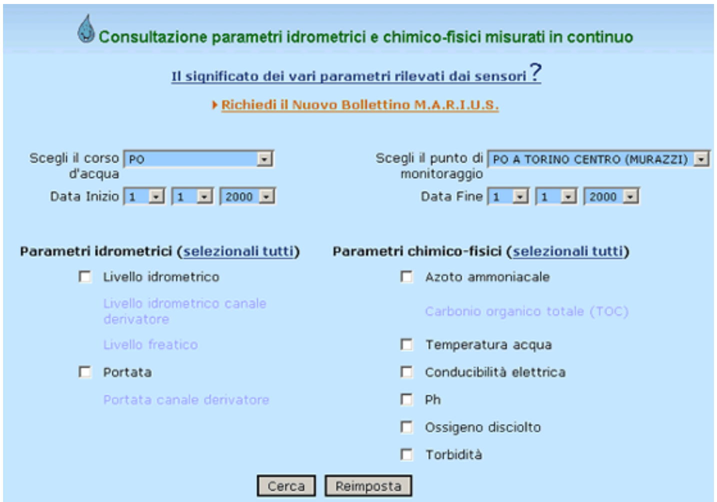
Following a user-centered approach, we developed the system by involving domain experts and end users since the first design phases. After a requirements analysis phase, we developed a number of mock-ups, which we discussed and redesigned after several focus group sessions with the experts and the users involved in the project. We decided to adopt a cooperative design approach (Greenbaum & Kyng, 1991) in order to utilize the experience of domain experts and technicians in the design of an effective user interface. We based the development of our first prototype on the collected feedback. As the ACQUA system is devoted to the Public Administration, we had to satisfy usability and predictability requirements that imposed the design of a simple user interface. Specifically, our interlocutors suggested the following:

- The interface should be usable and intuitive in order to satisfy user needs and expectations. This first requirement should be followed in every interface design project; however, Public Administrations have the mandatory goal of satisfying all the citizens, thus usability is also intended as a service for the collectivity.
- The system behavior should be highly predictable (Dix et al., 1998) to support first-time visitors in their search task, but also to avoid frustrating professional users who would regularly use it at work. Notice that the predictability requirement has some subtle aspects: for instance, not only the user should foresee what is going to happen next, but also what should *not* be expected from the service. This is very important to prevent the user from starting the exploration of paths that will not provide her/him with the information, or the functionality (s)he is looking for.
- The system should provide the user with data that can be analyzed without preprocessing. Therefore, search results should be presented in machine-processable formats, in addition to the pictorial ones suitable for a general-purpose presentation in Web pages.
- For the sake of accessibility, the pages of the user interface should be optimized for standard browsers, without the need of special equipments or software environments.

In order to maximize the usefulness of the information that can be retrieved from the Web site, we decided to make the system generate the search results in formats, such as MS Excel® tables and textual (TXT) files, directly supporting the data analysis and interpretation at the user side. We also tried to address efficiency in the retrieval of information by reconsidering the design of the general Web site to be presented. We wanted to offer the right information the user is looking for; thus, we decided to show the main search functions in the home page of the Web site, and to move textual information, such as the pages describing the Public Administration divisions, in secondary pages, which can be reached by following hypertextual links.

Moreover, having analyzed the data about the users interested in water resources, we identified two main targets to which the system should adapt. For shortness, we denote these categories as novices and experts.

Figure 1. Searching quantitative data (continuous hydrometric and chemical-physical parameters) about Po River in the Torino-Murazzi observation point



- *Novice users*, such as students and generic citizens, visit the Web site on an occasional basis and are not familiar with the content presented by the information system.
- *Expert users*, such as technicians, farmers, and the personnel of other Public Administrations, frequently visit the site and are familiar with the domain-specific information provided by the system.

In order to take the interaction requirements of these users into account, we defined two search functions:

(i) The *simple search* is a geographical search modality and guides the user step by step in the retrieval of information;

(ii) The *advanced search* offers forms where the expert user may compose the queries in single step. Figure 1 shows the user interface of the ACQUA prototype supporting the advanced search; the menus enable the user to specify the river ("Scegli il corso d'acqua"), observation point ("Scegli il

Figure 2. Portion of the page describing the Torino observation point on Po River

punto di monitoraggio"), start date ("Data Inizio"), and end date ("Data Fine"). Moreover, the user interface enables the user to select the hydrometric and chemical-physical parameters to be inspected.

Thus, novice users may search for information in a friendly modality and the eligible choices are restricted and presented along the path, while expert users benefit from a faster search function.

As a matter of fact, the information about water resources exploited by the system is unavoidably incomplete. For instance, some data are collected by automatic stations, which have been set up at different times over the years and sometimes are out of order. Moreover, unfortunately, data collected in manual observation points have been stored in unstructured formats and the historical series has been reconstructed only for the very recent past.

For the sake of predictability, the simple and advanced search functions prevent the user from composing any queries that are incorrect, or are aimed at searching for unavailable data. The idea is that, in both cases, the system should only present the choices leading to available results. For instance, as shown in Figure 1, the labels of the parameters, which are not available for the Po River, are shaded and cannot be selected by the user to define a query.

Adaptive Features

The information about water resources concerns rivers, lakes, and underground waters and includes the following:

- Descriptive data about resources and observation points: for example, maps of the points, charts representing environmental changes, pictures, documents, publications, and descriptions of the monitoring stations. For instance, Figure 2 ("Caratteristiche della stazione di monitoraggio TORINO" ["Features of the Torino monitoring station"]) shows the coordinates and other information about the observation point on Po River located in Torino, Parco Michelotti.
- Measurement parameters concerning physical dimensions and other features, which characterize the environmental state of the resources. These parameters are grouped in two main classes:
    - *Qualitative parameters*, which are periodically measured: technicians visit the observation points, collect data, and take samples for laboratory tests.
    - *Quantitative parameters*, which are monitored by automatic stations.

These stations carry out the measurements on a daily basis.

The ACQUA Web site is organized in four main sections, respectively devoted to the presentation of qualitative and quantitative information about rivers, information about lakes, and information about underground waters. The system enables the user to retrieve data about water resources by performing a simple or advanced search in all the sections of the site. Therefore, a large amount of heterogeneous data is accessible, ranging from biological and chemical data to capacity measurement and hydrometric levels (for details, see Gena & Ardissono, 2004).

We noticed that, by performing queries aimed at selecting a large number of data items, belonging to different categories, the results returned by the system were complex and hard to present in an intuitive results table. However, as shown by the repository of user requests we analyzed, users often need to combine heterogeneous data to accomplish their goals. For example, in construction feasibility studies, users are interested in qualitative and quantitative parameters of rivers and underground waters, considering the historical series. In order to keep the user interface simple and to guarantee that the presented results are not confusing, we decided to limit the user's freedom in composing the queries: to retrieve very heterogeneous types of information, the user must define more than one search query. For example, as shown in Figure 1, the ACQUA query interface enables the user to choose from different rivers, observation points, years, and data types. Other categories, such as qualitative and quantitative data about rivers, lakes, and underground waters are treated as separate sections of the Web site and have their own query functions.

Unfortunately, although this approach enforces the clarity of the results, it makes the search for multiple types of information a lengthy task. Therefore, a compromise between clarity and efficiency must be found. In order to address this issue, we extended the system with an *intelligent search component*, which complements the user's explicit queries with *follow-up queries* (Moore & Mittal, 1996) frequently occurring together in navigation paths. When possible, the system anticipates the user's queries and makes the extended search results available as personalized suggestions that can be downloaded on demand. If the user is interested in the recommended information, (s)he can retrieve it by clicking on the adaptive suggestion links, without performing any further queries. At the same time, the system retrieves the extended results only after the user clicks on a suggestion link in order to avoid precaching possibly useless data.

For instance, Figure 3 shows the recommendations generated by the system in the lower portion of the page ("Ti consigliamo anche i valori dei parametri chimici e microbiologici" ["We also suggest results about chemical and microbiological parameters"]).

During different interaction sections, the same user may be interested in rather different types of information; therefore, we decided to base the system's recommendations on the analysis of her/his navigation behavior, leaving the management of a long-term user model apart. One immediate advantage is the fact that the user can interact with the system in an anonymous way, without signing up for the service. The follow-up queries are generated as follows: the

Figure 3. Annotated link for the suggested information and descriptions of the monitoring stations

search queries performed by the user while (s)he browses the Web site are monitored and association rules which suggest other, strictly related queries are applied.

Each association rule has a condition part specifying constraints on the previous navigation behavior, and an action part defining a relevant follow-up query to be performed in order to retrieve complementary information. The rules we defined in our current prototype are mutually exclusive and they are selected and fired by applying a very tiny and efficient inference engine. This engine would not be suitable to manage a large set of conflicting rules: a general-purpose rule-based engine should be employed to that purpose. However, we prefer to maintain a simple set of adaptation rules, and to avoid embedding complex rule-based engines in order to keep the adaptive features as light-weight as possible. In fact, the management of the interaction is subject to a relevant overload due to the generation of results in multiple formats, which is a main requirement for the information system. In this situation, minimalist but efficient adaptation to the user is strongly preferred to flexible but complex one.

Association Rules

In order to define the *association rules* to be applied for anticipating the user's information needs, we analyzed a repository of requests, which real users posed to the Water Resources Division over the years; the requests consisted of e-mail messages and fax documents. As we noticed that different kinds of information frequently occurred together in these requests, we decided to analyze the frequency of co-occurrence in order to identify the regularities. Specifically, we analyzed 97 requests and we selected a set of features describing the requests in a systematic way. These features concerned rather different aspects of the requests; thus, for clarity purposes, we grouped them in subcategories. In the following, we report the subcategories we defined and for each one we list some sample features:

- *Kind of request:* for example, environmental impact study, construction feasibility studies, and lawyers' studies.
- *Request features:* for example, information about one or more rivers, about lakes or underground waters, about one or more observation points on a river or lake.
- *Kind of data:* for example, qualitative or quantitative parameters, biological and chemical data, hydrometric level, average daily capacity.
- *Data features:* for example, raw data, or elaborated data such as medium, maximum, and minimum values during a time interval.
- *User features:* for example, research center, Public Administration, technicians, farmers, and attorneys.

We computed the frequency with which the features co-occurred in the requests: if the frequency exceeded a given threshold, the set of involved features became a possible candidate for an association rule. Then we compared the extracted associations with their original requests in order to validate our findings with factual knowledge, and finally we asked the technicians of the Water Resources Division if our conclusions were correct. After this last check, we selected the correct associations and we encoded the rules in the system.

For instance, a rule suggests to retrieve qualitative parameters about a water resource if the user has asked for quantitative historical data for more than one observation point on that resource, supposing that (s)he is looking for information for a construction feasibility study. Another rule suggests retrieving the environmental state indexes of a resource if the user has requested biological and chemical data, under the hypothesis that (s)he is involved in an environmental impact study.

Evaluation of ACQUA

We first evaluated the ACQUA prototype in a usability test by involving external users who were not cooperating at the project (see Dumas & Redish, 1999, for methodological details). The evaluation highlighted some usability problems concerning the presentation of basic information, such as the choice between simple and advanced search and the background color of the menus. After having solved those problems, we tested the final prototype with real end users representative of the users the Web site is devoted to. In particular, we involved technicians working at the Water Resources Division in different fields (rivers, lakes, underground rivers, etc.) and not collaborating to the design of the project. We carried out both an experimental evaluation and a qualitative session to assess the suitability of the adaptive features offered the system.

Subjects. We evaluated 10 potential users of the ACQUA system, four females and six males, aged 30–50. All the users worked in the water resource area and none of them was involved in the project.

Procedure. The subjects were split up in two groups (five subjects each) and randomly assigned to one of the two groups. The experimental group had to solve some tasks using the adaptive Web site, which applies the association rules described in Section "Adaptive Features" to compute the results of follow-up queries related to the users' explicit queries. Instead, the control group had to solve the tasks without adaptation.

Experimental tasks. Every subject had to solve seven tasks, each one representing a real task the user can perform in the Web site. As suggested by our correlation study, the tasks were strictly correlated and could be grouped in three search activities the user often performs together. The first activity conveyed the whole information useful to an environmental impact study. The second one supported construction feasibility studies. The third activity supported lawyers' studies and activities.

- In the control group, the users had to submit a new query for every task, in order to obtain the requested results. The new queries were submitted by filling in the query specification forms (see, e.g., Figure 1).

- In the experimental group, the users could obtain the extra information related to the next task to be performed by clicking on an adaptive suggestion link that supports the immediate retrieval of the suggested information (see, e.g., Figure 3).

Experimental design. Single-factor (the adaptivity) between-subjects design.

Measures. The subjects' navigation behavior was recorded by using Camtasia Studio®. We measured the task completion time and then the subjects' satisfaction, by means of a post-task walk-through.

Hypothesis. We hypothesized that the users working in the experimental group could obtain better performance results than those of the control group.

Results. The ANOVA (analysis of variance) showed that the subjects of the experimental group achieved the best performance results. In addition, we calculated the effect size (treatment magnitude) and the power (sensitivity) as suggested in Chin (2001). The effect size (ω^2) measures the strength, or the magnitude, of the treatment effects in an experiment. In behavioral sciences, small, medium, and large effects of ω^2 are 0.01, 0.06, and >0.15, respectively. The power of an experiment (*n'*) is the ability to recognize treatment effects and the power can be used for estimating the sample size. In social science, the accepted value of the power is equal to 0.80, which means that the 80% of repeated experiments will give the same results. In the following, we show a summary of the results:

Task 2.

ANOVA: $F(1.8) = 12.45$ $p<0.01$; $\omega^2=0.53$; $n'=3.49$

Task 3.

ANOVA: $F(1.8) = 12.12$ $p<0.01$; $\omega^2=0.53$; $n'=3.60$

Task 5.

ANOVA: $F(1.8) = 14.16$ $p<0.01$; $\omega^2=0.57$; $n'=3.04$

Task 7.

ANOVA: $F(1.8) = 9.23$ $p<0.05$; $\omega^2=0.45$; $n'=4.86$

It should be noticed that all the results are significant and have a large estimate of the magnitude of the treatment effect. In addition, by exploiting a power of 0.80 and the corresponding ω^2 for each task we could determine the requested sampled size, which fits our sample size (n=5) (for details about statistics, see Keppel, 1991).

Post-task walk-through. During any *post-task walk-through*, test subjects are asked to think about the event and comment on their actions. Thus, after each test we talked to the subjects to collect their impression and to discuss their performance and the problems encountered during the test. In this session, we also aimed at retrieving useful feedback for a qualitative evaluation of the site. In fact, although our experimental evaluation reported significant results supporting our hypothesis, the actual user behavior could be different. As recently pointed out by Nielsen (2004), statistical analyses are often false, misleading, and narrow; in contrast, insights and qualitative studies are not affected by these problems because they strictly rely to the users' observed behavior and reactions.

In most cases, the interviewed users were satisfied with the site. Most of them encountered some problems in the execution of the starting query of task 2, thus we modified the interface form.

- All the users of the experimental group followed the adaptive suggestion link provided by the system but they did not realize that it represented a personalization feature. When we explained the adaptations, they noticed the particularity of the suggestion ("We also recommend you ..."). Anyway, they were attracted from the suggestions and they appreciated the possibility of skipping the execution of a new query. The adaptive suggestions were considered visible and not intrusive.
- The users of the control group reported similar considerations when we described the adaptive features offered by the Web site. Even if they did

> not receive any suggestions during the execution of tasks, they explored the result pages in order to find a shortcut to proceed in the task execution. After having followed some links, they went back to the previous query page or to the home page by clicking on the "Back" button of the browser.

Both groups displayed a common behavior pattern: the users explored a results page before starting a new search. Nevertheless, their behavior could be influenced by the test condition, because tested users tend to pay a lot of attention to their own actions and to the page design.

We conclude by admitting that although the test subjects were satisfied with the adaptation features, only the real system usage can demonstrate our hypothesis. However, both quantitative and qualitative test results are encouraging and we think that the adaptations are correctly placed. After this test, we presented the adaptive version of the Web site to the technicians of the Water Resources Division collaborating on the project. They confirmed the correctness of association rules we defined and they decided to replace the non-adaptive version of the prototype system with the adaptive one.

Comparison with Other Solutions

The ACQUA system has a plain user interface, designed to meet simplicity, usability, and predictability requirements, but it offers advanced interactive features enabling the user to create a personal view of the information space. Two search features, targeted to novice and expert users, are available, and the search results are presented in both pictorial and machine-readable formats in order to support direct data manipulation at the user side. Moreover, the system analyzes the user's queries to identify her/his information needs, and it employs association rules to propose follow-up queries complementing the search results with strictly related information. The follow-up queries are applied on demand; thus, the user can ignore them if (s)he is not interested in the additional data, and the system does not need to retrieve any uninteresting information.

The advanced search features we presented differ from the related work in various aspects. On the one hand, the inferences performed by our system are simpler than the probabilistic ones applied in other automated assistants, such as Lumière (Horvitz, Breese, Heckerman, Hovel, & Rommelse, 1998) and ACE (Bunt & Conati, 2003), which exploit Bayesian networks to capture the dependencies among the user actions. The point is that the user interacting with the ACQUA system does not carry out a complex task requiring a problem-solving activity. Therefore, lightweight rules associating contextually related search queries are sufficient to predict the implicit information needs and to complement the search for information accordingly. Our approach also differs from the follow-up question answering techniques proposed by Moore and Mittal (1996): in order to efficiently manage the query selection process, our follow-up queries are precompiled in a set of association rules, instead of being generated by a planner.

On the other hand, we apply query analysis techniques to identify regularities in search patterns. This differs from the typical inferences carried out in recommender systems, which reason about the features of the selected items to identify the user's priorities (see, e.g., Billsus & Pazzani, 1999), or about the regularities in the selection of individual items (see, e.g., the work by Cotter & Smyth, 2000; GroupLens, 2002).

Liu, Yu, and Meng (2002) propose other query analysis strategies for personalized Web search. However, instead of personalizing the proposed results, their system supplies a small set of categories as a context for each query. The system combines the user's search history with a general user profile automatically extracted from a category hierarchy to offer a personalized context for disambiguating the proposed query results. In ACQUA, we do not manage long-term user preferences because we noticed that, in different interaction sections, the same users are interested in rather different types of information. We thus decided to base the recommendations only on the analysis of the user's search behavior.

Future Trends

It is worth mentioning that the manual definition of the first set of association rules supporting the user's search task was a lengthy work and might not be easily replicated to revise the rules along time. However, if the Water Resources Division employs the ACQUA system as its official Web site, the log files generated by the system will provide structured evidence about user behavior (in addition to e-mails and faxes). Thus, data-mining techniques could be exploited to automatically recognize usage patterns and revise the association rules accordingly.

Indeed, we believe that these techniques can support the analysis of user behavior in an effective way, but they still have to be coupled with human analysis, in order to validate and interpret results: in several cases, these techniques have generated some very interesting results, but also other irrelevant or hardly understandable findings, which have been discarded.

At any rate, Web usage mining techniques, derived from machine learning methods such as knowledge discovery in data (KDD or data mining) can contribute to automate the adaptation of Web-based systems to the users. According to the scheme proposed by Pierrakos, Paliouras, Papatheodorou, and Spyropoulos (2003), ACQUA can be classified as a Web personalization system offering *task performance support*: this functionality involves the execution of a particular action on behalf of the user. In our case, the system generates queries and makes the results available as links to some files storing them. This functionality is considered as the most advanced personalization function and it is seldom offered by Web-based personalized services.

The most suitable data-mining technique, given the adaptive goals of the ACQUA system, is the *sequential pattern discovery*, which is aimed at identifying navigational patterns (event sequences) in the analyzed data (in our case, Web usage data). This methodology supports the discovery of event sequences that can be summarized as follows: "If event A, B, and C occur in that order, then events D, E, and F always follow." Two types of methods are generally applied to discover sequential patterns: *deterministic techniques*, which record the navigational behavior of the users and extract knowledge from the analyzed data, and *stochastic methods*, which use the sequence of already-visited Web pages to predict the behavior occurring in the next visits. Once sequential patterns have been discovered, the extracted knowledge can be automatically integrated in the personalization process, and the system behavior adapted accordingly.

Conclusion

We presented our experience in the design and development of ACQUA, an interactive prototype Web site for the Public Administration. The system presents information about water resources and supports the user in the search for generic information, as well as technical information about the rivers, lakes, and underground waters.

The usability and functional requirements that emerged during the design of the ACQUA system were very interesting and challenging, as they imposed the development of functions supporting the efficient retrieval of data by means of a simple user interface. We found out that the introduction of basic adaptivity features, aimed at understanding the user's information needs in detail, was very helpful to meet these requirements.

We were asked to develop a system having a simple user interface, designed to meet usability and predictability requirements. This fact limited our freedom to add advanced interaction features, desirable in a Web site visited by heterogeneous users; however, it challenged us to find a compromise between functionality and simplicity. In order to address this issue, we developed two interactive features enabling the user to create a personal view on the information space:

- The system offers a simple and an advanced search functions targeted to novice and expert users, respectively.
- Moreover, the system carries out a query analysis aimed at identifying the user's information needs, and applies association rules to extend the user's queries and complete the search results with data that is usually retrieved together by end users.

Qualitative and quantitative evaluation results showed that the adaptive user interface was more successful than the nonadaptive one. The reason was probably the concrete help offered by the adaptive suggestions, which speed up the execution of time-consuming search tasks. Moreover, the adaptive features were not perceived as intrusive and the user was allowed to skip useless suggestions. Furthermore, the system did not impose a previous annoying and discouraging registration phase.

As discussed in Section "Future trends," the adaptive features offered by the ACQUA system could be improved by the integration of Web-usage mining techniques aimed at discovering real usage patterns. In that way, the association rules employed to identify the user's implicit information needs could be automatically updated along time. However, we believe that the rules we manually defined provide a knowledge base that cannot be replaced with automatically extracted rules. In principle, both kinds of rules could be integrated in order to enhance the effectiveness of the system adaptations.

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Section III

Mental Reasoning and Interaction

Chapter VIII

Swarm-Based Wayfinding Support in Open and Distance Learning

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Abstract

Open and distance learning (ODL) gives learners freedom of time, place, and pace of study, putting learner self-direction centre stage. However, increased responsibility should not come at the price of overburdening or abandonment of learners as they progress along their learning journey. This paper introduces an approach to wayfinding support for distance learners based on self-organisation theory. It describes an architecture *that supports the recording, processing, and presentation of collective learner behaviour designed to create a feedback loop informing learners of successful paths towards the attainment of learning goals. The approach is presented as an alternative to methods of achieving adaptation in hypermedia-based learning environments which involve learner modelling.*

Introduction

Open and distance learning (ODL) gives learners freedom of time, place, and pace of study, putting learner self-direction centre stage. Brockett and Hiemstra (1991, p. 24) define learner self-direction as the learner's assumption of "primary responsibility for and control over decisions about planning, implementing and evaluating the learning experience," and Hiemstra (1994) notes learners' preference to take on responsibility for their own learning. However, taking on new responsibilities is not without its challenges. Brookfield (1985, p. 7) notes that although self-directed learning "has connotations of autonomy, independence and isolation," investigations have highlighted that "adults would like more, rather than less, assistance in their learning pursuits." Similarly, Candy (1991) writes that self-directed learners are often challenged to assume certain responsibilities, and that when deciding how to approach learning tasks, the self-directed learner is "confronted with the problem of how to find a way into and through a body of knowledge that is unknown at the outset. Without the benefit of any explicit guidance, a self-directed learner is obliged to map out a course of inquiry that seems appropriate, but that may involve a certain amount of difficulty and disappointment that could have been averted" (p. 283). Candy's description calls to mind the image of the distance learner as navigator, charting a course through educational waters, following Darken and Silbert's (1993) definition of navigation as the "process of determining a path to be travelled by any object through any environment" (p. 157). In subsequent work, Darken and Peterson (2002) use the term "wayfinding" to refer more specifically to the navigator's decision-making process. We use the term "educational wayfinding" to describe the cognitive, decision-making process carried out by self-directed learners as they assume responsibility for choosing and sequencing their learning events. The wayfinding decisions with which learners are faced arise from the freedom offered to them by learning providers on their way to the attainment of particular goals. In some highly constrained situations, both the choice of learning events and their ordering may be fixed by a learning provider. More likely, learners may be permitted to select and order modules, perhaps to accumulate credit points towards a certificate. In this context, we note Yorke's (1999) warning that "as the unitization of curricula spreads through higher education, so there is a need for greater guidance for students to navigate their way through the schemes" (p. n/a). This provides the background to this chapter: difficulties in the educational wayfinding process can lead to learners not reaching their goals, or taking unduly long to do so. The rationale for our work is that self-directed learners can benefit from support in the educational wayfinding process, and we describe a new approach to supporting the educational wayfinding process which has the potential to address the drawbacks of existing approaches found in the literature. We examine a number of alternatives to the provision of such support, and introduce our approach to issue, which builds on self-organisation theory.

Approaches to Wayfinding Support in ODL

There are a number of approaches to wayfinding support used today in ODL in addition to those identified in ODL research but not yet widely implemented.

The first approach involves fixing routes through materials in advance of their delivery, creating curricula or content plans to be followed by learners thereby reducing navigational choices. However, this preplanning limits the possibilities for learner self-direction, and Evans (1994) notes that the didactic models used in open and distance education are often "founded on highly didactic models which provide [the students] with little control over their own learning … and the students are left with little option but to adhere to the curriculum" (p. 68). This observation suggests the need for a flexible, adaptive approach to wayfinding support.

Such flexibility can be realised through so-called "learner support services" (Simpson, 2000). Although capable of providing highly individualised advice, learner support services do not come without a price. Costs are likely to be variable with student numbers and be exacerbated by the less predictable, demand-driven nature of ODL.

A significant amount of research has explored the creation of *educational hypermedia systems* (De Bra, 2002) as part of the Adaptive Hypermedia research area (Brusilovsky, 2001; Cristea & De Bra, 2002). Thus activity continues the research line established in the 1980s in the area of intelligent tutoring systems, and seeks to "build a model of the goals, preferences and knowledge of the individual user and use this through the interaction for adaptation of the hypertext to the needs of the user" (De Bra, Brusilovsky, & Houben, 1999, p. 58).

User models are representations of a world outside the computational environment and may contain wrong, outdated, or inadequate information (Fischer, 2001). A case in point is cited by Kilfoil et al. (2003)—the digital video recorder automatically recording programs it assumes its owner will like, yet based on an inappropriate assumption regarding the owner's lifestyle. As De Bra notes (2000, p. 76), "bad guidance is worse than no guidance." Self (1987), writing over 15 years ago, noted the absence of a theory of learning which might be used to maintain learner models. In a later article, Self (1988, p. 20) describes the scope of the student modelling problem—"from computational questions, to representational issues, through plan recognition, mental models, episodic memory to individual differences—to encompass, it would seem, almost all of cognitive science." Concerns on the practical application of user modelling continue to be raised (Atif, Benlamri, & Berri, 2003; Kay, 2001; Strachan, Anderson, Sneesby, & Evans, 1997).

This raises a research question for cognitively informed systems: Is there an alternative approach to wayfinding guidance in ODL which might provide a cost-effective solution yet which does not rely upon learner modelling?

Self-Organisation and Wayfinding

The previous section reviewed three sources of wayfinding support—*course designers*, attempting to predict efficient paths; *learner support services*, providing flexible advice but at a price; and *adaptive hypermedia systems,* still challenged to prove their practical application. A fourth source can be found in the social context of learning, a point noted by Brookfield (1985) when he states that the "successful self-directed learners … place their learning within a social setting in which the advice, information, and skill modelling provided by other learners are crucial conditions for successful learning" (p. 9). This observation finds echoes in the information navigation literature, where the term *social navigation* (Höök & Benyon, 2003) has been coined to describe research reflecting the fact that "navigation is a social and frequently a collaborative process" (Dieberger, 2003, p. 294). This point is also made by Forsberg et al. (1998) who state that "most information navigation in the real world is performed through talking to other people" (p. 13). However, we need to question whether learners would be prepared to support their peers in advice-giving dialogues given the pressures on their time.

In fact, social navigation does not always involve direct interaction. The field has been divided into two areas of research. The first, *direct* social navigation, sees actors as "co-present and in direct contact with one another" (Dieberger, Höök, Svensson, & Lönnqvist, 2001, p. 107). In contrast, *indirect* social navigation exploits traces of interactions left by others (Shipman et al., 1996; Wexelblat, 1999). Applications of indirect social navigation can be found in the educational literature (Shipman, Furuta, Brenner, Chung, & Hsieh, 2000; Zeiliger, Reggers, Baldewyns, & Jans, 1997), although the focus has tended to fall on teachers or students predefining trails through information space for others to follow later. This approach brings with it a certain cost to the ODL learner who may not be disposed to investing time and effort to create a trail for unknown learners coming along later. The ideal approach would avoid anyone precreating wayfinding guides and have them somehow "emerge" so that learning processes, as it were, spontaneously acquire (sequential) structures or organisations. This is the language of self-organisation—"the spontaneous formation of well-organised structures, patterns or behaviours, from random initial conditions" (Soraya Kouadri et al., 2003, p. 62). Indeed the "acquiring of spatial, temporal or functional structure" is seen as the essence of self-organisation by Hadeli et al. (2003, p. 54), and is echoed by Heylighen and Gershenson (2003)—"a self-organizing system not only regulates or adapts its behavior, it creates its own organization. In that respect it differs fundamentally from our present systems, which are created by their designer" (p. 73).

Bonabeau, Dorigo, and Theraulaz (1999) give ant foraging trails as an example of the spatio-temporal structures which emerge as a result of self-organisation. The ability of ants to find efficient (i.e., short) routes between nests and food sources suggests an approach to cost-effective, flexible, and implementable wayfinding support. Paths identified by ants are not preplanned but emerge, spontaneously, as a result of indirect communication between members of an ant colony—a form of indirect social navigation. Dorigo and Di Caro (1999) describe how ants deposit a chemical substance known as pheromone which can be sensed by other ants. When a navigational decision has to be made, such as taking a left branch or a right one, ants make a probabilistic choice based on the amount of pheromone they smell on the branches. Initially, in the absence of deposited pheromone, each of the branches is chosen with equal probability. However, if one branch leads to food faster than the other, ants on their way back will select the shorter branch due to the presence of the pheromone they deposited on the forward journey. More pheromone is deposited, leading to more ants selecting the shortest path, and so on, creating a feedback loop which leads ants along efficient paths to their destination. This process of indirect communication exploited by members of ant colonies is known as "stigmergy." In their overview article, Theraulaz and Bonabeau (1999) state, "The basic principle of stigmergy is extremely simple: Traces left and modifications made by individuals in their environment may feed back on them…. Individuals *do* interact to achieve coordination, but they interact indirectly, so that each insect taken separately does not seem to be involved in coordinated, collective behavior" (p. 111). Stigmergy, self-organisation and ant colony algorithms are the subject of much interest in the computer science community for optimisation and routing problems (Di Caro & Dorigo, 1998; Dorigo, Bonabeau, & Theraulaz, 2000; Schoonderwoerd, Holland, Bruten, & Rothkrantz, 1996). The application of stigmergy is also being explored in the e-learning domain (Dron, 2002; Dron, Boyne, & Mitchell, 2001), albeit not in the area of wayfinding support.

In the educational arena, efficient paths are not defined in terms of distance but rather time. We can imagine learners' interactions with learning resources being recorded automatically as they progress through a body of knowledge. The time stamping of these interactions allows sequences to be identified which can be processed and aggregated to derive a given "pheromone strength" favouring paths which are faster to complete. This information can be fed back to other learners, providing a new source of navigational guidance indicating "good" ways through the body of knowledge—a self-organising, stigmergic approach to wayfinding support. Such an approach seems to provide an answer to ODL needs in this area. It is cost-effective, since trail creation occurs unnoticed as a side effect of learner interaction with e-learning systems, it is flexible, able to emerge from and adapt to different circumstances, and holds the prospect of being implementable, since its adaptivity (Cristea & De Bra, 2002) does not depend upon learner modelling. Indeed, such an approach abstracts entirely from the characteristics of individual learners, relying instead on the collective behaviour of the swarm of learners to identify efficient paths.

The next section introduces an architecture which supports the feeding back of collective learner behaviour to support learners in reaching their educational goals efficiently.

A Software Architecture for Wayfinding Support

Our work on ODL wayfinding support is being carried out within the context of a larger research and development programme, designed to help the creation of flexible learning facilities that meet the needs of learners at various levels of competence throughout their lives. We refer to these network facilities for lifelong learners as "Learning Networks" (LNs) (Koper et al., 2004). LNs support seamless, ubiquitous access to learning facilities at work, at home, and in schools and universities. LNs consist of learning events, called activity nodes (ANs), in a given domain. An AN can be anything that is available to support learning, such as a course, a workshop, a conference, a lesson, an Internet learning resource, and so forth. Providers and learners can create new ANs, can adapt existing ANs, or can delete ANs. An LN typically represents a large and ever-changing set of ANs that provide learning opportunities for lifelong learners ("actors") from different providers, at different levels of expertise within the specific disciplinary domain.

Wayfinding support in LNs relies on the following concepts:

- The learner's *goal* is a description of the level of competence a learner wants to achieve (e.g., the bachelor's or master's level in a particular discipline).
- A *route* is a plan to reach a goal, described as a series of selections and/or sequences of ANs. ODL providers offer programmes with curricula (i.e., routes) by which individuals can reach their goals.
- A *learning track* is the sequence of ANs successfully completed by a learner.
- The learner's *position* is the set of ANs that have actually been completed (i.e., the learning track) together with those which can be considered as completed, perhaps as a result of exemptions arising from previous study or work experience.

Position and goal equate to "you are here" and "there's where I want to be," respectively, and the wayfinding guidance, which is fed back, concerns effective ways of getting from here to there, based on the behaviour of previous learners along the available route(s).

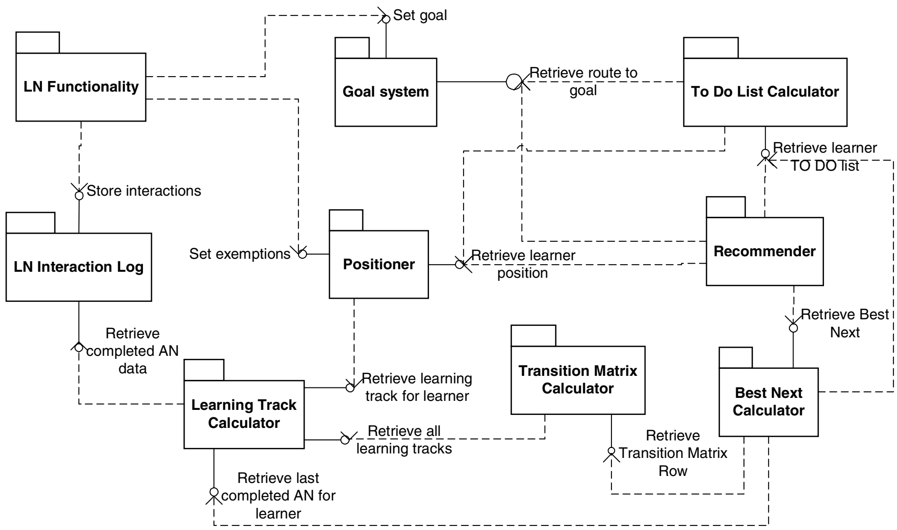
The architecture we propose combines elements which record, collect, process, and present collective learner behaviour. Andersson et al. (2002) use the phrase *emergent interaction systems* to describe systems which "consist of an environment in which a number of individual actors share some experience/phenomenon. Data originating from the actors and their behaviour is collected, transformed and fed back into the environment. The defining requirement of emergent interaction is that this feedback has some noticeable and interesting effect on the behaviour of the individuals and the collective—that something 'emerges' in the interactions between the individuals, the collective, and the shared phenomenon as a result of introducing the feedback mechanism" (p. 1).

The "something that emerges" in our situation are paths through bodies of knowledge, rather like well-worn footpaths in forests. Our initial focus is on *efficient* paths, that is, those which minimise the time taken to reach a certain goal from a particular position. Subsequent research will investigate *attractive* paths, those rated highest by other learners, in line with work on recommender systems (Herlocker, Konstan, Terveen, & Riedl, 2004; Resnick & Varian, 1997).

Central to the approach are logs of learner information indicating what learners did and when. The use of Internet technologies in e-learning has brought with it an increase in the level of standardisation of transmission protocols and data, and logging information is no exception. The World Wide Web Consortium has defined common and extended log file formats (World Wide Web Consortium, 1996) and a whole area of research is now dedicated to the processing and analysis of these files for various purposes, known as Web usage mining (Punin, Krishnamoorthy, & Zaki, 2001; Spiliopoulou, Pohle, & Faulstich, 1999; Srivastava, Cooley, Deshpande, & Tan, 2000). The techniques have also been applied in education (Sheard, Ceddia, & Hurst, 2003; Zaïane, 2001).

However, the events which are registered in these logs are extremely low level. This complicates their analysis, making it difficult to know which users are interacting (since only IP addresses are logged) and what they are doing (since only cryptic uniform resource locators [URLs] are logged). Oberle et al. (2003) note that "an interpretation of URLs in terms of user behaviour, interests and intentions is not always straightforward … web usage analysis is not interested in patterns of URLs but rather in patterns of application events" (p. 155). The route to solving this problem taken by Oberle et al. is to enhance the logs with additional information drawn from a formal ontology. However, the characteristics of our domain suggest a different type of log is more appropriate, one incorporating a higher level of application event and which records not

Figure 1. A software architecture for wayfinding support for learners



only which learner did what, but also whether or not this was successful (e.g., by including the results of an assessment).

Such a level of logging is available in the learner records data store described in the IEEE *Draft Standard for Learning Technology—Learning Technology Systems Architecture* (IEEE, 2001). This data store, specifically designed to cater for the nomadic nature of lifelong learners, is defined as a repository of "learner information, such as performance, preference, and other types of information. The learner records may store/retrieve information about the past (e.g., historical learner records), but may also hold information about the present (e.g., current assessments for suspending and resuming sessions) and the future (e.g., pedagogy, learner, or employer objectives)" (p. 18).

With these notions in place, the elements of an architecture for self-organising wayfinding support for learners can be introduced (Figure 1).

Learners interact with the *LN Functionality* available in a learning network (Koper et al., 2004). Part of the functionality available allows learners to select from a list of the learning goals in a learning network (the *goal system*), and thereby also identify the route to the goal. Learner interaction is stored in an *LN interaction log* (i.e., a learner record store, as described above), including information on the learner, the AN, a time stamp, and an indication of

Figure 2. A transition matrix showing learner transitions from *ANs (rows)* to *other ANs (columns)*

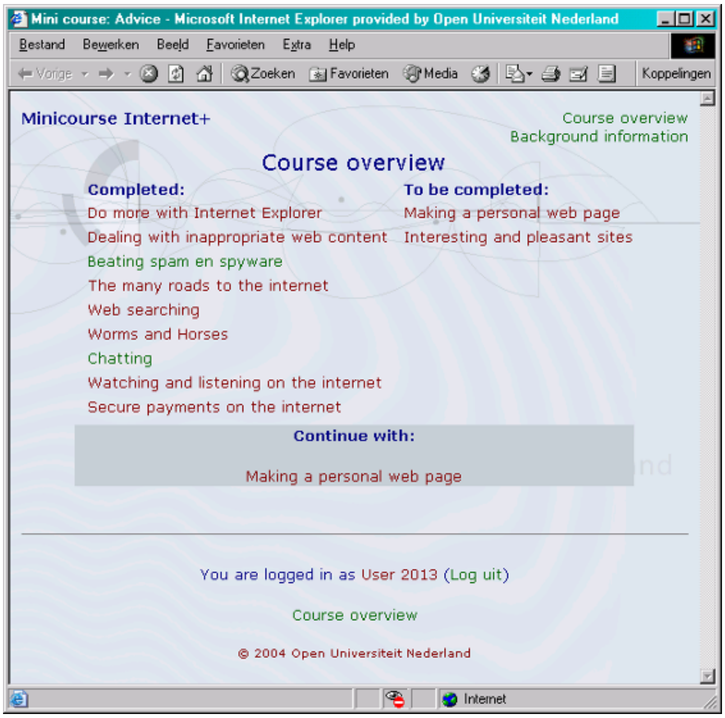
	A	B	C	D	E
{}	1	3	2	4	5
A		4	2	5	1
B	2		2	1	3
C	3	4		1	2
D	4	2	4		5
E	1	2	5	3	

performance (e.g., pass or fail). This information can be processed to create sequences of ANs successfully completed by learners (done by the *Learning Track Calculator*—see Mobasher (2004) for an examination of the techniques involved). Using information on the tracks of all learners, a transition matrix (Deshpande & Karypis, 2004) can be calculated (by the *Transition Matrix Calculator*) over pairs of ANs, indicating, for each *from* node, how many learners have successfully progressed to the following *to* node (see Figure 2).

The *Positioner* deals with the maintenance of the ANs which have been completed by learners, or can be considered as having been completed. The former is straightforward to calculate, since it is the learning track for a given learner. The latter, referred to as the Recognition of Prior Learning or Prior Learning Assessment (Breier, 2005; Starr-Glass, 2002), is considerably more complex (see Van Bruggen et al. (2004) for an examination of approaches to this problem).

The *To Do List Calculator* maintains the difference between the requirements expressed in the route associated with the learner's goal, and his/her current position. Using the transition matrix and the Learner's To Do list, the *Best Next Calculator* selects an AN to recommend based on the progress of the swarm of other learners. The algorithm used to select the AN from the candidates is that described by Koper (2005). Using the transition matrix shown in Figure 2, if we imagine a learner having just completed the AN labelled "A" and en route to a goal which requires A, B, C, D, and E to be successfully completed, a list is first drawn up of all the transitions made from A by all previous learners (i.e., four from A to B, two from A to C, five from A to D, and one from A to E):

Figure 3. The prototype Recommender component



[B, B, B, B, C, C, D, D, D, D, D, E]

The recommendation is identified by drawing one item randomly from this list. The result is that the most frequently followed path has a higher probability of being selected (in this case A to D), although, to prevent suboptimal convergence to this path, there is a chance that the other paths (A to B, A to C, and A to E) will be selected. The use of randomness in the procedure follows the ingredients for self-organisation described by Bonabeau et al. (1999).

The final component in the architecture is the *Recommender*, which pulls together the various pieces of information to present a coherent picture to the learner, including information on the learner's goal, position, to do list, and the recommendation itself. Figure 3 shows a prototype of the recommender, implemented in the open source virtual learning environment, Moodle (Dougiamas, 2004).

Discussion

This chapter has described the rationale behind our research into self-organising wayfinding support, and described an architecture for its provision. Our approach is designed to adapt support for decisions on the sequencing of learning events not on the basis of a model of the individual learner but using information on the collective behaviour of the swarm of other learners.

We are currently carrying out experiments to measure the actual value of the approach using two groups of learners. One group of learners will receive feedback on how others have progressed to their shared target, the other group will be left to their own devices, and we will compare the numbers of learners who manage to reach the goal in a given time period. The results of the experiment will be used to determine whether to adopt the approach on a larger scale in our institution.

In conclusion, our work is intended to open a new source of information to help learners in deciding how to progress towards their learning goals using a feedback loop on how others with shared positions and goals have fared. The envisaged feedback loop has an advisory character, not intending to push all learners down a single path as quickly as possible but rather to allow learners to make informed choices concerning steps on their learning journey.

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Chapter IX

From Engineer to Architecture? Designing for a Social Constructivist Environment

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Abstract

This chapter examines the design requirements of a social constructivist virtual learning environment. It uses the example of teaching expertise to practitioners to demonstrate the practical application of the cognitive theories underpinning a community of practice, with the objective of providing an insight into some of the complex issues involved in creating such an environment. It is argued that the analogy of designer as architect is most appropriate, reflecting a move from task-centred courseware to learner-centred situated environments.

Introduction

The focus of this chapter is on the marriage of instructional approaches, based on the theory of the cognitive process involved in learning, with appropriate technology, to facilitate teaching and learning. Specifically, this is examined in the design of a social constructivist virtual learning environment (VLE).

From a teaching perspective, Lynch, back in 1945 (in Ertmer & Newby, 1993) called for employing an engineering analogy as an aid for translating theory into practice, providing a bridge between learning research and educational practice. More recently, Hung (2001) puts forward the idea of teachers as "pedagogical engineers" with the "responsibility to plan a lesson(s) with the most relevant instructional approaches and technologies at his or her disposal" (p. 286).

From the technologist's perspective, Bednar, Cunningham, Duffy, and Perry (1995) contend that the field of instructional systems technology prides itself on being an eclectic field, "Dewey's proverbial linking science between theories of the behavioural and cognitive sciences and instructional practice" (p. 100). The primary strategy for providing this link has been to collect concepts and strategies suggested by the theories and make them available to the practitioners.

More recently, Goodyear (2000) highlights the "emerging responsibility of educational technologists to move beyond the design of instructional tasks to the requirement to become architects and creators of virtual learning environments reflective of real world activities" (p. 1) and to move toward student-centred educational, technology-mediated learning. The designer as architect creates online learning spaces that afford and nurture learning but do not determine it.

This chapter will recap the drivers toward a social constructivist learning environment by examining the change in cognitive theories underpinning learning, and the changes in the higher education sector. Teaching expert professional practice to distance-learning students at university level will be used as an example of cognitive strategies that might be used, giving examples of how these have been employed in a managed learning environment in the author's institution. The issues involved in creating and supporting such a system are then discussed.

Background

Educational theory has shown a recent shift from an acquisition metaphor to a constructivist view, and from a focus on the individual to an emphasis on the social context of learning (Mayes, 2001) which argues that learning does not occur in isolation, but requires emotional and personal support from others, context, feedback, and reflection (Alexander & Boud, 2002). To highlight the resulting changes at a practical level, a generalisation of the main groups of theories will be presented.

Behaviourism

In behaviourism, learning is seen as a change in observable behaviour. Key concepts include stimulus response, and conditioning and reinforcement, through the work of Thorndike, Watson, Pavlov, and Skinner (Bartlett, Burton, & Peim, 2001). Learning is the correct response to an environmental stimulus. A principle is that behaviour that is positively reinforced will recur. This type of learning may be effective in some situations, such as the learning of a manual skill or rote repetition of facts, but ignores the cognitive processes involved. Early computer-aided instruction (CAI) was based on behaviourist principles.

Cognitivism

In contrast, from recognition of these limitations, cognitive learning theory attempts to explain the cognitive process involved in learning such as knowing, understanding, remembering, and problem solving. Concurrent progress in computing resulted in an information-processing model of learning, with memory taking a central role. Incoming information is attended to, encoded, and stored for subsequent retrieval. Information is organized in schema (mental maps) developed from previous knowledge and experience, similar to frames of knowledge within artificial intelligence (Bartlett et al., 2001). CAI supplying appropriate responses to student input is based on a recognition of the cognitive processes being employed.

Constructivism

Constructivists believe that individuals actively construct knowledge through problem solving, utilizing prior knowledge, experience, and beliefs. Knowledge stored is therefore not fixed but changes. Learning is interpreting the environment from an individual's perspective and creating meaning from experience. Here computer "instruction" is a process of supporting that construction rather than communicating chunks of information (Lefoe, 1998).

Social Constructivism

Social constructivism recognises individual construction of knowledge but believes that the interpretation of knowledge is dependent on the cultural and social context through which the knowledge was constructed, with interaction with other people, mediated by language, crucial in cognitive development (Hung, 2001). Learning is not just an individual process but is influenced by interaction with others.

In practical terms, these can be viewed as a hierarchy of complexity in terms of cognition, the computer environment and tutoring processes involved. Edgar (1995) uses the analogy that the "PC is to Piaget as WWW is to Vygotsky" (p. 1). There has been much debate about whether these theories are mutually exclusive (Goodyear, 2000). Ertmer and Newby (1993) believe that the key question for instructional designers is which theory is the most effective in fostering mastery of specific tasks by specific learners, which is "not to suggest that one should work without a theory, rather that one should be able to intelligently choose the appropriate methods for achieving optimal instructional outcomes in that situation" (p. 67). In contrast, Bednar et al. (1995) believe that "abstracting concepts and strategies from the theoretical position that spawned them strips them of their meaning," arguing that instructional design requires to be based on a theory of learning and/or cognition, with effective design only possible where the designer has a "reflexive awareness" of, and deliberately applies, the theoretical basis underpinning the design (p. 102). Hung (2001) proposes that for a balanced perspective, a distinction should be observed between cognitive paradigms and instructional approaches. Thus, for example, reservations surrounding a behaviourist paradigm should not cause us to discard CAI as an instructional approach.

It is widely accepted that different approaches are required at different stages in the complex process of learning. Ertmer and Newby (1993) describe a continuum of knowledge from knowing what (behavioural), to knowing how (cognitive), then reflection in action (constructivist). Similarly, different tasks require different levels of cognitive processing, with tasks requiring high levels of processing best learned by social constructivist strategies such as situated learning, cognitive apprenticeship, and social negotiation.

Jonassen, Mayes, and McAleese (1993) have linked these to the stage of the learner. At the first phase of introductory learning the learner has little prior or transferable knowledge and is in the early stages of schema development. At this stage behaviourist and cognitivist instructional design to achieve predetermined learning outcomes are effective. At the second phase of advanced knowledge acquisition, as in a university setting, constructivist approaches are appropriate to support complex problem solving. The final phase is the development of expertise, which I will argue requires a social constructivist approach.

In summary, the significant, practical differences from a design perspective are that while objectivist (behaviourist and cognitivist) approaches transmit knowledge to achieve prescribed outcomes, constructivist approaches facilitate learners playing an active role in discovering the environment rather than reacting to it, the learning outcomes of which may not be predicable (Jonassen et al., 1993). This requires that the systems approach is modified to accommodate constructivist values (Schwier, 1995). However, Jonassen (1994) reassures us that "constructivist environments are not the unregulated, unsupported, anarchic, sink-or-swim, open-discovery learning cesspools that many fear" (p. 35).

The remainder of the chapter examines what a constructivist environment might look like, using an example from the author's institution.

Expertise in a Social Constructivist Virtual Environment

What is Expertise?

The module in question is for nurses aiming to become expert practitioners. Benner (1984) applied the Dreyfus model of skill acquisition to nursing practice, defining an expert as someone who no longer relies on analytical principles such as rules and guidelines when assessing a situation and acting appropriately, having a deep and intuitive grasp of the whole situation from extensive experience. An expert nurse practitioner is thus required to develop higher levels of judgement, discretion, and decision making in his/her clinical practice. As nursing is situational, much of the knowledge needed for effective practice is embedded in practice itself. This presented a challenge in converting from a face-to-face to distance mode of delivery. However, it has been observed that distance learning provides a unique context in which to "infuse" constructivist principles as it is expected that learners will behave as "self-motivated, self-directed, interactive, collaborative participants in their learning experiences" (Tam, 2000, p. 1).

A social constructivist virtual environment is most suitable to facilitate this, offering an approach to learning which matches the affordances of the technology, by emphasizing student centredness and by enabling learning to be related to context and to practice (Oliver & McLoughlin, 1999) with a focus on knowledge construction not reproduction, reflective practice, context- and content-dependent knowledge construction, collaborative construction of knowledge through social negotiation, and multiple representations of reality (Jonassen et al., 1993) and tasks authentic to the practice field in which the knowledge and skills are embedded (Mayes, 2001).

The virtual learning environment available within the author's institution was Blackboard (version 5). Blackboard was used primarily to provide resources and allow computer-mediated communication (CMC).

Cognitive Underpinnings of the Approach Used

Garrison (2002) contends that the connectivity and asynchronicity provided by CMC is congruent with the reflective, metacognitive, self-directional, and collaborative dimensions of the deep learning required; "there is every reason to believe that asynchronous online learning can be extremely effective in supporting higher-order learning and creating quality cognitive presence online" (p. 2). He further argues that CMC has the potential to significantly enhance learning environments and outcomes, based on its ability to support virtual communities of inquiry. Palloff and Pratt (1999) agree, observing that "community" and "communicate" have the same root "*communicare*" which means "to share." Through this communication of language, the members of a community "learn to carve out the world in similar ways; they develop similar anticipations about external reality" (Hung, 2001, p. 282).

Shaffer and Anundsen (1993, in Palloff & Pratt, 1999) define community as a dynamic whole that emerges when a group of people share common practices, are interdependent, make decisions jointly, identify themselves with something larger than the sum of their individual relationships, and make a long-term commitment to well-being (their own, one another's, and the group's). Most appropriate to the author's context are "communities of learning" and "communities of practice."

The "learning community" is the vehicle through which learning in a cohort of students occurs online. Members depend on each other to achieve the learning outcomes of the course (Palloff & Pratt, 1999). Communities of practice are "groups of people who share a concern, a set of problems, or a passion about a topic, and who deepen their knowledge and expertise by interacting on an ongoing basis" (Wenger, 2004, p. 1). McConnell (2002) distinguishes the two in that communities of practice do not set out to focus on their learning, whereas learning communities deliberately do so, and look reflectively at their learning processes. In contrast, a community of practice is a social phenomenon where learning is the lived experience of making meaning in a group situation. Wenger (2004) observes that in the real world we learn most in the process of becoming part of a community and contributing to what it is doing.

Within a community of practice, two theories of cognition are important—situated cognition and cognitive apprenticeship.

Situated Cognition

Learning in a community of practice is predominately by situated cognition (Lave & Wenger, 1991), which asserts that knowledge and understanding are a product of the learning situation and the learning activity, being embedded in that context (Miao, 2004), with an active learner and the environment part of a mutually constructed whole (Hung, 2001).

Lave and Wenger's work on situated learning shows the importance of legitimate peripheral participation for enabling effective learning in many (perhaps most) contexts, with learners initially learning from observing but gradually gaining knowledge and skill, as well as the values and thought patterns of the experienced practitioners. In a community of practice, the community models the role and language of a practitioner, and the individual's identity is shaped by participating within the community (Wenger, 1998). This is a form of cognitive apprenticeship.

Cognitive Apprenticeship

Cognitive apprenticeship (Brown, Collins, & Duguid, 1989) is a situated model of teaching where the teachers' thinking, problem-solving, and decision-making processes are made visible to the student to facilitate their learning of these cognitive and metacognitive skills. Techniques identified by Brown, Collins, and Duguid are modelling, coaching, scaffolding, articulation, reflection, and exploration. Jonassen et al. (1993) contend that this is an appropriate model for providing real-world experiences. The combination of the two approaches is important and synergistic. Apprenticeship implies working in a situation in which the knowledge/skills learned are to be applied. Thus, "the situated context structures knowledge appropriate to its use, modelling expert performance and making tacit knowledge explicit" (Jonassen et al., 1993, p.). In addition, students are able to reflect on their performance in relation to the expert and other students.

A similar theory that supports the value of working with others and of a scaffolded model is that of Vygotsky's zone of proximal development. This is defined as the difference between independent problem-solving ability and potential ability under guidance (Hung & Chen, 2001). Learners can only reach higher cognitive levels if appropriate scaffolding is provided by more competent peers or the teacher (Faggiano, Roselli, & Plantamura, 2004). Mentis, Ryba, and Annan (2001) introduce the concept of a "collective zone of proximal development," where learners form an intellectual collective where there is both participation and mutual guidance between peers, resulting in individual learning for all participants as well as group learning. There is also integration of learning with the workplace: McConnell (2002) from analysis of CMC transcripts observes that the meaning discerned in discussions is taken back to the workplace, applied, and tested, thus developing the learner's professional practice. Knowledge and insights gained from this are then taken back to the group and used in its projects. This results in a weaving together of work, theory, and practice that "becomes almost natural."

In summary, situated learning is based on social interaction where learners learn together as a community of practice where the community embodies certain beliefs and behaviours, based on the assumption that learning is a direct function of the activity, context, and culture in which it takes place.

How did we Attempt to do this on Blackboard?

Students were trained nurses working toward a degree in the field of infection prevention and control, in a variety of acute hospital, community, and public health settings. As stated previously, Blackboard was used primarily to provide resources and allow CMC in the practice context. Resources included key professional documents and guidelines required for practice. Students were asked to apply resource material to practice scenarios on the discussion boards, drawing on their work experiences. Other activities included, for example, identifying good and bad practice from photographs of clinical settings, and seminar PowerPoint presentations on current topics in the field. Each cohort comprised approximately 20 students, predominately from across the United Kingdom.

Collaborative learning included group problem solving of practice incidents on the discussion board including PBL (problem-based learning) moderated by tutors who were specialist practitioners and visiting experts in the field. In PBL, students were presented with a practice scenario such as a transcript of a phone call. Students individually identified their learning needs and then asked questions on the discussion board and responded to those of others. This raised awareness of different approaches in different practice settings and countries, causing students to reflect on the assumptions underlying their own practice, and come to a group consensus on the actions they would take. Learning from previous students' experiences was facilitated by the use of frequently asked questions, footprints (messages left for those following behind), and examples of good work.

Discussion

What are Some of the Issues Involved in Designing a System Such as This?

Technological Infrastructure

Turoff (1995) observes that the sophistication and flexibility of software designed to support distance education varies widely. The author has discussed the use of a VLE, defined as "learning management software systems that synthesise the functionality of computer-mediated communications software and online methods of delivering course materials" (Britain & Liber, 1999, p. 2). Issues of access, cost, and organizational issues, including novelty of use and speed of implementation usually result in teachers requiring to use a commercially designed VLE (Mayadas, Bourne, & Moore, 2003). The aim of commercial VLEs is to enable them to be used by instructors with little knowledge of HTML and Web navigation, but these constraints have a negative impact on flexibility (Storey, Phillips, Maczewski, & Wang, 2002). As can be seen by the examples, in addition to asynchronous discussion boards, students are required to access and read documents, give PowerPoint presentations, and engage in group work. Hung (2001) has identified five types of tools: "individual instructive tools," "informative tools" (materials and resources), "individual constructive tools" (generic purpose tools, e.g., word processing), "social communicative tools" (e-mails, video conferencing), and "social constructive tools" (e.g., document sharing), noting that in the course of a problem-solving activity, learners could require all of these, thus an environment is needed in which these can all be integrated. Blackboard was very limited in its ability to do this, primarily acting as a CMC board and resource repository. For example, word processed documents could be posted only as attachments and opened with students' own software. PowerPoint presentations required to be e-mailed to instructors, published as Web pages then uploaded into Blackboard. The environment was supplied segregated into different sections such as "course information," "assessment," "learning materials," and "discussion board," with very limited customisation available. This led to a tendency for fragmentation of learning activities, particularly evident where discussion took place away from the associated directions and resources. As observed by Klemm and Snell (1996), the threaded discussion system provided does not aid team building and effective group working. Facilities for group work were limited to separate group areas with a discussion board and student file share, but no ability to add learning materials, or for student-shared editing of work or resources. A basic virtual classroom was available for synchronous discussion but required at sometimes lengthy download of a Java Plug-in, which again caused problems at a distance, and was blocked by some hospital firewalls. In addition to known accessibility problems, this raised issues of equity.

Learner Factors

Biggs (1999) notes that there have been extraordinary changes in the structure, function, and financing of universities within the past decade. These include childhood to adult to lifelong learning, teacher-centred to student-centred, the few to the many, theoretical to practical/vocational, and of course face-to-face to distance, meaning that the traditional view of a course and student group is no longer valid (Jarvis, Holford, & Griffin, 1998). Where previously students in the author's department were school leavers, many are now mature adults, and increasingly studying part time at a distance. The learners therefore tend to have an expectation of knowledge being delivered to them. Many also lack study skills such as self-direction and time management, and have not been exposed to group work. IT skills are often also poor. As found by previous authors, students had a "considerable degree of anxiety" (Moore & Kearsley, 1996, p. 155) requiring both academic and nonacademic support (Simpson, 2002). There was therefore a need to scaffold IT and self-directed study skills. Initial activities required to be easy to find with clear and comprehensive instructions. At the beginning of the module, additional resources provided needed to be simple to use, for example, a direct Web link to a passage of interest rather than the need to search or navigate an external site. There was a tendency for students to attribute any problems, such as nonfunctioning Web links, to their perceived incompetence rather than the technology. This further increased their anxiety, requiring reassurance, and where possible warnings such as the need for Acrobat Reader, or that a document may take a few minutes to download. Nevertheless, all students were able to use the basic functionality of Blackboard competently within a few weeks. However, an attempt to use an electronic portfolio facility to allow students to share their work and enable peer assessment was unsuccessful due to the high stress levels generated in students and high workload for staff in trying to guide students at a distance through the complex sequence of technical procedures required.

CMC, Collaboration, and Social Negotiation

Using asynchronous discussion forums requires that a new student learn not only about the medium and how to use it practically, as discussed above, but also the rules of a new type of discourse (Kaye, 1989). Review of the literature by Bullen (1998) suggests many of the attributes of CMC, vis-à-vis place and time independence, many-to-many, and text-based communication, can promote or discourage participation in CMC. Similarly, Hammond (2002) notes its attributes may be two edged, for example, permanency allows reflection but means comments cannot be undone. McDonald (2002) suggests potential negative impacts include a lack of responsiveness, hesitancy in committing ideas/feelings to print, and misunderstandings as a result of the lack of nonverbal communication. However, she points out that while these are deterrents for some participants, in reality, research has found that more students respond, responses are longer and more complex, and interactions are increased compared to face-to-face. In a study by Bullen (1998), shy students reported CMC as liberating, and personality conflicts and distractions have been noted to be less intense (Klemm, 1995); however, others experience feelings of detachment, and anxiety in terms of being unsure who the student is communicating with, when to expect a response, and what type of response it will be (Bullen, 1998). Hammond (2000) suggests there is a high threshold for many to cross to participate. Its value is also dependent on the knowledge and experience students can bring to the discussion, thus it is particularly suited to professional, adult learning (Kaye, 1989). Harasim (1989) notes that CMC is a generic tool, and to be successful in collaborative learning is difficult and requires a tremendous amount of effort by the tutor. The more supports or "scaffolds" built in to support the learner, the more likely it is to succeed.

The scaffolding model we employed to structure activities to facilitate collaborative and deep learning was Salmon's (2000) five-step model, which moves from socialization and "using the technology" activities, with a lot of teacher/moderator support, working up to knowledge construction, and ultimately emancipation, thus scaffolding students in progressively acquiring the required skills at each level. All material was written in a friendly tone, addressed to the student. The first activity was to introduce themselves to their fellow students, thus requiring no preparation and with no right or wrong answers, both to help students get over the first hurdle, and to begin to get to know each other. Optional face-to-face tutorials were provided and students who had met each other at these reported that it was easier to converse on Blackboard. However, where students were local enough to attend several, there was a tendency to reduced participation on Blackboard perhaps due to less of a feeling of isolation. The ability for students to add a photograph or biographical details to Blackboard might assist socialisation for students unable to have any face-to-face contact. Photographs and contact details of the tutors are provided on Blackboard. In addition, information was provided on netiquette and good practice was modelled by the tutors.

To enable students to learn from each other's experiences, differentials in type and amount of experience are required; however, it was necessary to design and sequence activities so that everyone, even those new to the job, felt they had something useful to contribute. It was important to time activities to keep the momentum going so that students could contribute each time they logged in, without causing information overload. To give everyone an opportunity to contribute, students were initially restricted to giving only one part of the answer to early activities to prevent a student logging on to find everything they wanted to say had already been said. Later in the module where activities required deep learning responses, there was occasionally a delay with students appearing not to want to be the first to respond. This was overcome by starting the discussion with an experience-based question then moving on to the more theoretical issues. Moderators of the discussions thus had a major role to play in initiating, shaping, clarifying, explaining, weaving, and summarising discussions and bringing them to a conclusion, in a climate that encourages and role models negotiation and critical analysis (Kaye, 2003; Garrison, 2002). A lot of tutor input and encouragement was required initially, but by the end of the module, the tutor became largely superfluous, with students helping, answering, and challenging each other. Later activities aimed at fostering social negotiation skills as well as deep learning with students required to articulate their practice, reflect on differences, examine the underlying theory, and either defend their position or agree a change or compromise.

Examples of Activities

Some examples of students' activities are given below.

1. An early, simple, initially individual activity, limited to giving only part of the answer, but one where the total problems identified would be greater than any one student could achieve on his/her own:

"What is one point that you could make about the attached photo that demonstrates an aspect of decontamination practice? Maybe it is a good practice that you can identify, or a poor practice that could be improved."

2. A slightly later, structured activity with resources and detailed guidance provided, but where the students are required to begin to work as a team.

"What surveillance you might do as a result of the scenario…. Using the suggested steps in the paper by Lee and Baker to help focus your thoughts (activities 3.19 and 3.20), what surveillance will you undertake? If there is more than one approach suggested, try to come to an agreement as a team."

3. A late, unstructured activity to generate debate, once students are familiar with each other.

"What did you think of the article? Do you think it has implications for infection control? Do you see health promotion as part of your role?"

4. This activity occurs at the end of the module as a group versus group activity. The scenario begins with one infectious patient and evolves depending on the decisions made by the students, leading to very complex situations, requiring critical application of theory to practice and social negotiation:

"By today, you have eight wards closed, including three in the surgical block, but all your control measures are in place and you think you might be getting on top of the outbreak. However, as you all anticipated, the local press are now making inquiries. How do you convince the public and hospital workers that the hospital is safe? What are some of the wider management issues that the outbreak team might take into consideration in deciding whether to close the hospital?"

Community

Ryan (2001) also suggests "a skilful facilitator can create a community of learners which can replicate the social learning atmosphere needed by most learners" (p. 89), and can reduce the lack of support that leads to student withdrawal. Student factors are also important, for example, social presence, defined as the "ability of learners to project themselves socially and affectively into a community of enquiry" (Rourke, Anderson, Garrison, & Archer, 2001, p. 3).

Is it possible, therefore, to design community into a learning environment? Conrad (2002) likens the attempt of course designers to build community through structure to an "arranged marriage," where learners are pushed not pulled into community; however, online literature suggests students will not collaborate unless it is built into the course (Vonderwell, 2003). Similarly, Conrad herself proposed from her study that participation in online learning activities exists before community that it contributes to community, that it is the vehicle for maintaining community and that it eventually becomes the measure of the health of the community. Whilst agreeing that communities need their own dynamic and it might not be possible to create them artificially, Goodyear (2000) argues that we can lay out the appropriate environment and frameworks within which they can function effectively.

Did it Work?

Palloff and Pratt (1999) provide indications that an online community has been forming based on the premise that "socially constructed meaning is the hallmark of a constructivist classroom in which an active learning process is taking place" (p. 32)—the ability to collaborate and create knowledge and meaning communally.

These indications that an online community has been forming are as follows:

- Active interaction involving both course content and personal communication
- Collaborative learning evidenced by comments directed primarily student to student rather than student to instructor
- Socially constructed meaning evidenced by agreement or questioning, with the intent to achieve agreement on issues of meaning
- Sharing of resources among students
- Expressions of support and encouragement exchanged between students, as well as a willingness to critically evaluate the work of others. (p. 32)

The (abbreviated) examples below, taken from the discussion board of a PBL scenario surrounding meningitis, demonstrate that these criteria were met, with formation of community and social construction of knowledge:

"Hi, Karen, If meningitis was suspected and as benzylpenicillin was given, confirming that this was suspected, why was the patient admitted to an open ward? All hospital staff should be aware that the patient must be isolated due to the risk of airborne transmission."

"The Trust I work in follows a 48-hour rule of isolation including antibiotic treatment during this period. Therefore, I would feel that the patient being nursed in an open bay prior to 48 hrs of treatment could pose a potential risk to others. Immunosuppressed patients, visitors, and staff could all be affected."

"Meningitis is spread by respiratory droplets, nasal or oral secretions. I believe from my conversations with HPA (health protection agency) that it is not as easy as is commonly thought to pass on to others. One method is by kissing which would not be taking place (I hope!) between the patient and healthcare staff, or patient to other patients. Meningitis does not survive for a long period outside the body. Therefore, with the above in mind, although we also isolate until the patient has received 24 hours of antibiotics, perhaps this is not necessary, and it begs the question that if the isolation is so important what about the ambulance drivers who may have brought the patient in (not specifically thinking about this question now)?"

"I feel that there is perhaps an increased risk of others being susceptible within a hospital as patients are immunocompromised, and perhaps this is the reason we isolate, but I have a feeling that it is because it has a feel-good factor to isolate. It is certainly something I will think about and look into, but also one of the symptoms of meningitis can be photophobia and therefore the patient may prefer a side room."

"Hello, everyone, I suppose a risk assessment should be made with regard to isolation, there is evidence to show that patients isolated for the

purposes of infection control are less likely to receive care from staff (all grades), so the morbidity may increase. If this pt. is very sick it may be unsafe to isolate."

"Ok, I'll defend my position! I have found a reference which states that on admission to hospital all patients with known or suspected meningitis should be isolated in a single room, for at least 24 hours following the start of antibiotic therapy. Damani N (2003) I will continue to look for further evidence to support my previous statement of 48 hours."

"The HPA states that the meningococcal bacteria is not highly infectious and rarely develops into meningococcal disease. However, if infection does occur it can spread rapidly and is fatal in about 10% of cases. Statistics demonstrate that 1 in 8 people who do recover can experience long-term effects, including headaches, joint stiffness, epileptic fits, deafness, and learning difficulties. I suggest that the risk of mortality and the evidence of morbidity following this infection would be factors indicating that isolation is advisable!"

"Hi, Pam, I would agree with you that it seems sensible to isolate especially as although it may be relatively difficult to transmit, the consequences of having it transmitted to you can be enormous, I was just playing devil's advocate really and trying to work through the process."

"Mel, thanks, have enjoyed the lively debate. Still looking for evidence! Pam"

"The HPA site has an article describing an outbreak of meningococcal disease among university students which I have found interesting and is useful comparison to this scenario; Communicable Disease and Public Health Vol 2 No 3 September 1999."

"It certainly made me think about the practice we carry out at the Trust I work in."

Table 1. Number of messages at each SOLO level

SOLO Level	Number of Messages	
	Forum 1	Forum 2
Prestructural	0	0
Unistructural	0	0
Multistructural	3	2
Relational	6	4
Extended Abstract	18	13

Depth of Learning

Looking at the depth of learning achieved, Beer et al. (2002) examined a similar context to the author (use of PBL amongst occupational therapists), using the SOLO (Structure of the Observed Learning Outcome) taxonomy to examine transcripts for deep learning in group work. Thought process in messages relevant to the learning outcomes were coded as prestructural, unistructural, multistructural, relational, and extended abstract (Biggs, 1999). Examining two discussion forums using this methodology (Table 1) demonstrated that the majority of messages were extended abstract, indicating deep learning. There were no messages at prestructural or unistructural levels. This is a function of the ability of the students, plus the fact that limited information is given at the start of PBL requiring students to think laterally and explore surrounding issues, as shown in the example above.

Student Comments

Comments on the student end of module evaluation questionnaires reflected similar themes:

"I like to have contact and reassurance that what I am doing/thinking is along the right lines or completely off the wall. Blackboard has given me that communication."

"It was all so new to me, I mean looking at everything from an ICN's point of view. I felt I couldn't contribute much to the discussion but I did enjoy

reading what everyone had to say. I feel more confident about using Blackboard now and I'm sure I will give my opinion more in the next module."

"Blackboard has been a great support throughout the last few modules. Being able to see other peoples' comments has helped me learn and sometimes look at things differently."

"Although I didn't often have much to say I've enjoyed reading the messages and have picked up on things that I hadn't thought of, or was just about to ask myself."

"Thank you all for your comments, your support, your good humour and help during the modules we've used blackboard for. I'll miss visiting the site when it finally closes."

Conclusion

The examples above show a successful social constructivist virtual learning environment in action, with deep learning evidenced by individual and community knowledge construction through collaboration and social negotiation of meaning. Improvements in the technology would have further facilitated this, such as provision of good group-working tools and transparent technology, requiring minimal skills and support. Research suggests that when tools are difficult to navigate or frustrating to the user, they can have a negative effect on learning, as we found (Storey et al., 2002). In addition, tools to improve socialisation would be beneficial, such as synchronous chat and student resumes.

As previously discussed, the principle differences in designing for a constructivist environment are the focus on process not product, outcomes that are flexible not predetermined, and the use of open-ended rather than closed systems. To return to the analogy of engineer to architect, there is still a need to engineer; interactions need to be planned and managed, including those that happen spontaneously in classroom settings (Hirumi, 2002), and good design of activities and scaffolding of skills (such as IT, lifelong learning, group working, and critical thinking) is essential. However, the essential difference is that the product cannot be predetermined—each student will construct his/her own knowledge based on the experiences he/she brings and his/her engagement with the task and community. Furthermore, the knowledge generated by each cohort of students will be different—we are merely architects of the environment.

Jonassen (1994) suggests that a constructivist design process should be concerned with designing environments, which support the construction of knowledge, a meaningful authentic context, collaboration among learners and with the teacher, be designated the three C's (context, construction, and collaboration). Whilst these still hold true, I would like to extend these to the three S's—situated, social, and student centred. The shift required is in using technology to create environments that support authentic activity rather than creating courseware in which learner tasks are prescribed (Goodyear, 2000). Well-designed tasks based on cognitive theory are still required, but as a resource for situated learning activity. The second difference is that a "space" becomes a "place" in which a learning community can develop (Goodyear, 2000).

In conclusion, in the author's experience, the albeit limited technology of the Blackboard VLE has been effective in enabling distance learning to be situated in a practice context, and providing the virtual space for a community of practice in which students could collaborate in authentic tasks, facilitating the application of theory to practice, and the development of metacognitive skills required for specialist nurse practitioners. The architecture required for this is an environment emotionally and intellectually conducive to learning, which facilitates the cognitive processes involved, such as conflict or disagreement, explanation, internalization, appropriation, shared cognitive load, mutual regulation, and social grounding (Dillenbourg, 1999, in Goodyear, 2002). Ultimately however, whether this occurs depends on a complex interaction of learner, group, tutor, activity, and environmental factors. Feenberg (1989) observes that organising groups in the "written world' demands an unusual insight into group processes as well as an awareness of the technical features of communications systems; "failures and breakdowns occur at the social level far more often than at the strictly technical level" (p. 8). "The quality of learnplaces, the conviviality of learning communities, the richness of learning activities: these are key. But we may be mistaken in believing we can work on these things directly" (Goodyear, 2000, p. 15). However, good architecture can nurture them.

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Chapter X

Enriching Computer Support for Constructionism

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Abstract

The dominant emphasis in current e-learning practice is instructionist in character. This is surprising when we consider that the benefits of constructionism as a learning paradigm are so widely recognised. Moreover, though the constructionist philosophy can be seen as applying to activities that are not necessarily computer based (such as bricolage and concept mapping), its modern application in educational technology has been closely linked with computer use. In particular, Papert's work on mathematical education through Logo programming has both informed the original concept of constructionism and been a major influence over subsequent computer-based constructionist developments. This chapter questions whether — despite these precedents — traditional computer programming paradigms are well suited for the constructionist educational *agenda. It argues that other approaches to computer model building, such as those based on spreadsheet principles, are in fact much better aligned to the objectives of constructionism. Building on this basis, it proposes that more effective computer support for the constructionist perspective can potentially be offered by Empirical Modelling (EM). Adopting this approach demands a reappraisal of the relationship between the formal and the informal with relevance for education, mathematics, and computing.*

Introduction

The development of e-learning environments has been driven by the needs of universities, where the lecture is the dominant teaching method. The Internet can serve as an efficient mode of effecting lecture delivery. In some situations, the delivery of factual information is entirely appropriate. On the other hand, educationalists recognise the importance of interaction, and constructionists (Harel & Papert, 1991) go further to propose principles that facilitate active learning. In this chapter, we reflect on two complementary experiences: of developing microworlds as part of an e-museum, and of experimenting with a novel approach to building computer-based models for educational applications—that of Empirical Modelling (EM). We draw on these experiences to raise fundamental questions about how computer support for constructionism can best be provided. We identify respects in which conventional thinking about general-purpose computer programming conflicts with the aspirations of constructionism. This leads us to propose EM as a promising alternative foundation for constructionist practices. Though we introduce a simple illustrative example to inform the discussion, a full demonstration of the practical usefulness of EM is outside the scope of this chapter. In any case, without a broader infrastructure for our principles and tools, a proper empirical evaluation of EM in an educational context would be premature at this stage. And although there are indications that EM potentially has useful educational application across a wide range of subjects (see, e.g., McCarty, Beynon, & Russ, 2005; Roe, 2003), our attention in this chapter is confined to mathematical education. This is in keeping with Papert's original motivation for introducing constructionism, and informs a brief discussion of the deeper foundational issues that are topical in understanding mathematical concepts.

Principles of Constructionism

Throughout its history, educational software has progressed through many phases, mirroring the development of cognitive theories of learning. Early instructional software was dominated by programs that reflected a behaviourist outlook—the inspiration for much "drill and kill" software—where the computer acts as a replacement teacher, simply asking questions and gauging learning from the pupil's responses. Over recent years, educational software has tended to reflect a constructivist approach that acknowledges the active role played by the learner in the making of meaning.

A more specific form of constructivism began to emerge in the 1960s when a team, headed by Papert and Feurzeig, was developing the Logo programming language at MIT. This early work was primarily concerned with programming and problem solving in the context of mathematical education (see Papert, Watt, diSessa, & Weir, 1979; Watt, 1979). In particular, it advanced the radical notion that children need to play with and use mathematical concepts within a supportive computer-based environment before being introduced to formal work with those concepts (Papert, 1971, p. 18):

When mathematizing familiar processes is a fluent, natural and enjoyable activity, then is the time to talk about mathematizing mathematical structures, as in a good pure course on modern algebra.

These initial ideas led Papert (1980) to a vision for mathematical education that was subsequently elaborated into a new paradigm for teaching and learning mathematics—the *constructionist* approach (Harel & Papert, 1991). Following (Roe, Pratt, & Jones, 2005), we shall discuss model building with reference to six underlying features of constructionist learning distilled from the literature:

1. *Quasi Concrete Objects—Turkle and Papert (1991):* The computer allows formal ideas to be accessed in a concrete way, through developing iconic representation of abstract mathematical ideas that can be manipulated directly by the user.
2. *Integrating the Informal and the Formal—diSessa (1988):* Incorporating formal representations of mathematical objects in models in different ways may help a child to make connections between the various formalisations and their informal use.

3. *Using Before Knowing—the Power Principle, Papert (1996):* In everyday life, we typically use tools for particular purposes. Through such use, we learn about the effectiveness of a tool, its limitations, how well it serves its purpose, and may sometimes gain some insight into how it works. In schools, mathematics is a subject where, in general, you learn how to generate the object before you use it. In practice, the task of object generation proves too difficult, especially when disconnected from purpose. The computer makes it possible to invert the activity of learning mathematics so that use precedes generation.
4. *Dynamic Expression:* When Papert proposed the turtle as a tool for constructing a dynamic notion of angle (and, of course, much else), he acknowledged that the computer offers a medium which—unlike paper and pencil—can incorporate dynamic representations of the world. He suggests that systems that are expressive of dynamic and interactive aspects of the world are more engaging to learn than static and abstract formalisms.
5. *Building:* Constructionism is based on the tenet that encouraging the building of artefacts is a particularly felicitous way of teaching mathematics. Pratt (2000) has demonstrated how this approach generalises to related activities such as *mending*.
6. *Purpose and Utility:* The microworld approach can encourage purposeful activity through the building and modification of artefacts. Through such interaction, the usefulness of the relevant abstractions is appreciated and their limitations are gradually discriminated.

The e-Muse project illustrates an application of constructionist principles. The broad aim of this project was to develop an Internet museum. The output of the project comprised exhibits relating to the ancient Olympic Games, explanatory material related to the exhibits, and interactive activities to engage visitors. These resources were developed with both museum and schools environments in mind.

From the first, the project engaged with two tensions. In developing a virtual museum that bridged museum and school environments, there was an underlying cultural conflict. Whereas museologists were concerned primarily with accuracy and appropriate presentation, classroom practitioners' foremost concern was promoting interaction and engagement. The second tension stemmed from the first. The primary interest of the museologists—in common with that of the designers of so-called e-learning environments—was in the efficient delivery of accurate materials, whereas that of the educationalists—in common with that of classroom practitioners—was on stimulating learning and engagement.

In e-Muse, two microworlds were developed. These provided an interactive experience for e-museum visitors. They were based on the throwing events of the Olympics and targeted at children of 10 years old and upward. Their development reflected a constructionist perspective: it made use of the Imagine Logo programming environment (Kalas & Blaho, 2000), and was guided by observation and feedback obtained at a local school, where prototypes were trialled with schoolchildren.

One of the primary findings of the e-Muse project was that the realisation of constructionist ideals for learning was obstructed to some considerable degree by the lack of a facility for children to build or modify models themselves (Roe et al., 2005). Though the Imagine Logo environment offered many features to assist the developers in empowering the user to interact with models in imaginative ways, the task of adapting models in response to children's perceived and expressed needs was typically too technical to be undertaken by any participant other than the primary developer. For this reason, the e-Muse environments afforded less flexibility and openness in interaction than was ideally envisaged.

The predominant delivery model for e-learning exhibits similar restrictions and lack of flexibility in interaction, perhaps to an even more marked degree. As Bannan Ritland, Dabbagh, and Murphy (2002) observe, designers of e-learning environments typically structure content in a particular sequence for delivery to the learner. This leads them to remark (p. 12) that

...there are alternative theoretical foundations other than a traditional instructional system design perspective that can be applied to learning object systems based on constructivist philosophy of learning. To the best of our knowledge, a learning object system based in theoretical approaches steeped in constructivism has not yet been developed.

Of course, it is not self-evident that the level of interaction advocated by a constructivist philosophy is achievable. Indeed, Ehrmann (2000) has argued that the idea of attaining interactive courseware that can give full support to constructionist principles is a mirage. He claims that this is due to the high human costs needed to achieve appropriate levels of interactivity. We shall argue that whatever ultimate limits may have to be set on the aspirations of computer support for constructionism, the adoption of an alternative approach to computer-based modelling offers the potential for far greater levels of interactivity in e-learning environments. In the next section, we provide the background and motivation for this argument by considering the relationship between conventional programming and constructionism, both in its historical context, and in relation to the findings of the e-Muse project.

Constructionism and Programming

Of particular significance in the constructionist tradition are environments that support "active learning," in which learners are actively involved in building their own public artefacts. The emphasis in active learning is on the mental processes that occur during the construction of the artefact, not on the quality of the final product. The situated and public nature of the construction activity is also identified as important. For instance, in developing his vision for constructionism, Papert stresses that the active building of knowledge structures in the head often happens especially felicitously when it is supported by construction of a more public sort "in the world" (Papert & Harel, 1991). There are many reasons why active learning is seen as particularly beneficial: learners can pursue their particular interests, can see a tangible result with potential application and relevance, and are motivated to communicate their understanding to others.

The advent of computer technology for learning has opened up new avenues for developing concrete models in the form of interactive computer based artefacts. To meet the requirements for (computer-mediated) active learning, it must be possible for ordinary computer users to construct such artefacts, so that meaningful learning of a domain can proceed in tandem with the construction of the interactive artefact. In her study of end user programming, Nardi (1993) claims that those who are not computer specialists can create personally meaningful computer models if the programming environment eliminates much of the accidental computational complexity. By way of example, she cites end users creating computer-aided design models, Logo programs and spreadsheet models.

In our view, the issues surrounding computer support for active learning have yet to be adequately addressed. Ever since Papert first developed the Logo environment, there has been some ambiguity about the relationship between computer programming and the educational objectives of constructionism. Is computer programming to be viewed as an activity that—of itself—serves the educational objectives of the constructionist agenda, as the Logo environment might suggest? Or is computer programming simply the means to set up environments for model making using techniques that are not—or at any rate are not perceived as—computer programming? In practice, the distinction between "learning about computer programming" and "learning about a domain independent of computer programming" is not always clearly respected in computer based environments that support active learning. What is more, educationalists and computer scientists alike seem relatively insensitive to the potential implications of adopting different perspectives and approaches to constructing computer models.

In this chapter, we argue that there are highly significant distinctions to be made between the different perspectives we can adopt on providing computer support for active learning. In particular, there is a fundamental conceptual distinction to be made between using spreadsheet principles and other programming paradigms that focus on programs as recipes for performing goal-directed transformations. Our thesis is that programming paradigms rooted in the classical view of computation (which embrace the full range of traditional programming idioms including procedural, object-oriented, and declarative approaches) are not well suited to providing support for the constructionist learning agenda. On this basis, we propose an alternative framework that builds on the principles for spreadsheet engineering identified by Grossman (2002). The remainder of the chapter is in two principal sections: the first discusses the relationship between classical computer programming and constructionism; the second briefly introduces and illustrates the alternative perspective afforded by Empirical Modelling.

The relationship between computer programming and constructionism is conceptually complex. Papert's aspiration for the use of Logo is that constructing a program should be a valuable learning experience in which a pupil becomes familiar with geometric concepts and with strategies for problem solving and design (Papert, 1993). There is an implicit assumption that the process of program construction is well-aligned to useful domain learning and to constructionist principles, but there are potentially problematic issues to be considered:

- *Extraneous activity:* Much of the learning associated with model building is computer programming specific: it is concerned with manipulating programming language commands, procedures, and parameters rather than with developing knowledge of geometric concepts or abstract thinking strategies;
- *Planning rather than exploration:* Classical programming is not conceived as an iterative experimental process: programmers are encouraged to plan and preconceive their application rather than to develop a model in an open-ended fashion where its significance can emerge during the development.

Extraneous activity in computer-supported domain learning is a problem for which many different remedies have been proposed. Soloway (1993) raises "the heretical question: *Should* all students learn to program?" and advocates the use of domain-specific, scaffolded, computer-aided design environments as an appropriate substitute for "those pesky semi-colons." The educational experts who responded to his question were positive about the importance of learning to program, and about the valuable—if not essential—contribution it can make to broader domain learning. The diversity of opinions about how to teach programming so that it does not obstruct domain learning highlights such issues as how best to provide programming interfaces for end users; whether to use graphical front ends; whether to use object-oriented principles or recursion, linked lists, and trees.

The significance of being able to treat computer programming as an exploratory activity, rather than a planned activity, is likewise well-recognised. Ben-Ari (2001) discusses how computer programming, as practised, contains the element of redesign in response to interaction with the partially developed programme that is characteristic of bricolage (Levi Strauss, 1968). This is endorsed by Fred Brooks's observation (1995) that programmers see their work as a craft where they wrestle with incompletely understood meaning, and by proposals for software development based on techniques such as "eXtreme Programming" (Beck, 2000).

The thesis of this chapter is that a proper appreciation of the problem of providing computer support for constructionism can only be gained through looking at a deeper issue than the flavour of programming paradigm, the interfaces for the end user, or the method of software development. There is a profound ontological distinction between an artefact that is developed in active learning and a computer program. To interpret computer support for constructionism effectively it is necessary to shift attention from the concept of computer program that is endorsed by the classical theory of computation, and focus instead upon the way in which the programmed computer itself serves as a physical artefact. This is best appreciated by comparing the thought processes that accompany contemplation of the artefact in active learning with those associated with developing a computer program.

In active learning, the artefact under development is a source of experience. Throughout its development, the learner is invited to project possible interpretations and applications on to the artefact as it evolves. The learner asks such questions as "What can I do with this now?" and "How can this particular kind of interaction with the artefact now be interpreted?". Insofar as some reliable interactions with the artefact are familiar to the learner, it implicitly embodies knowledge. At the same time, since many of the plausible interactions contemplated may be as yet unexplored, the artefact in some respects embodies the learner's ignorance. The educational qualities of interaction with the artefact mirror those exhibited in an informal exposition of a proof. Such an exposition is mediated by artefacts, so that the reader can be invited to anticipate the next step, and introduced to the situations in which false inferences can be drawn or unsuccessful strategies adopted.

By contrast, developing a program is understood (from the perspective of the classical theory of computation) with reference to assertions of the form "this is what the program is intended for; these are the kinds of interaction that it admits; these are the ways in which responses to this interaction are to be interpreted." It is, of course, the case that in any complex programming task, essential knowledge of the domain is developed through experimental activity involving artefacts (as represented by use cases, UML diagrams [Jacobson et al., 1992], and prototypes of various kinds). But while this domain knowledge plays a fundamental role in programming, it is primarily directed at the intended functionality and interpretation of the program. For this reason, the artefacts developed in framing requirements serve only for reference purposes once the program implementation begins. A computer program resembles a formal proof in that it follows an abstract pattern of steps whose meaning is entirely contingent upon adhering to a preconceived recipe that is invoked in the correct—fastidiously crafted—context.

The above discussion suggests that the conventional perspective on computer programming is unhelpful in understanding how to give computer support to constructionism. This is not to deny the practical value of computer based environments that have already been developed for active learning, but to observe that they ideally demand a conceptual framework quite different from that offered by classical computer science. With the possible exception of domains in which learning is primarily concerned with understanding *processes*, it is in general inappropriate to think of a learning artefact as a computer *program*. For reasons to be briefly explained and illustrated in the following sections, we prefer to characterise computer-based artefacts for active learning as *construals*.

Our proposal to discard the notion of program in favour of "construal" is in the first instance significant only as a metalevel shift in perspective. In practice, spreadsheets already provide examples of such construals. It is also likely that in asserting that "we need to fundamentally rethink how we introduce programming to students," "we require new types of programming tools," and "we need new programming paradigms," Resnick and Papert (Soloway, 1993) have in mind a much broader notion of "program" than the classical view of computation supports. Nevertheless, making the explicit distinction between programs and construals liberates a radically different view of what computer support for constructionism entails, and lays the foundation for a better understanding with implications for theory and practice. For instance, it can help to identify more effective principles and tools for building learning artefacts, and may help to explain practical developments, such as the success of spreadsheets and the relative lack of popularity of programming as a learning tool for the non-specialist (cf. Nardi, 1993), and the emergence and subsequent disappearance of Logo from the UK National Curriculum (cf. Noss & Hoyles, 1996).

Constructionism and Empirical Modelling

Our description of a learning artefact as a construal borrows from the work of David Gooding, a philosopher of science. Gooding (1990) used the term to describe the physical artefacts and procedures for interaction, observation, and interpretation that Faraday developed to embody his understanding of electromagnetic phenomena, as it evolved through practical experiment and communication with other experimental scientists. In that context, experiment has a significance beyond the popular understanding of the scientific method (as in Sannella, 1997): "One develops a theory that explains some aspect of reality, and then conducts experiments in order to provide evidence that the theory is right or demonstrate that it is wrong."). Although Faraday's experiments did eventually underpin Maxwell's mathematical theory, they initially had a far more primitive role. For instance, they served to distinguish transient effects from significant observables, and to relate Faraday's personal construals of a phenomenon to those of others who had typically employed different modes of observation and identified different concepts and terminology. Such experiments were not conducted post-theory to "explain some aspect of reality", but rather to establish *pre-theory* what should be deemed to *be* an aspect of reality.

A construal is typically much more primitive than a program. It is built in an open-ended fashion with a situation rather than a specific purpose in mind. The conventions for interacting with it and interpreting these interactions are quite informal and fluid. In general, whether a particular interaction has an interpretation can only be appreciated by consulting the immediate experience it offers and recognising this as corresponding to an experience of the referent. A possible construal for the electromagnetic phenomenon associated with a wire coil, such as Faraday himself first developed as a physical artefact, and we might now realise on a computer, would depict the relationship between the direction and strength of the electric current and the disposition and density of the associated magnetic field. A primitive interaction with such a construal would involve observing the impact of changing the current on the strength of the magnetic field in both the computer model and its referent. The relationship between current and field would be perceived as a direct correspondence between dependencies in the model and its referent. In this context, the counterpart of a program would be a much more sophisticated construction—such as a model of an electric motor—that has some autonomous reliable behaviour that cannot be experienced through being present in just one situation.

Empirical Modelling (EM) describes the characteristics of a construal (cf. a spreadsheet) with reference to three key concepts: observables, dependencies, and agency. An *observable* is a feature of the situation or domain that we are modelling to which we can attach an identity (cf. a spreadsheet cell). The main requirement of an observable is that it has a current value or status (cf. the value of a spreadsheet cell). A *dependency* is a relationship amongst observables that expresses how they are indivisibly linked in change (cf. the definition of a cell). Unlike constraints, which express persistent relationships between values in a closed world, dependencies express the modeller's current expectation about how a change in one variable will affect the value of another in an open-ended exploratory environment. Observables and dependencies together determine the current state of an EM model. An *agent* is an entity in the domain being modelled that is perceived as capable of initiating state change. In developing an EM model, our perspective on agency within the domain evolves with our construal.

Developing a construal in EM is a voyage of discovery, a creative activity that is quite unlike conventional programming, where the emphasis is on representing well-understood behaviours. An EM model is empirically established (informed by experience and subject to modification in the light of future experience) and experimentally mediated (our experience with it guides its evolution). A construal must be testable beyond the limits of the expected range of interactions with it. In specifying a conventional program, the modeller has to preconceive its behaviour, thereby restricting the exploratory interactions that can be undertaken. In contrast, EM model construction privileges experimental interaction. Interactions can take account of the changing real world situation, can probe unknown aspects of a referent, and may even be nonsensical in the world.

The potential implications of adopting an EM perspective on computer support for constructionism will be briefly illustrated using a simple example. A *beam detector* for the unit circle is a set of points that intercepts all lines crossing that circle. Eppstein (1998) describes a beam detector constructed by taking a regular hexagon ABCDEF that circumscribes the unit circle, joining the points ABDE using a Steiner tree, and dropping line segments from the two vertices C and F on to the nearest side of the quadrilateral ABDE. The length of such a detector is $2/\sqrt{3} + 4 = 5.1547$.... Eppstein observes that this is nonoptimal and conjectures that nonregular hexagons can be used to reduce this length.

A teacher wishing to exploit Eppstein's beam detector as an aid to active learning might consider many issues:

- *Motivating the search for a detector of optimal length:* To this end, Ian Stewart (2004) devises a detective story, recasting the problem as digging trenches of minimal size that are guaranteed to detect a drainage pipe in the neighbourhood of a statue. To exploit this interpretation, it might be helpful to construct a virtual reality model;
- *Situating the problem within computational geometry:* Eppstein's construction is an application for Steiner trees. This motivates making a model that incorporates and builds on a method of Steiner tree construction. For further investigation, this model could be extended to display

critical lines that pass through just one of the five straight line segments of the given beam detector;

- *Using the beam detector to illustrate school geometry:* Modelling the detector is an exercise in geometric construction that helps students to learn about tangency, trigonometric relationships, perpendicular lines, and so forth;
- *Using the detector as a case study for modelling tools:* Students could make a geometric model of the detector using a special purpose tool such as Cabri Geometry, or study it as an optimisation problem using a spreadsheet.

Issues of presentation are also relevant. The teacher might wish to present Eppstein's construction of the beam detector using an interactive whiteboard, to distribute instances of the construction to the pupils for them to experiment and compete to find the best solution, and to monitor and to display the details of the detector of smallest total length encountered so far concurrently in real time (e.g., as might be done in a sporting event).

If we regard these potential applications as specifications for independent programming exercises to be addressed, there is a prohibitive overhead. Model building directed at capturing the different functional requirements involved in developing a virtual reality environment, setting up a spreadsheet, or emulating CABRI, cannot exploit abstraction above the level of a general purpose programming language. By building a construal, on the other hand, it is possible to build an integrated family of models adapted for each of these different purposes.

Screenshots and extracts from variants of an EM model of Eppstein's beam detector are shown in Figures 1 and 2. A full account of the principles behind the construction of the model and its variants is beyond the scope of this chapter. The details of the models can be inspected and exercised more closely by accessing the beamdetectorRoe2004 directory of the EM repository at http://empublic.dcs.warwick.ac.uk/projects/. Other models from the repository illustrate that the features needed to make the extensions of the Beam Detector model envisaged above are broadly within the scope of the current EM tools. The following brief discussion will highlight some of the most salient points about the development of the Beam Detector models.

The original source for the Beam Detector model was developed by the first author at the suggestion of a colleague who was studying beam detection as an abstract optimisation problem in computational geometry. The model was

Figure 1. The original Beam Detector model and some of its script definitions

```
%donald
viewport Figure
line SSE, NNE, NS
point SE, NE, S, N
real lenS, lenN, len
SSE = [S, SE]
NNE = [N, NE]
NS = [N, S]
S = O - {0, 0.6 * rad}
N = O + {0, 0.6 * rad}
lenS = 0.75 * rad
lenN = 1.01 * rad
SE = S + {lenS @ (-pi div 6)}
NE = N + {lenN @ (pi div 6)}
label lSE, lNE, lS, lN
lSE = label("L", SE + {offset, -offset})
lNE = label("U", NE + {offset, offset})
lS = label("S", S - {0, offset})
lN = label("N", N + {0, offset})
point extNW
line constNW, constSW
point extSW
extNW = N + {len @ (5 * (pi div 6))}
constNW = [N, extNW]
constSW = [S, extSW]
extSW = S + {len @ (7 * (pi div 6))}
```

Listing 1(a) – Some preliminary definitions

```
%donald
real angleNNE, angleSSE
angleNNE = acos((N.1 - S.1) div dist(N, S))-(pi div 3)
angleSSE = acos((N.1 - S.1) div dist(N, S))-(2*pi div 3)
SE = S + {lenS @ angleSSE}
NE = N + {lenN @ angleNNE}
extNW = N + {len @ (angleNNE + (2 * pi div 3))}
extSW = S + {len @ (angleSSE - (2 * pi div 3))}
```

Listing 1(b) – Definitions for extension and revision

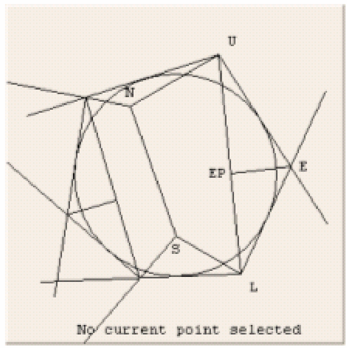


Diagram 1(c) – The basic beam detector

constructed over a period of 2 or 3 days, and involved some 3 or 4 hours development. The listings in Figure 1 illustrate the kind of activity that was involved—the creation of a script of definitions to record the key observables (such as points, lines, and labels) and dependencies (such as relationships of incidence and perpendicularity) in Eppstein's construction. The script creation was an incremental process, so that the definitions in Listing 1(a) were devised first, and those in Listing 1(b) were developed subsequently (see beamdetectorRoe2004 for all the subscripts involved in building up the entire model stage by stage, from which the listings in Figure 1 have been extracted).

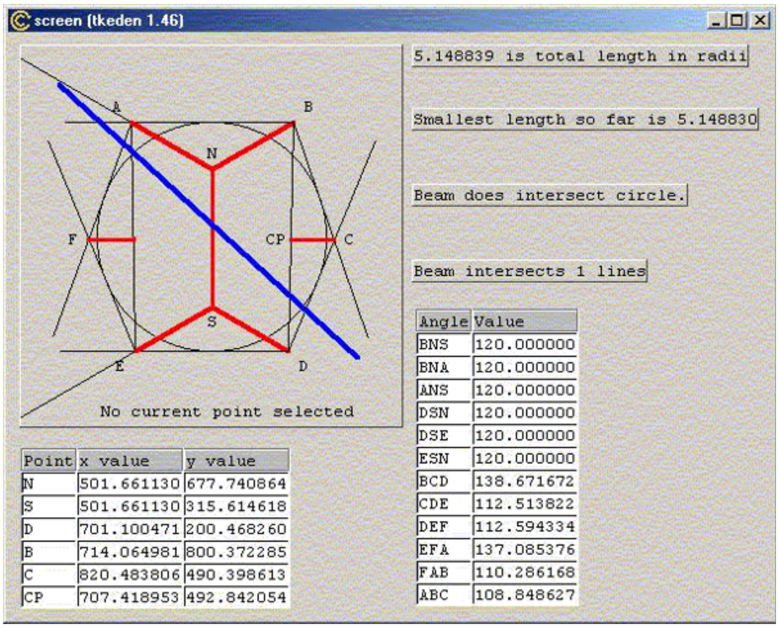
Figure 1 illustrates some general characteristics of EM. The script of definitions for the model evolves in conjunction with the visual artefact as the modeller's understanding is clarified. At any stage of the development, there is a script and an associated visualisation that records such observables and dependencies as the model builder has so far explored. Some experimental interaction, guided by the visualisation, is typically involved in each step of the incremental construction. In introducing the definitions in Listing 1(b), for instance, some experimentation was used to establish and confirm how the principal value of the angle denoted by the acos function was being selected. The overall character of EM in this context is consonant with the way in which Edwards and Hansom (1989) identify modelling as an iterative process comprising understanding the particular phenomena to be modelled, identifying the key variables and explicitly defining the relationships amongst the variables.

As Figure 1 also illustrates, a script of definitions serves as both a description of the model in its current state of development, and a record of the interaction that has led to this current state. This dual role lends to the script the rather loose and messy quality that is characteristic of much of learning activity. The evolution of the models reflects different stages in the understanding, for which different configurations and visualisations of observables are generally appropriate. In Listing 1(b), for instance, the observable SE in the model, which refers to the geometric location of the point labelled "L" in the diagram, has been redefined. This redefinition has been made in order to ensure that whenever the points N and S are relocated, the angle NSL is 120^o, as is appropriate in a Steiner Tree.

The attentive reader will note that in Figure 1(c), which depicts one of the possible states of the basic Beam Detector model in (EMRepository: beamdetectorRoe2004), the angle NSL is no longer 120^o. This is because, at a subsequent stage in the model building, the definition of SE was restored to that in Listing 1(a). The explanation for this is that—without loss of generality—any location of the points N and S leads to a beam detector configuration that is congruent to one in which the line NS is vertical. On this basis, a full exploration of the design space of optimal beam detectors on Eppstein's pattern can be carried out without needing to reorient the line NS at any stage. With this fact in mind, there is a useful educational purpose in neither constraining angle NSL as in Listing 1(b), nor preventing NS from taking up a nonvertical orientation. Allowing a student to displace N and S arbitrarily then supplies experimental evidence that deviating from a Steiner Tree can only make the length of the beam detector suboptimal.

The above discussion illustrates the complexity of the issues involved in building models to support learning, and in particular the subtle role played by placing

Figure 2. An extension of the basic EM model of a Beam Detector



constraints on interaction. The virtue of the basic Beam Detector model as an interactive artefact for experiential learning is that, unlike a conventional program, it is not developed with closed learning objectives and ease of use in mind. However, we may extend the basic model with a view to making it less open-ended and more self-explanatory, so as to give greater prominence to specific targets for the learning. Figure 2 is an extension of the Beam Detector model, carried out by the second author at a much later date, that incorporates features to assist the learner. In this model, points and lines can be manipulated dynamically, rather than merely relocated in a discrete fashion, so that experience of a different quality is brought to bear in trying to minimise the length of the beam detector. The geometric components of the beam detector have been highlighted and a representation of the beam itself has also been added, as have spreadsheets and textboxes to display significant values. This process of extension has precisely the same character as the creation of the original model, and exploits reuse of other EM models.

Perspectives on Constructionism

In the previous section, we have compared and contrasted the support for constructionist principles afforded by EM and by conventional programming. Our illustrative example, the Beam Detector model, like the e-Muse microworlds, relates to implementing a constructionist approach to mathematics education. In this section, we review our findings from a broader perspective, briefly discussing how they relate to topical perceptions of education, mathematics, and computing. In this way, it becomes apparent that some of the specific tensions between learner, teacher, and developer perspectives alluded to in the previous section are symptomatic of more profound conflicts in thinking about mathematics, education, and computing, both interdisciplinary and intradisciplinary. When trying to bring these disciplines together, these conflicts are not merely unresolved—they are to a large extent unacknowledged.

From an educational perspective, model-building by computer is an activity that superficially appears best aligned to teaching mathematics, or a mathematical science. There are a number of plausible reasons for this. Computer support for constructionism has its historical roots in mathematics education. Programming computers is perceived as primarily a logical exercise in framing sequences of action that, like formal mathematics, requires great precision and abstract thought. The kind of model-building with computers that has most educational credibility is model-building that is based on mathematical theory, as when Newton's Laws of Motion are implemented in an e-Muse microworld.

Orthodox computer science thinking endorses this attitude to computer use in education only partially. Having regard to the still unresolved problems of the "software crisis," building software from a theory is perceived by many as the only way forward for computing (see, e.g., Turski & Maibaum, 1987). In this context, the issue of which computer programming techniques are to be commended, and which deprecated, is a matter of great controversy. It is widely recognised that what is actually involved in instructing the computer by way of programming is far less significant than how these instructions are linked to the key observables of the domain in which the program operates.

The difference in viewpoint between educationalist and computer scientist can call the educational value of computer supported constructionism into question. For instance, in rule-based programming in the context of a microworld (Goldstein, Noss, Kalas, & Pratt, 2001), the educationalist sees value in engaging a bright pupil in discussion of whether a particular rule should be attached to one object or another. The computer scientist, by contrast, recognises the kind of uncomfortable pragmatic decision that is typically encountered in thinking about applying programming paradigms; decisions for which the lack of principled grounds for judgement underline the very disconnection of program from domain understanding that computer science seeks to avoid.

In fact, the formal computer scientist's dream of building software from theories is far from being realised in practical computing. On the contrary, as critics such as Brian Cantwell Smith (2002) have argued, theoretical computer science is most ill suited to accounting for contemporary computing practice. What is even more discomforting for computer science as it is presently understood is that—whilst much practice remains unconvincing and incoherent—some aspects of practice deliver results unanticipated and unexplained by computational theory. In particular, classical thinking about computation has little relevance for one of the most widely used and powerful techniques for computer based model building—modelling with spreadsheets. It is indicative of how far practical experience has outstripped theoretical explanation in computing that Baker and Sugden (2003) conclude their extensive review of the applications of spreadsheets in education by observing: "There is no longer a need to question the potential for spreadsheets to enhance the quality and experience of learning that is offered to students."

It is against the background of such highly confused and contradictory visions for making sense of the relationships between mathematics, computing, and education that EM has been conceived. In EM, the aspiration is to develop principles and tools that can support computer-based model-building that is intimately connected with domain learning. The precedents for EM are drawn not from traditional computer programming or formal mathematics, but from other disciplines where practical activities have a well-developed role, such as laboratory sciences, engineering design, the humanities, and the arts. In these domains, practice also takes mature forms, more difficult to formalise than mathematical model-building, but established on far sounder conceptual foundations than computer programming. Consider for instance, the "scientific method," architectural design, and musical analysis.

A key observation is that although the association of mathematics education with computer programming and with constructionism is very natural, it is also potentially misleading. Because both mathematics and conventional computer programming operate with precise and abstract concepts, traditional computer programming can offer good support for mathematical model building in some respects. In the Beam Detector model, many of the functional relationships that feature in definitions use simple mathematical operators whose implementation requires relatively straightforward procedural code. However, constructionism is not essentially about precise and abstract concepts; on the contrary, it is motivated by the desire to engage with pre-articulate experience and tacit knowledge that is made accessible only through exposure to situations. Whilst the educator is able to envisage imaginative ways of introducing mathematics into the world of experience (cf. the e-Muse microworlds), classical computer programming—with its roots in logic and abstract computation—is a reluctant fellow traveller.

In keeping with the features of constructionism identified earlier in the chapter, EM typically entails blending the formal and informal. As the discussion of the Beam Detector has shown, EM can support this integration of the formal and the informal without in any way compromising its own integrity. In this respect, it resembles the "scientific method," which is fundamentally concerned with interaction in the world, yet (in the context of the school science laboratory, if not necessarily in its more authentic setting of the research laboratory) is typically exercised in conjunction with abstract theoretical understanding. EM is also distinguished from mathematics and from computer programming as they are conventionally conceived, in that its characteristic movement is from the informal to the formal (cf. Beynon, Rungrattanaubol, & Sinclair, 2000), rather than from the formal to the informal.

The adoption of an EM perspective on computer based model building involves a switch of priorities where pre- and post-theory understanding is concerned. In the context of mathematics education, this is consistent with the "revaluation of the concrete" to which Turkle and Papert (1991) refer in their discussion of constructionist practices. Such a shift in perspective also has a philosophical aspect concerned with whether we take a Platonistic or intuitionist view of the foundations of mathematics (Goodman, 1994). Where the Platonist is merely setting formal ideas in the context of concrete experiences in order to make them more accessible (cf. the discussion of characteristic features of constructionism earlier in the chapter), the intuitionist regards their very meaningfulness as contingent at some level upon experience. Of the "two versions of constructivism" in the foundations of mathematics alluded to by Goodman (1994), EM seems best aligned with what Goodman describes as "Among philosophers the most influential contemporary version of constructivism ... the intuitionism of Michael Dummett (1977)." Dummett's intuitionism follows "an essentially Wittgensteinian philosophy of language: to understand mathematics is primarily to understand mathematical speech, the meaning of which must be constituted by its use." More specifically, Dummett advocates a version of phenomenalism with respect to which "The phenomenalist ... must interpret the sentence 'the book is on the table' by explaining what sense experiences would justify the assertion of the sentence." Also relevant in this context is Goodman's observation (1994) that, according to the mathematical empiricism of Lakatos, "mathematics is expounded in an order almost the reverse of that in which it is discovered."

Conclusion

This chapter has argued that established thinking about the nature of computer programming and its relation to formal mathematics is obstructive where enhancing computer support for constructionism is concerned. In our view, the use of EM to build construals can better approach the ideal of integrating the roles of learner, teacher, and developer to which constructionism aspires. To fully understand the prospects and implications for EM in this respect requires a more mature and coherent understanding of the relationship between mathematics, education, and computing than we have at present.

Shifting the emphasis away from mathematical model building based on pre-existing theory echoes the philosophy of engineering developed by Vincenti (1990). Vincenti characterises engineering as a species distinct from applied science, where there is a role for *blind variation*—interaction "without complete or adequate guidance"—potentially leading to discovery. When seeking to support personal engagement and creativity in learning, the motivation for a perspective of model-building in which there is no preconceived and fixed framework for interpretation is clear. Modelling activity that enables us to manage cognitive conflict and construct new meanings to resolve such tensions is an essential foundation of constructionist learning. It will not prove easy to gain full acceptance for such an approach to modelling, as it superficially appears to encourage just such practices—experiment without abstract specification, exploration without preconception—as are deprecated in conventional software development. Helpful precedents are to be found in existing modelling tools that exploit dependency, such as spreadsheets and engineering design packages. Effective model building to support learning demands something conceptually much more radical than merely adding dependency to the arsenal of conventional programming techniques, however—in this connection, EM principles are vital in helping to discriminate between emerging understanding and incoherence in interaction.

Where e-learning is concerned, the general application of constructionist principles will require a model-building approach that can be adapted to a much broader range of disciplines. The range of topics addressed in the EM repository already indicates that EM has much wider potential application than has been illustrated in this chapter. Some preliminary thinking about how EM might be applied in modelling for the humanities is further described in McCarty, Beynon, and Russ (2005).

An interesting development in the use of the Web for learning is that adopted by the WebLabs project (WebLabs). The WebLabs portal has been designed to encourage children to share their projects, written in ToonTalk (Kahn, 1996), with other children both local and remote. Such sharing involves posting a project onto the Web site, commenting directly on other peoples' projects, running projects directly on the Web, and downloading them to allow reprogramming in ToonTalk.

The WebLabs project clearly highlights the enormous potential for collaborative e learning within a constructionist framework, but the arguments advanced in this chapter suggest that it will be exceptionally difficult to deliver to this potential with the chosen programming paradigm. In the longer term, we believe that EM will prove far more effective at meeting the challenge of implementing the kind of interaction envisaged in the WebLabs project. For this purpose, we would favour interaction through multiuser—potentially concurrent—redefinition in scripts, such as has been illustrated in distributed EM models, and is commended for collaborative Web-based modelling in Cartwright, Adzhiev, Pasko, Goto, and Kunii (2005).

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Section IV

Individual Differences and Individually Based Systems

Chapter XI

An Architecture for Developing Multiagent Educational Applications for the Web

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Abstract

New applications in training and education are emerging daily trying to meet the requirements of distance learners. Network-based or World Wide Web (WWW)-based intelligent tutoring systems (ITSs) are expected to meet most of these requirements. In this context, software agents seem to be a promising distributed software technology that can be used to implement WWW ITSs. In this chapter, we present a multiagent approach for constructing an educational application for distance learning. The proposed architecture exploits the assumption that each teaching subject

can be regarded as the synthesis of elementary pieces of knowledge, each of which can be presented by an independent expert. Moreover, in order to better support individualized learning, a mobile agent is placed at the disposal of each distance learner.

Introduction

The increasing Internet penetration rate and the potential of World Wide Web (WWW) could be used as an enabling technological framework for the development of courseware applications, which could meet the requirements of distance learners. Currently, popular Web-based courseware applications provide location independent learning; however, they exploit disadvantages such as (a) nonrenewable educational material without the interfering of the trainer, (b) nonadaptable to the different levels of trainees' needs, and (c) nonuse of existing information on the WWW. Most of these shortcomings are not new; they had already been encountered again in the past and led to the development of intelligent tutoring systems (ITSs) (Sherman, Singley, & Fairweather, 1999). On the contrary, network-based or WWW-based ITSs are expected to meet most of the requirements of the distance learners, allowing the emulation of a human tutor in the sense that an "intelligent" tutor can know what to teach, how to teach it, and are able to find out certain teaching-related information about the learner being taught. Most of the network-based ITSs provide server-based access to the courseware. Such an approach, although having benefits in terms of development, maintenance, and access control, is lacking in flexibility and scalability.

In the light of these, an approach based on agent technology seems to be a promising distributed software technology that can be used to implement flexible, truly distributed WWW ITSs. In this chapter, an agent is considered as a resource-bounded autonomous software entity, which is capable of collaborating with peers and of exhibiting reactive and proactive behaviour (Jennings & Wooldridge, 1998). Then, a multiagent system (MAS) is considered as a loosely coupled network of communicating and cooperating agents possibly situated on distributed machines, which provide complementary services (Sycara, 1998). In brief, the main features of the proposed architecture are the possible distribution of teaching knowledge among different network nodes and the support of end-user mobility. The proposed architecture uses a network of communicating agents and exploits the assumption that each teaching subject can be regarded as the synthesis of elementary pieces (or aspects) of knowledge, each of which can be presented by an independent expert. Moreover, in order to better support individualized learning, a mobile agent is placed at the disposal of each distance learner.

A brief survey of WWW ITS architectures and agent-based systems on the Web is presented in section 3. Then, in section 4, this chapter proposes a new software architecture for distributed courseware applications, which is based on the multiagent paradigm. Two applications of the proposed architecture are described in section 5, while some implementation issues are described in section 6. The advantages of the proposed architecture as well as future work are discussed in the last section of the chapter.

Issues Related to Distance-Learning Courseware

When designing a courseware to be used by distance or network-based learners, designers should take into account issues related to technology and to the special learning situations.

Technology-related issues include the following:

- *Availability of training service:* In contrast to stand-alone learners, network-based learners may suffer from network unavailability or breakdown.
- *Robustness:* The software should guarantee a minimum level of educational services available under all conditions.
- *Quality of service (QoS):* This issue is, in fact, a complex one and can be analyzed in constituent issues, such as
    - *Accessibility,* which may depend on whether the learner logs via a LAN or WAN (Internet), or uses a dial-up connection to the educational service provider. Different educational software designs need to be developed for different platforms of learner access.

- *Performance:* This may prove of paramount importance if large files of dynamic data have to be transferred across the network. Again, modularity of content and stream-based transmission may improve the situation.
- *Response time:* Learners are aware that they are using interactive software, so the latter should behave as one. Research has shown that once a learner starts a 1-hour lesson, there should be a probability higher than 95% that he/she eventually gets through the lesson (Rindos, Vouk, Woolet, Hines, & Lester, 1995).

Issues that stem from the special nature of network-based learning include the following:

- *Management of learner profiles:* In order to achieve personalized tutoring, the educational software has to maintain learner profiles.
- *Communication and collaboration:* Communication initiated by the service provider towards the distance learners may increase their confidence to the process. Collaboration may be required between a group of learners, between learners and tutors or even involve the participation of experts (André, Rist, van Mulken, Klesen, & Baldes, 2000).
- *Knowledge management:* Knowledge management includes (a) access to distributed information databases over WANs, (b) updating the information that is presented to the trainee, (c) filtering a large amount of information according to current teaching procedure's needs, and (d) dynamically composing a teaching material for each learner through interaction with him/her (Andriessen & Sandberg, 1999).
- *Mobility:* Contemporary learners tend to use a variety of network access devices and locations. Educational software should be able to adapt the content presentation depending on the access point and device used.
- *Instructional strategy:* Because learners differ in many respects, an educational software system should track these differences and adopt the instructional strategy. Currently in the literature exist four kinds of instructional strategies (Clark, 1998): (a) Receptive, in which the learner has the minimum control of his/her own learning; (b) Directive, in which the learner responds to several instructional events, in order the system to offer a personalized and immediate feedback; (c) Guided discovery, in which the system only depends on the answers given by the learner to accomplish

its tutoring actions; and (d) Exploratory, in which, complete freedom is given to the learner to navigate in the instructional system.

In addition to these, there exist a few more issues related to the educational content:

- *Interactive and dynamic content:* Distance learners may easily be distracted from the process by events that take place in the environment. That is why the educational software should engage the learner in a highly interactive learning process.
- *Property rights:* Since everything distributed via the Internet can be publicly accessed, educational service providers have to ensure that (a) they have the right to distribute educational content and (b) only subscribers to the service access the content.
- *Certification:* Subscribers to educational services need to be assured of the high quality of the educational content and the training process.

State of the Art

New applications in training and education are emerging daily trying to meet the requirements of lifelong or distance learners, such as (a) constant updating of knowledge, (b) accessing distributed information databases over the network, (c) managing (filtering) huge amount of information, (d) providing anytime and anywhere learning, (e) providing learning to people of different ages, (f) taking into account learners' needs, and (g) exploiting adaptation to different didactic strategies. Existing applications come under four categories:

Network-Based Tutoring Systems

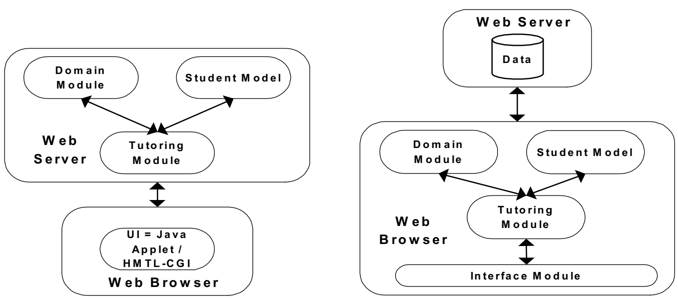
A large number of high-quality network-based tutoring systems have been developed recently. Most of the systems exploit the capabilities of a traditional computer-assisted training (CAT) system and support the management of a virtual classroom, the ability of anytime and anywhere learning, an (typically) unlimited number of learners, and the trainer with a set of tools for easily developing, deploying, and preserving courses. Such systems usually run on a Web server and can be accessed via an Internet browser and make use of mature (but sometimes expensive) network technologies. Examples of the previously described systems are the Course Management System (former eCourse) by eCollege and the Learning Management System (former Learning Space) by Lotus. The main disadvantage of the previous systems is that they do not support multiple instructional strategies and they are not adaptive to user needs.

Network or WWW-Based Intelligent Tutoring Systems (ITSs)

As stand-alone ITSs do, network-based ITSs can be used to act as the learner's private tutor, while the human trainer or tutor is then free to focus on more complex and individualised learner needs. This requires the representation of a domain expert's knowledge (called the *Domain Module*), an instructor's knowledge (called the *Instructional* or *Tutoring Module*), the learner that is being taught (called the *Learner Module*) and the way of learner-computer interaction (*Interface Module*). Figure 1 displays two popular WWW ITS architectures.

In the first one, the learner uses an Internet browser with a downloadable Java applet or pure HTML script (representing the Interface module of the ITS) to interact with the ITS whose Domain, Student, and Tutor modules reside on a Web server. An example of this architecture is the AlgeBrain equation-solving tutor (Sherman et al., 1999), which provides an environment for practicing

Figure 1. Web-enabled ITS architectures



algebraic skills learned in a separate instructional setting. In the second architecture, most of the modules of the ITS reside on a downloadable Java applet and only some data needed for student modelling reside on the Web server. Representative examples of the previous architecture are ELM-ART (Weber & Brusilovsky, 2001) and CITS (Abdel Razek, Frasson, & Kaltenbach, 2003).

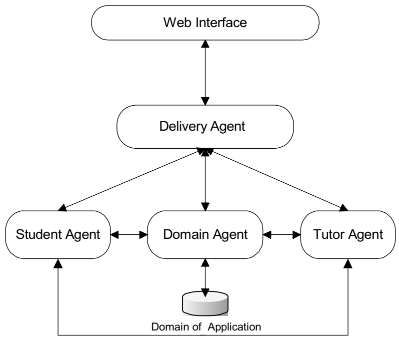
Multiagent-Based ITSs

Agent-based courseware, as an evolution of the traditional ITSs, is built upon previous research on intelligent tutoring systems. Furthermore, it has to deal with many of the same concerns that agents in general must address, such us managing complexity, exhibiting robust behaviour in rich, unpredictable environments, coordinating their behaviour with that of other agents, and managing their own behaviour in a coherent fashion, arbitrating between alternative actions and responding to a multitude of environmental stimuli.

In respect to the issues discussed in section 2, an MAS approach in building educational systems ensures the following:

- *Quality of service:* agents are inherently distributed in nature, and as a result MAS systems exploit (a) availability of the tutoring process to learners that are LAN, WAN, or even mobile users, (b) high response time, and (c) adaptability to network failure.
- *Communication and collaboration:* agents exchange messages only when necessary. Such communication requires low network bandwidth and provides the ability of supporting flexible collaboration among learners through exchanging messages.
- *Knowledge management:* distributed and mobile agents provide access to distributed information databases over WANs, in order to update information that is presented to the trainee and agents may embody artificial intelligence techniques in order to filter that information according to current teaching procedure's needs.
- *Availability, Robustness:* the MAS approach ensures a high level of workload scalability by sharing the workload through the pool of agents (variable in number) distributed on different machines in order to optimise the reply time and the workload of all servers.

Figure 2. MAS ITS functional architecture



From a software engineering point of view, MAS approach enhances performance along the dimensions of computational efficiency, reliability, extensibility, robustness, maintainability, responsiveness, flexibility, and reuse. Currently, most of the multiagent courseware systems implement (some or all) the modules of a traditional ITS architecture (Figure 2) as separate agents and the whole tutoring system is delivered to the learner through a Web-based user interface. Particularly, the *Delivery Agent* is responsible for monitoring and transferring users' events to the rest of agents. The *Student Agent* is responsible for the creation and maintenance of a personalised student model. The *Domain Agent* retrieves information about the domain, which is stored in a database. The *Tutor Agent* is responsible for the metastrategies to be applied in the tutoring process.

Typical examples of the above architecture (Figure 2) are JADEF (Silveira & Vicari, 2002) and Alvarez and Fernandez Castro (2003).

Mobile Agent-Based ITSs

Mobile agents constitute an entirely different approach from Web-based approaches, for example, applets, which are programs downloaded as the result of a user action, then executed from beginning to end on one host. They exploit several advantages that make them suitable for personalized and distance learning, such as the following:

1. *Distance learning:* A mobile user interface agent may move through the network to the learner's place and interact with him/her.
2. *Availability of the courseware to a large number of learners* (typically there is no upper limit) by producing only one educational application, which is a result of the following notions: (a) each mobile user interface agent that is attached to each learner is a clone of a generic one and (b) the rest of the agents are common for all learners.
3. *Reduction of network traffic:* The information transmitted over the network is minimized, which has strong cost implications for devices connected by public wireless networks.
4. *Support for disconnected operation:* A mobile agent is still operational even though the client that it is situated on is disconnected from the network.
5. *Security:* It is possible now to deploy a mobile-agent system that adequately protects either a machine against malicious agents or the tutoring system itself and educational materials' copyrights through authentication of the user.

A representative example is Macro Cell (Deng, Shih, Huang, Liao, Wang, & Hsu, 2002) in which a mobile agent becomes the user interface of the ITS, replacing traditional Web approaches.

Proposed Educational Application Architecture

In order to support knowledge management for self-learners and possibly mobile learners, a software system has to provide (a) *distribution of content***:** the use of Internet as a library of knowledge and information enables isolated learning in which the learner gains the required knowledge through the unconditional synthesis of distributed information, which sometimes may be contradictory; (b) *distribution of expertise*: traditional classroom practice has shown that learners gain the appropriate knowledge through a guided composition of distributed, different but sometimes limited or incomplete expertise; (c) *support for distributed learners***:** the software system has to support learners who form virtual, distributed classes, the members of which change dynamically depending on learner profiles and requirements; and (d) *dynamic content synthesis*: in order to meet the constantly changing requirements of the contemporary educational settings, educational applications need to dynamically synthesize educational content and strategy based on the distribution of expertise.

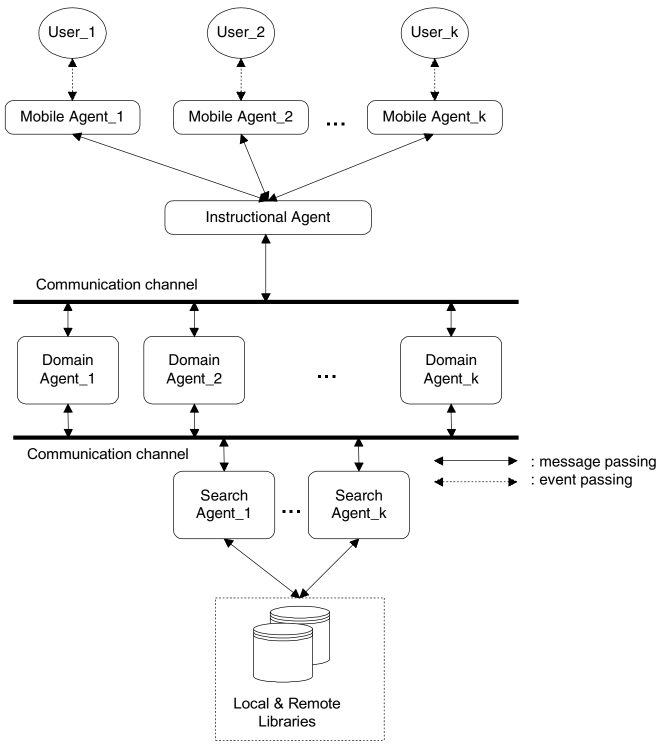
Web ITSs and MAS ITSs lack the capability of dynamic synthesis and distribution of expertise because in each case the domain module of the tutoring system resides either on the domain module of the ITS or on a single agent that embodies the domain module of the MAS ITS. Moreover, in a Web ITS, the learner, usually via a Web browser, accesses the tutoring system, which is situated on a single-server machine over the network (client-server implementation framework). As a result, such tutoring systems do not support management of distributed resources of knowledge, content, and information as well as dynamic synthesis. In particular, the adoption of client-server framework, allows the management of educational resources local to the server machine only. In any case, the author of the courseware is charged with the development of the appropriate content to be presented to the learner.

The architecture for distributed intelligent courseware proposed in this section implements a network of communicating agents. By distributing both domain knowledge and expertise into several agents, it allows the efficient management of distributed information resources and the dynamic synthesis of the information that is presented to the learner. In particular, each educational application may consist of one instructional agent and many domain expert agents, the configuration of which dynamically changes during the teaching process (Figure 3).

The *instructional agent* undertakes the responsibility to control the information that is presented to the learner based on a specific instructional strategy, which is embodied in the instructional agent's knowledge base. This instructional strategy is implemented as a set of teaching plans; each plan is a sequence of teaching steps, each of which can be carried out by a team of expert agents. Note that the instructional agent is only aware of the specialty of the expert agents required per plan step; it then dynamically configures agent teams, based on the set of agents that are active within the system at a particular instance of time.

A *domain expert agent* is responsible for providing information and educational material to the learner about its particular domain of knowledge. A domain expert contains a set of plans for recalling and presenting information

Figure 3. The proposed educational application architecture



modules to the requesting agent. To this end, it is aware of the information resources, which are associated with a specific domain of the educational subject that the tutoring system deals with. In general, each domain expert agent can contribute a part of knowledge or an approach in different parts or cases of the subject; then a team of agents can collectively teach a subject that is beyond the individual capabilities and knowledge of each of the domain expert agents. The synthesis and the management of the distributed expert knowledge are the responsibility of the instructional agent.

A pool of *search agents* undertakes the responsibility of searching for educational material through local or remote information resources on behalf of each domain expert agent, who filters the results of the search according to its domain knowledge. During each step of the teaching process, based on the instructional strategy, the instructional agent forms a team of domain expert agents (based on the specialty and availability of each). Vertical communication between the instructional agent and the expert agents includes (a) the request from the instructional agent to each expert agent to execute one of its plans, (b) the acceptance or rejection of the request by the expert agent, and (c) the response of the expert agent to the instructional agent with the information modules that, according to the expert agent, provide a better match to the request of the instructional agent.

Moreover, the members of each team communicate horizontally by exchanging messages in order to best meet the tutoring objectives. Such communication may involve (a) one expert agent requesting another expert agent to execute one of its plans, (b) one expert agent requesting another expert agent to act as its replacement for the execution of a plan, (c) the acceptance or rejection of the request by the expert agent, (d) the response of an expert agent to the request of another expert agent with the information modules that, according to then called expert agent, provide a better match to the request of the calling expert agent. Then, each domain expert agent serves as a source of information (possibly synthesizing and) providing the appropriate educational material.

In order to implement this teaching practice, two fundamental issues have to be resolved: (a) Subject experts are available: They are capable of working independently, of sensing the educational context, and of cooperating with the teacher and provide the knowledge bits he/she asks from each of them, and (b) the teaching material is structured in a way that it can be efficiently communicated. Moreover, it includes a description of its content that can be used by the teacher to synthesize a broader course.

Each learner accesses the application remotely through a *mobile agent*. As long as the learner registers himself/herself once, through a Web interface, this agent will follow him/her wherever he/she wants to start/continue the educational process. The mobile agent is the user interface of the tutoring application, hence its responsibility is to display the educational material to the learner as well as to track learners' actions and to inform instructional agent about them.

Applications: A Use Case

The proposed architecture has been initially designed for and applied to the development of medical courseware. In general, medical education involves the transfer of voluminous knowledge that is constantly growing. The successful application of medical skills calls for a synthesis of different knowledge sources which sometimes offer contradictory and incomplete information. Traditional medical education adopts a system-oriented approach: each system of the human body is examined from several perspectives of medical interest.

We approached the CBME problem in a manner that is common among physicians: each specialist in a medical subject contributes his/her knowledge on the case at hand, in order to solve as a team a problem that is beyond the individual capabilities and knowledge of each of them. Each developed application is a decentralized system, composed of "medical agents," each of which implements a medical specialist system. A medical specialist system can be regarded as a representation of a medical expert: it contains the knowledge and is aware of the information resources, which are associated with a specific domain of medical science. In the case of CBME, the domain that the systems are aware of becomes a cognitive domain that can be used to describe (teach) a part of a generic medical subject. In essence, each specialist system can contribute a part of knowledge or an approach in different parts or cases of the subject. Each aspect of the medical subject is taught by a specialized medical agent, who is responsible both for acquiring and for delivering the information pertinent to the subject, according to his specialty.

The main idea underlying our approach is similar to the one behind Huang, Jennings, and Fox (1995). Although this system deals with healthcare management and patient treatment, it also uses a multiagent architecture to deal with the distributed, multidisciplinary and uncertain nature of medical knowledge. Our design focuses mainly on issues concerning the implementation and deployment of the multiagent system, as well as issues regarding the retrieval and synthesis of medical knowledge with respect to concrete instructional plans.

In general, an organization populated by agents provides a framework for agent interactions through the definition of roles, behaviour expectation, and authority relations. Sycara (1998) points out four kinds of organizations: the *Hierarchy*, where the decision control belongs to a single agent and interaction takes place through vertical communication; the *Community of Experts*, where a group of specialists interact through rules of order and behaviour; the *Market*, where a group of agents interact through bidding and contractual mechanisms; and the *Scientific Community* where solutions to problems are published for testing and refinement.

In the proposal, we adopt a hybrid organization that combines features from the first two approaches. In order to collect and synthesize medical knowledge, a group of medical specialist agents is formed according to the *Community of Experts* organization. However, even though we permit vertical and horizontal communication we do not adopt the decision control to be based on bidding and contractual mechanisms. On the contrary, decision control belongs to a single agent, as in the *Hierarchy* organization.

An application based on the proposed architecture (a) consists of an instructional agent and a set of domain expert agents and (b) contains a logically integrated (but probably physically distributed) database of educational material. This is partitioned into self-contained modules called Learning Units (LUs). An LU is a hypermedia construct of multimedia material and is described by attributes that represent both static information used to identify the unit (i.e., title, type, location, size, etc.) and dynamic information that describes the behaviour of the unit (i.e., pedagogical prerequisites and objectives, display constraints, etc.).

The development of an educational application involves the design of (a) the instructional strategy that the educational system should adopt during a teaching procedure; (b) the domain knowledge for each domain agent that populates the multiagent system; (c) the interrelations among the agents; and (d) the educational material that will be presented to the learner.

Using this system, and as a form of evaluating the approach, we have developed two educational applications: Dermatology Tutor (Zaharakis, Kameas, & Nikiforidis, 1998) for teaching psoriasis, and OPD Tutor (Triantis, Kameas, & Nikiforidis, 2000) for teaching the treatment of "outlet" impingement in orthopaedics.

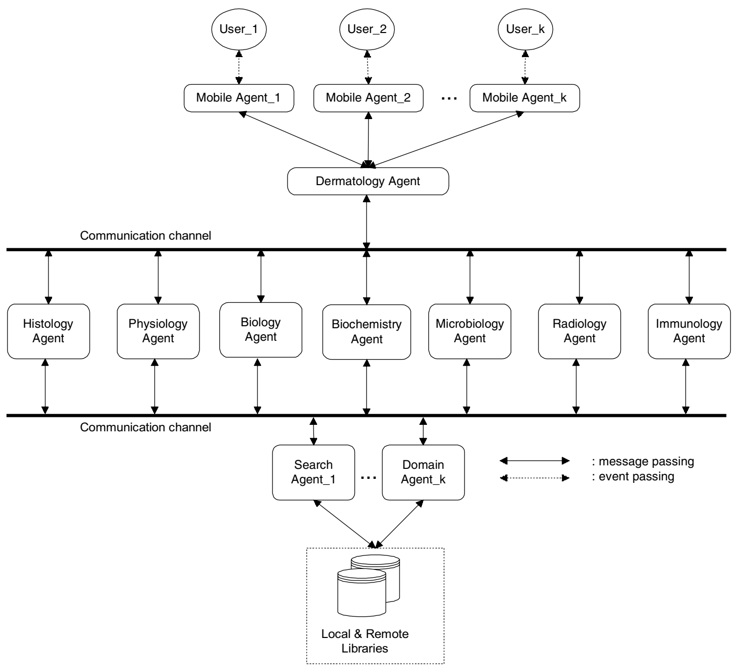
Dermatology Tutor

As mentioned above, Dermatology Tutor implements the proposed architecture (Figure 4) in order to teach psoriasis. Each medical discipline of the subject (e.g., physiology, anatomy, immunology, microbiology, etc.) is taught by a specialized medical agent, who is responsible both for acquiring and for delivering the information pertinent to the subject, according to its specialty.

As the proposed architecture is composed for tutoring purposes, only the *Dermatology Agent* can act as an instructor; the instructional strategy necessary for the tutoring process is contained in this agent's plan presented in Table 1. Each step of this plan constitutes a lower-level plan, which can be further analysed (Table 2).

Based on its plans, the Dermatology Agent can form and manage teams or communicate with the other agents via the communication channel. The domain

Figure 4. Dermatology Tutor architecture



agents populating the society can be members of a team formed by the Dermatology Agent; they can also communicate with each other via the communication channel.

For example, if the learner wishes to learn about the etiology and pathogenesis of psoriasis, the Dermatology Agent will try to teach the specific topic based on the corresponding plan (Table 1). According to this plan, it needs to form a team with Biology, Biochemistry, Immunology, and Histology medical agents. In particular, in order to fulfil its first partial goal ("Disorder of protein expression in keratinocytes"), the Dermatology Agent requests, through message communication, the action from Biochemistry, Biology, and Histology agents. As the Biochemistry, Biology, and Histology agents have a corresponding plan about the requested action, they execute the plan and return the appropriate educational material to the Dermatology Agent. The Dermatology Agent controls the flow of the educational material that is presented to the learner according to the learner's events. The educational material is presented

Table 1. Dermatology Agent plan for teaching psoriasis

Plan name:	*Teach psoriasis*
Preconditions:	
Plan body:	Definition and Epidemiology
	Clinical View
	Histological View
	Etiology and Pathogenesis
	Treatment

Table 2. Etiology and pathogenesis plan of the Dermatology Agent

Plan name:	*Etiology and Pathogenesis*	
Preconditions:		Associated Agents
Plan body:	Disorder of protein expression in keratinocytes	Biology, Biochemistry, Histology
	Antigenic stimulation and immunology activation	Immunology
	Proteases and intense mitotic activity	Biology, Biochemistry
	Metabolic disorders	Biology
	Histopathologic changes of psoriasis	Histology

to the learner via the mobile agent. Finally, each domain agent uses a search agent in order to retrieve the appropriate LU from the database. Moreover, each search agent retrieves LUs based on a set of keywords that was given (in a form of message) by a domain agent.

OPD Tutor

As mentioned above, OPD Tutor implements the proposed architecture in order to teach treatment of "outlet" impingement in orthopaedics. The case at hand requires the contribution of the following medical experts: Orthopedist, Anatomist, Kinesipathist, Radiologist, Pathoanatomist, Pathophysiologist, Laboratorian, and Physiatrist, each of which is a medical expert in orthopedics, anatomy, kinesipathy, actinology, pathoanatomy, pathophysiology, laboratory, and physiatry, respectively. Bearing in mind that this architecture is used for tutoring purposes, only the *Orthopaedist Agent* can act as an instructor; all the instructional strategies necessary for the tutoring process of "outlet impingement" are contained in this agent's plans.

Low-Level Architecture

In order to achieve modular, open, and dynamically changing behaviour of the system, the proposed architecture uses an agent called *Facilitator* (Genesereth & Ketcpel, 1994). Facilitator is not involved in the teaching procedure. This is the reason why Facilitator is not shown in the high-level architecture of the educational system. Facilitator is responsible for maintaining an accurate, complete, and timely list of the services that a registered agent can provide. When each agent is started, its first responsibility is to register itself and its services to Facilitator. Each agent that participates in the organization is implemented as an individual, autonomous program without either knowing the capabilities or the existence of the other agents, except Facilitator. All the communication that takes place among the agents passes through the Facilitator. For example, if the Dermatology Agent wishes to send a message *a* to the Radiologist Agent, he will first send a message *b* to the Facilitator asking for it to forward the message *a* to the Radiologist Agent. The answer of the Radiologist Agent will pass through the Facilitator, too.

Allowing point-to-point communication only between an agent and the Facilitator, provides to the educational system with desirable properties such as (a) *Modularity*: each agent can be implemented by different people and different programming tools with the restriction of knowing the communication means (explained later) between it and the Facilitator; (b) *Reusability*: it permits an agent to be a member of more than one educational systems; (c) *Adaptability*: it is easy to change the instructional strategy of the educational system simply by changing the instructional agent without programming and recompiling the whole system; (d) *Openness*: it is possible to replace any medical agent "on the fly" (dynamically and transparently), while the system is in use; (e) *Plug 'n' play:* by registering his capabilities to Facilitator, each agent enters the tutoring processing upon instantiation; (f) *Scalability*: considering that a Facilitator controls one educational domain, the system can easily be scaled up to support multidomain education by adding one or more multiagent systems, each with its own Facilitator, which interact through a "common" Facilitator of a "higher" level.

The main disadvantage of point-to-point communication only between an agent and the Facilitator is the unavoidable delay of message transportation from one agent to another. The delay increases if more than one domain participates in the tutoring architecture, since communication may pass through the Facilitator of two domains. Nevertheless, the above-mentioned advantages and the speed of contemporary computers make up for these delays. The above advantages of the selected low-level architecture fulfilled the goals of this framework.

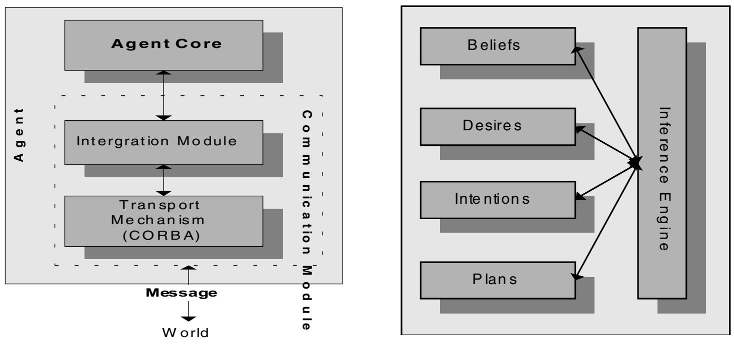
Implementation Issues

In our work we consider an agent to be a modular and autonomous executable program. His implementation comprises the development of three separate parts: the Message Structure, the Agent Core, and the Communication Module. The **Agent Core** (Figure 5) is the essential part of each agent. It comprises the knowledge base and the reason-about mechanisms of each agent. Its structure is based on the well-known BDI logical framework (Cohen & Levesque, 1990) where each agent is viewed as having the three mental attitudes of belief, desire, and intention (BDI). In addition every agent contains a plan library, an inference engine, and a communication module. Plans describe the possible ways that an agent can bring about an intention. The Inference engine is the mechanism that handles and updates the agent's mental state (beliefs, desires, and intentions), selects, executes, and rejects plans according to the mental state and processes the incoming message that transfers the observations of the agent's environment.

In our framework, we implement the Agent Core using the PROLOG programming language because we believe that the built in backtracking mechanism as well as the data structures that it supports, makes it suitable programming language for nondeterministic management of knowledge and information.

The **communication module** is responsible for message transportation. It consists of two separate parts: the integration module and the transport mechanism. The integration module is responsible for the integration between the Agent Core and the transport mechanism. In this way, we support the ability to choose the appropriate transport mechanism according to the current implementation circumstances without the need of adjustment of the whole agent's implementation.

Figure 5. The agent structure



The transport mechanism is the physical means for message exchange. Several transport mechanisms have been proposed in agent literature. In our framework, considering each agent as a client/server entity, the transport mechanism has been implemented with CORBA for two reasons: (a) FIPA addresses a minimal set of requirements on the communication protocol for building open, distributed systems (FIPA, 1999), which are fulfilled by CORBA, and (b) CORBA offers services, such as naming services, trader services, access control services, event services, which make it suitable to easily implement interagent communication mechanisms.

The Message Structure

A message is an individual unit (building block) of interagent communication that is based on the speech act theory (Searle, 1969), where every intended communication action from an agent changes the world in an analogous way to that of a physical action. A message as defined by FIPA in (FIPA, 1999) and implemented in our framework has the following structure*: **Communicative Act(Sender, Receiver, Content(), in-reply-to, reply-with, Language, Ontology)***. The communicative act (CA) implies the action that an agent performs. The parameters of the action described by the elements of the message. In our framework, we make use of a subset of FIPA's CAs, which are common for all the agents that populate the society of the medical educational system. Each CA implies that the content of the message contains a specific set of actions. In this case the *cancel*, *request,* and *refuse* CA implies that the receiver will perform a specific action. The *inform* CA implies that the receiver will update his knowledge base and especially his beliefs about specific things of the environment. The *failure* and *not-understood* CA implies that the receiver will update his knowledge base and will act in order to deal with the error handling.

The comprehension and the execution of the action depends on what actions the recipient can perform. These actions are defined by the *Content* element, which has precisely defined syntax, and semantics (FIPA, 1999). In our framework, we make use of the PROLOG language structure and syntax, in order to define the *Content* element. As a consequence, each action is a PROLOG data structure. The *Content* is not the same for all the agents, but depends on the actions that each agent performs. In this case, the actions are divided into those supported by Facilitator and those supported by either of the medical agents or the Instructional Agent.

Actions Supported by Facilitator

Register: An agent registers its services to the Facilitator in order to publicise some or all of them to other agents. There is *no* intended future commitment or obligation, on the part of the registering agent implied in the act of registering. For example, an agent can refuse a request for a service, which is advertised through the Facilitator. There is a commitment on behalf of the Facilitator to honestly broker the information it holds.

Search: A search action implements a request from an agent, who wants as a result, a specific list of agent names that involve specific services. The Facilitator is responsible for searching his database of the registered and active agents and to provide the list of agent names. The answer to a *search* request is a *result* information.

Modify: This action involves changing an agent's registration fields. The content of a modify message will replace the information which is currently registered for that agent.

Deregister: An agent deregisters in order to remove any record of his services from a domain. The deregister action has the consequence that there is no longer a commitment on behalf of the Facilitator to broker information relating to that agent.

Forward: An agent can ask the Facilitator to forward a message to a destination agent. In the case that the sender does not know the name of the receiver then Facilitator has to search among the registered agents with the service as a keyword and forward the message to one of the agents (randomly) that provides the same service. For example, when the Orthopaedist Agent needs someone with knowledge of Anatomy, it requests the Facilitator to forward the message to a registered agent who provides Anatomy services.

Actions Supported by the Rest of Agents

Teach: The teach action implies that the recipient will undertake the responsibility of finding the appropriate LU for the specific plan name and return the LU's location to the sender.

Location: The location action returns to the sender the appropriate LU's location according to the requested plan name. The location action is an answer to the teach one. The location action updates the sender's knowledge base.

Result: The result action is an answer to the requested action search. The Facilitator returns to the sender a list of agents who can provide the requested service. The result action updates the sender's knowledge base.

Conclusion

The proposed architecture implements distributed intelligent courseware by using features of MAS. It approaches an educational subject as a set of distributed knowledge and expertise modules, and delivers educational content to the learner through a mobile user interface agent. There are several advantages that emerge from the proposed architecture:

1. *Reusability*. A domain expert participates in more than one tutoring system. Thus a domain expert can be part of the teaching procedure of more than one subject. In addition, an instructional agent of a particular tutoring system can be a domain expert to another application.
2. *Adaptivity*. The instructional strategy can be adopted according to the needs of the instructional process since it is easy to replace the existing instructional strategy by replacing the instructional agent.
3. *Scalability*. Each instructional agent defines a different tutoring application. Thus, the developer can scale up the proposed architecture to support multiple subjects by adding the appropriate instructional agent as well as the missing domain agents.
4. *Rapid prototyping*. The modular structure provides a variety of stable intermediate forms that are essential for the rapid development of complex systems.
5. *Maintenance*. Individual domain agents or organisational groupings can be developed in relative isolation and then added into the system in an incremental manner.
6. *Distribution of expertise,* as a result of the proposed educational architecture, which consequently provides quality control independently from the educational domain, by a number of experts (domain expert agents).
7. *Network fault tolerance* through the existence of more than one expert agent that exploits the same expertise. In the case that a domain expert comes out of order, the request can be addressed to another domain expert that shares the same knowledge with the previous one.
8. *Communication decongestion:* agents exchange messages among themselves only when necessary, without keeping a constantly open connection among themselves, as the traditional client/server approach requires.

Future Work

After designing and implementing educational systems for medical education, we are now in the process of applying the described architecture to alternative educational subjects. Currently, the research team is designing an application for teaching aspects of educational software evaluation. Evaluating educational multimedia software is a difficult subject matter, since it ought to cover an extensive range of topics. It should be based on a predefined set of specifications and predictable results arising from the use of the evaluated product. This application deals with the process of evaluating educational multimedia software and in particular it considers the subjects of the evaluation factors and the guidelines needed for selecting and evaluating educational software.

The embodiment of student modelling techniques to the proposed application may be achieved (a) either by implementing a separate student modelling agent, which will interact with the instructional agent in order to adapt the instructional strategy to the learner's profile, or (b) by enclosing these techniques to instructional agent plan library.

Finally, in the context of a research project the authors have already proceeded to the implementation of an integrated authoring environment for developing multiagent distance learning systems based on the proposed architecture. The authoring system, which is currently under evaluation, allows the trainer (author user) to specify and describe the instructional strategy of the system as well as the plans of the participating agents via a graphical formal model. Based on this model, the authoring system produces automatically the educational multiagent system, applicable to any educational domain, which is as complex, large, and dynamic as any medical domain.

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Chapter XII

Impact of Individual Differences on Web Searching Performance: Issues for Design and the Digital Divide

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Abstract

This chapter will encourage the consideration of the role of individual differences in determining Web behavior and performance, which could inform and improve the development of search engines. Currently, users of search engines may experience differences in their level of success in searching for information. This difference could be realized through search success or search strategies. However, there is currently no definitive explanation regarding the characteristics that influence differences in search engine use and behavior. This chapter will serve as *an introduction to and explore the phenomena of online Web searching and the potential role of individual differences in investigating this situation. An overview of the literature will be detailed as well as issues regarding how individual differences can be incorporated into this type of research. This chapter will support the notion that individual usage and performance with Web search engines is influenced by a collection of factors, more specifically, individual differences.*

Introduction

The Internet is a revolutionary technology that is changing the way that people create and search for information, as well as communicate within the global society. The importance of this technology has been widely documented in terms of access to information, resources, organizations, virtual communities, and networks of people.

Currently, Internet search engines provide users with their primary source for locating content on the Web. They also assist in the information searching process and navigation of the Internet using keywords and search terms.

The majority of Internet search engines are straightforward technologies that do not include a great deal of capabilities for personal customization. The developers of Web search engines make an effort to add advanced searching features such as Boolean operators and character strings to make searching more specific to the desired subject. In addition, a combination of skills with the technology, knowledge of the subject matter, and knowledge of online search processes can be beneficial in searching for information on the Internet.

However, the experiences of users of search engines may differ in their level of success in searching for information. There are two ways in which the performance of individuals may vary with regard to search engines. Primarily, there is a difference in being able to find what one is searching for. In addition, there are differences in strategies that are used to search or the way in which people go about finding the information they seek.

So the question remains as to why some users are more effective searchers than others. Another question is whether the experience that a user may have with a Web search engine impacts his/her attitude toward Internet technology as a whole? The characteristics that can be attributed to one searcher performing more successfully than another are presently not well defined. It may possibly be that the design of these systems provides advantage to certain types of users rather than others. There may also be other factors. However, individual differences may play a role in the Web searching skills of users and their performance with Web search engines.

Individual differences could include a range of characteristics including gender, race, age, socioeconomic status, education, income, cognitive style, personality, self-efficacy, and so forth. So an individual user's skill and performance with a Web search engine can be motivated or influenced by a number of these factors. Our goal is to investigate how these individual differences play out in the performance of users of search engines, and what, if any, impact they have on the successful use of that technology. Although it is important to study the range of individual differences, our focus will be mainly on demographic differences.

In addition, we would like to frame the evaluation of this research in terms of social exclusion and the digital divide. Greater numbers of people are exposed to the Internet on a daily basis, but more research is needed to address the motivations and barriers to effective use of the Internet. So the study of the impact of individual differences in Web searching performance may also provide additional information as to why a disparity exists among users and nonusers of Internet technology.

Studying the role of individual differences with Web searching behavior is important on many levels for many different populations. On the societal level, Internet technology is increasingly becoming a part of everyday life as well as a requirement for many jobs. Access to the Internet has been studied in various dimensions to determine its effect on people's use of the technology (Katz & Rice, 2002). Access in this situation can be defined as a function of resources. Research has shown that physical access can be a barrier to use of the technology, but placing the Internet in publicly accessible places such as schools, libraries, and community centers, has not yet worked to close the digital divide. Therefore, it is important to continue to research the types of barriers that may be deterring users from participating in Internet technology. This should be carried out in an effort to determine what measures can be implemented to address the problem. If the Internet or its components can be improved to be a more inclusive and usable technology, then the resources and benefits of the Internet could have a more far-reaching effect. Ideally, the Web is a technology that serves all people, not just the privileged in society (Introna & Nissenbaum, 2000).

The purpose of this chapter is to encourage the consideration of the role of individual differences in determining Web behavior and performance, which could inform and improve the design of search engines. This chapter will serve as an introduction to the literature and basis for understanding the importance of individual differences in relation to human information behavior. The chapter will review current explanations of the digital divide to evaluate the facilitators and inhibitors of Internet use. Next, we will explore the user behavior literature to search for explanations of user behavior with search engines and information retrieval. Then we will explore the role of individual differences in information systems. We will then investigate what current research into individual differences explains, and introduce the individual differences theory by Trauth (Morgan, Quesenberry, & Trauth, 2004; Quesenberry, Morgan, & Trauth, 2004; Trauth, Quesenberry, & Morgan, 2004; Trauth, Quesenberry, & Yeo, 2005). Last, we will outline an agenda for researching individual differences in Web search engines and develop implications for design that integrate the concept of individual differences.

This study will contribute to the research community as well as to society by helping to identify the factors influencing different users' Web search skills and identifying behavior that could provide developers with recommendations to build better, more usable systems. In order to make technology valuable to the greater population of users it is necessary to understand the ways in which information technology can be beneficial to diverse users, and the underlying social judgments that people make when using technology.

Literature Review

In an effort to better understand this situation, this chapter will conceptually explore the role of Web search engines in relation to Internet use. By additionally evaluating the literature on human information behavior, the digital divide, and individual differences, we will show the need for the study of individual differences with Web searching behavior.

Web Search Engines and the Internet

If the Internet is an important technology in society today, Web search engines can be identified as the gatekeeper to them. According to Introna and

Nissenbaum (2000), "search engines constitute a powerful source of access and accessibility within the web." Although many companies, organizations, and individuals make a concerted effort to publicize their Web site URLs, search engines still provide the primary source of locating content on the Internet. The ability to search successfully has an impact on whether an individual will be able to locate a Web site that contains the information that he/she seeks. However, an individual user's skill and performance with a Web search engine can be motivated or influenced by a number of factors. These factors could include two types of individual differences. One level of individual differences takes in to account demographic and social characteristics, including age, race, gender, socioeconomic status, and so forth. The other level of individual differences takes in to account other characteristics, including education level, socioeconomic status, and geographic location.

Current Web search engines are built upon the principles of traditional information retrieval (IR) systems. Much of the functionality of these IR systems is based on a notion that users are able to represent their information need in the form of text. Web search engines follow in this tradition. The argument is made that much of the current complexity in search engines is a result of the size of the Web. Methods that originate from private collection IR systems are not scalable enough to meet the needs of a collection with the magnitude of the Internet. So traditional techniques have had to be adjusted and enhanced to operate effectively with the Web. In addition, Jansen and Pooch (2001) assert that information seeking in traditional information environments holds very important differences to Internet-based Web searching. Studies show that the advanced features of search engines are not as beneficial as they are described to be. Also, the indication of these advanced search operators is that they are useful only to those who are familiar with the structures and inner-workings of IR systems.

Introna and Nissenbaum (2000) discuss how the structure and politics of Web search engines affect users. The authors argue that Web search engines emphasize certain Web sites while making others virtually invisible. In addition, they state that many of the Web sites that receive visibility are popular and mainstream commercial Web sites that are maintained by large economic powers. These large organizations help to illuminate their own presence to the detriment of other small entities. Those neglected Web sites are then further alienated due to lack of traffic and eventually are completely taken down, which narrows the options and content availability on the Internet to Web users. The authors argue that access in its truest sense means a "comprehensive mechanism for finding and being found" (p. 30). They conclude that search engines are politically influenced through technical means such as crawlers, indexers, and ranking algorithms.

Arasu, Cho, Garcia-Molina, Paepcke, and Raghavan (2001) provide a comprehensive overview of Web search engine design and its challenges. A large number of Web search engines utilize IR techniques and algorithms. The difference in the size of the audience for Web search engines versus private collection IR systems makes the design of these systems even more complex and important. The use of new techniques and methods to meet the challenge of scalability for Web search engines improves chances for improving relevance in the retrieval of information. Research suggests that the Web structure mimics that of a "'bow tie" in which roughly 28% of the pages constitute the core of the bow tie and 22% make up the loop which connects also to the core but cannot be reached from it" (p. 3).

The impact of query operators on Web search engines was researched by Eastman and Jansen (2003) to determine if they result in improved searching capabilities. Presently there are roughly 32,000 search engines in existence which 71% of Web users visit to locate information on the Web (p. 389). In Web search engines, advanced phrase search capabilities and Boolean operators are used rarely. However, there is a perception that the use of these conventions increases the effectiveness of Web searching by "increasing the total number of retrieved documents, increasing the number of relevant documents retrieved, or improving the ranking of relevant documents" (p. 384). A number of the major Web search engines even recommends use of advanced operators to improve search on their Web sites. Research suggests that Web users do not utilize advanced searching capabilities for reasons that include laziness and search engine design flaws. The results of Jansen's research show that, in fact, advanced operators in Web searching actually do not increase or decrease the precision of the search. Additionally, these types of advanced functions are useless without a working knowledge of IR systems because integration of these conventions is not intuitive to the user.

Belkin, Cool, Stein, and Theil (1995) discuss the design of interactive IR systems. Traditional IR systems have focused on "representation of texts and queries, and on comparison of these representations" (p. 379). The inclusion of interactivity into the IR systems has placed new focus on the activities of the user, including formulation of queries and retrieval response. The authors present a theoretical basis that supports these types of activities occurring within the context of information-seeking strategies. Their model characterizes information retrieval distinctly as human-computer interaction impacted by information seeking strategies. This situation represents a dialogue between the user and the system, and should be designed and developed based on that notion. The structure of the resulting dialogue can be framed within different information-seeking strategies, and use of case-based reasoning can provide a model for patterns of interaction. Last, the integration of "information-seeking strategies, dialogue structures, scripts, and cases can be used in a system design that uses the advantages of each to ameliorate the disadvantages of each" (p. 394).

Searching is an important process to Internet use. People have different experiences of success and failure in regard to information that they seek on Web search engines. In addition, because it is possible that a person's experience with a search engine may affect his/her overall level of interaction with the technology, it is important to identify if individual differences of users affect their performance with Web search engines. If so, implications for the design of Web search engines and the higher-order effect for the digital divide should also be identified.

User Behavior

Users of technology interact with it in a number of ways, especially in their search for information. When looking to solve a problem or answer a question, users find different methods of formulating that question in the context of their own knowledge. Based on their knowledge, users look for a way to find the information they need in the environment of the information system. However, the arrangement of information systems is not always based on the way that different individuals organize their search for information. This makes the task of information searching very complex. In addition, the experience that a user may have with a Web search engine may also have an impact on their attitude toward Internet technology as a whole.

Bates (1989) describes a way in which to model online and information systems searching called "berry picking." Through this method, she challenges the conventional information retrieval model because she believes that it does not adequately represent the way in which users search for information. Bates argues that users begin with a piece of a larger topic and move iteratively through sources where the query continually evolves. More specifically, berry picking is characterized as the process that happens when users gather more and more information at each stage of searching, thereby satisfying the query by a series of selections, not the single retrieval set. Using a model such as berry picking that involves the wide horizon of user behaviors may allow for better design of information retrieval systems. Last, the author notes that users with the widest range of search strategies will be the ones with the greatest information retrieval power.

Borgman (1996) discusses the difficulty that users encounter with online catalogs. She cites the main reason for that difficulty being the "design that does not incorporate sufficient understanding of searching behavior" (p. 493). Important to her argument is the notion that online catalogs are being designed with skilled workers in mind instead of an average end user. The process of searching is described as one that happens over time through a combination of information technologies and resources, where the user works iteratively to explore his/her inquiry. This process is very complex because searchers have to interpret their information need based on their own knowledge of the problem and understanding of the system. The perspective of this article supports the notion that "information retrieval is a difficult problem because it requires information that [one] does not yet have" (p. 494). Borgman illustrates that for online catalog searching, three levels of knowledge are necessary: conceptual knowledge of the information retrieval process, semantic knowledge of how to implement a query in a given system, and technical skills in executing the query.

The study by Gauch and Smith (1993) demonstrates the use of an expert system that automatically reformulates queries to improve search results. The authors conducted this study based on the problem of user unfamiliarity with search tactics of online retrieval systems. The authors found that most users, even experienced ones, reformulate their queries incorrectly. Their expert system is a knowledge-based assistant that operates as a front end to information retrieval systems.

Belkin, Oddy, and Brooks (1982) discuss a different approach to developing IR systems based on anomalous states of knowledge (ASK). The authors' premise is that the information needs of users cannot be easily specified because they are not facts in themselves, but rather a means by which to find the resolution to a problem. Traditional IR systems utilize a method known as "best match" through which a system responds to a query based on the text whose representation most closely matches it. However, this technique requires that users be able to coherently express their information need in a simple text form, which may or may not completely represent their understanding of the problem. The authors' hypothesis for the ASK system is that information needs result from anomalies in the "user's state of knowledge regarding a topic or situation" (p. 62). Based on this notion, IR should use a process that helps to understand the users ASK rather than require them to specify their own request for information.

Saracevic and Kantor (1988a, 1988b) performed a study that aimed to characterize the components of information seeking and retrieving. The authors stress that human decisions and human-system interactions are the most significant factors in the processes involving searching for and retrieval of information. They also emphasize that the "key to the future of information systems and searching processes … lies not in increased sophistication of technology, but in increased understanding of human involvement with information" (p. 162).

The human search for information is a complex process which is further complicated by the inclusion of technology. Information systems in the form of online catalogs and information retrieval systems appear to require the user to search within the constraints of the system itself, rather than allowing the user to specify his/her own criteria. Bates' (1989) method of berry picking provides a model for the iterative process of human information searching. However, this model also highlights the difficulty that is encountered by users in trying to specify their information needs as being able to search for information often involves having some knowledge of the very topic on which the inquiry is based.

Beyond differences in user behavior, there also exists literature that discusses the differences with individuals who utilize technology and those who do not. Research on the digital divide highlights reasons for the disparity among users of technology and addresses implications for its existence.

The Digital Divide

In 2000, the percentage of households in the United States that reported having Internet access was 41.5% according to the National Telecommunications and Information Administrations' report entitled *Falling Through the Net*. The disparity in the amount of people participating and not participating with the Internet has been labeled the "digital divide." In addressing the digital divide, Kvasny and Truex (2000) state that as new technology is deployed, classes of users are empowered while others lose power. Explanations for the gap have been associated with the concept of unequal access.

Unequal access is largely correlated with technological access. Technological access is the traditional idea of access that corresponds to the physical availability of appropriate computing equipment or the ability to attain the hardware, software, and connectivity necessary to actually use Internet technology. An additionally important notion regarding the digital divide is that of social access. Social access is more concerned with the skills, knowledge, and perceived benefit to engage in using the Internet. Social access has been defined by Kling (1998) as the mix of professional knowledge and technical skills that augment professional practices and social life. A variety of external factors may cause individuals to use the Internet less, such as the need for technical support and a connection to a network of other online users. Kling asserts that the Internet is a medium that can be used socially by ordinary people to accomplish a variety of tasks.

The digital divide is a phenomenon that represents the gap between those who participate with technology and those who do not. Traditionally, the argument is framed in terms of the "haves" and the "have-nots" as it relates to physical access. Many different types of demographics are used to examine the use of technology and much of the early research points to access in order to solve the problem of the digital divide. However, access, though a first step in lessening the divide, is not the end all for eliminating the problem. The digital divide is largely a representative example of the inequality and the power struggle that exist in our society. The technology that is being developed in present times serves to further advantage those who already have privileged status and further exacerbates the inequalities that exist.

The National Telecommunications and Information Administration (NTIA) released a report in 1995 entitled *Falling Through the Net*. This report was one of the seminal works to introduce the notion of the information "haves" and "have-nots." This survey contrasted the goal of "universal service" that corresponds with the idea that all Americans should have the ability to access the telephone service, with the levels of penetration of the Internet across the nation.

Hoffman and Novak (1998) give a comprehensive look at the digital divide and the importance of race as it relates to computer usage. This article examines the differences between African American and White computer and Internet users at different demographic levels to determine how to better address the divide. Many key findings were addressed in this research based on a quantitative analysis of the Nielsen Internet Demographic Study. The authors state that household income is directly related to computer ownership in the home regardless of race. Also, the level of education that a person has correlates to access to computers at work regardless of race. However, race did become a factor in other areas of the study. African Americans are less likely to own a home computer than Whites at every level of education, and are more likely than Whites to have access to a computer at work when income is taken into account. Additionally, the authors say that both income and education affect computer access and subsequent Web use. This article concludes that African American students require multiple points of access to participate in computer technology. Education is also determined to be the most important factor in computer usage. This notion leads the authors to conclude that better educational opportunities for African Americans will result in better participation of all Americans with technology. The article concludes with the notion that if access to computer technology is ensured, then computer usage will follow.

Katz and Aspden (1997) report on the motivations and barriers to Internet usage based on a national telephone survey administered in 1995. The results of the survey showed evidence of a digital divide due to the wealthy and highly educated status of Internet users as opposed to large numbers of ethnic minorities who were largely unaware of Internet technology. The authors report that Internet interest is stimulated greatly by social and professional networks and that these also provide a means of support for users. Internet users are motivated to participate for social-personal development, but nonusers believe the value of the Internet to be in business/commercial use. The survey also determined barriers that people overall felt it difficult to get over when starting with the Internet, even those with technical experience. In addition, other barriers to use include the cost of Internet service and the complexity of use.

In an article that explores the digital divide as a phenomenon regarding more than demographics, Adams (2001) discusses the divide as a "complex web of interconnected issues, with its base in structural and social inequalities that have long been present in this country and world" (p. 6). The author's argument is that by allowing quantitative representations of the digital divide to explain their existence, the actual questions of "who" and "why" the divide is affecting is going unanswered. The presence of discrimination against minorities and the underprivileged has increased the level of difficulty in obtaining both the social and economic means by which to access and benefit from the Internet. According to Adams (2001), the benefits of using computers and the Internet are "access to job training and openings, the ability to strengthen social networks through email, productivity benefits, participation in democratic and political life, and access to an increasing pool of raw information and knowledge" (p. 6). Also as awareness about the digital divide grows, we should not assume that all individuals interact with technology on the same level. In order to function within the digital community, there is an underlying knowledge that who the user is, where he/she comes from, and his/her exposure to technology will affect the way he/she will interact with different technologies.

Kraut, Lundmark, Patterson, Kiesler, Mukopahyay, and Scherlis (1998) studied the effect of the Internet on social and psychological behavior. This longitudinal research looked at whether the Internet increased or decreased social involvement. Decreased social involvement is thought to lead to disenfranchisement by citizens, thus allowing crime and political unrest to enter in to the community. The results of the conducted research support the notion that the Internet adversely affects "social involvement and psychological well-being" (p. 11). The study affirms that an increase in the use of the Internet is connected to a minor decline in social involvement and a more prevalent feeling of loneliness. The measure of social involvement came from observations of family communication and the size of the person's social network.

DiMaggio and Hargattai (2001) discuss different types of prevalent inequality present in the information age. The authors argue that the digital divide represents more than a binary argument regarding those with and without the ability to access technology. The dimension in which digital inequality exists consists of five areas. Inequality of technical apparatus relates to availability of adequate computing equipment, software, and means of connectivity to the Internet. Inequality in the autonomy of use regards the location of Internet access and its affect on the users' ability to use the Internet for their desired activities. Inequality in skill refers to the ability of users to utilize the Internet in an effective way and for the desired outcome. Inequality of available social support includes the other people that the users may interact with to help and encourage them in the use of the medium. Inequality in variety of use encompasses the influencing factors such as education and income on the understanding of the opportunities for use of the Internet.

Hargattai (2003) advances digital divide research by placing a focus on the differences in the online skill of users. By doing so, the author expands the scope of the digital divide past the "haves" and "have-nots." By exploring the differences among users in ability to perform online tasks, there will be a better understanding of an additional potential barrier to equity in the use of technology. The results of the study show that variation exists among the users of the Internet in their ability to find content. Age showed to be an important factor in the research as younger users navigated online content with a much greater use than older users. The amount of time a user spends on the Web is also connected to better navigation of content. This study supports the notion that physical access alone cannot ensure participation in Internet technology.

The digital divide is a situation that is very complex and requires an in-depth analysis of the many ways in which it is perceived. Not only are there constraints in obtaining the necessary physical elements online, but there are also constraints in social elements. Users' skills and ability with the Internet also play a role in their level of participation. It is then important to understand the factors that influence the individual user's skill level and behavior with technology. The theory of individual differences can provide a useful lens in investigating this situation.

Individual Differences

The role of individual differences in information systems research is a growing but very important area. Individual differences have been applied in several disciplines and have been characterized in a variety of categories. Research in individual differences has been largely carried out to better understand the behavior of people in organizations or with technical applications. These types of studies are carried out at the individual level of analysis as opposed to the group or organizational levels. By studying the individual and his/her behavior or interaction with different types of technology, researchers can make recommendations for the improvement of systems based on different user characteristics. Many measures of individual differences have been utilized in research, such as personality, cognitive style, cognitive complexity, need for cognition, problem-solving ability, demographic differences, self-esteem, anxiety, and perceived usefulness.

Two very important measures of individual differences that will be used in the evaluation of users in the study are cognitive complexity and perceived usefulness. Cognitive complexity relates to the degree of differentiation with which an individual views the world (Ford, Miller, & Moss, 2001). Perceived usefulness is the degree to which a person believes that using a particular system would enhance the task he/she is trying to complete. These measures are important characteristics of users especially in relation to searching behavior. This is due to cognitive complexity being a measure of a user's perceptual difference or frame of reference to activity. Users approach the task of searching for information with a worldview that influences their search behavior. Perceived usefulness takes into account the value of systems in accomplishing their goals.

A recent study conducted in the area of individual differences and Internet searching was completed by Ford, Miller, and Moss in 2001. The authors recognize that increased access to the Internet is placing an emphasis on information-seeking skills to a more diverse body of users. This study utilized a positivist approach and gathered mainly quantitative statistical data. In addition, the authors chose not to use hypothesis testing but instead to aim for data exploration by way of factor and regression analyses to identify relationships between factors of individual differences and retrieval effectiveness. The dimensions of individual differences being researched are age, gender, cognitive style, levels of prior experience, Internet perceptions, and study approaches. The authors found that effectiveness of retrieval was linked to males, low cognitive complexity, an imager cognitive style, and several Internet perceptions and study approaches that correlated to low self-esteem of users.

In addition, the theory of individual differences has been largely applied in the context of gender and cognitive/information processing and personality. Trauth is presently working toward a theory of individual differences with respect to gender in the information technology (IT) workforce (Morgan et al., 2004; Quesenberry et al., 2004; Trauth et al., 2004, 2005). This theory seeks to address underlying reasons for the underrepresentation of women in the IT industry. This emergent theory focuses on the differences within instead of between genders and acknowledges that women respond in a variety of ways to external and internal influences. This theory also supports the notion that "both gender and IT are socially constructed at the individual level … [and that] … women as individuals, experience a range of different socio-cultural influences which shape their inclinations to participate in the IT profession in a variety of individual ways" (Trauth et al., 2004, p. 115).

Internet users are a diverse group of individuals. No one type of user can be identified as the benchmark for developing universal systems. Many differences exist among types of users such as race, education level, socioeconomic status, cognitive style, nationality, and so forth. The theory of individual differences reflects and acknowledges this diversity.

The world is a diverse place, so as Internet use becomes increasingly integrated into daily life, the more emphasis will be placed on usability of the technology. Accordingly, it is important that the variety of people accessing the Web be able to effectively use search engines. Importantly, the research shows that models of human information behavior are not always implemented into systems that are built to assist searchers in finding content. Therefore, it is possible that there is a mismatch in the system design of Web search engines with the user model of searching, or there could be other important factors that influence an individual's ability to find information and search successfully. So what is currently not addressed in the literature is the effect of individual differences on use and performance with Internet technology. Additionally, the connection is not evident about the role of search engines in inhibiting or facilitating continued use of the Internet.

Issues

Studying user behavior and the Internet can be accomplished in many ways. The implication of doing so serves a number of purposes. First, by evaluating the way that users interact with Internet technology, we can understand its utility and how it is able to serve user needs. We can also observe the effect that human interaction with technology has on patterns of use, learning, and performance. Based on these ideas, the study of individual differences is critical to identifying influences of these different types of user responses and behavior.

The theory of individual differences takes into account that people makes choices in their environment based upon personal experience and external influences. In the study of gender and IT, it has been used to illustrate that all people of the same gender do not necessarily exhibit a single response in behavior or choice in the IT workforce (Morgan et al., 2004; Quesenberry et al., 2004; Trauth et al., 2004, 2005). This theory is an appropriate basis for research on Web search skill and use, clearly because all users of this technology do not exhibit a single type of behavior nor do they perform at the same level. So investigation into individual differences can provide an explanation of the influences on user behavior and performance that could inform the design of improved systems. By extending and empirically testing the theory of individual differences, much can be learned about users in a way that could significantly affect performance issues by developing systems better suited to their behavior or learning style.

Current research into user behavior would benefit from the exploration of this theory because it would provide insight into how an individual's collective experience affects his/her performance with technology. Instead of viewing users as one dimensional beings, the study of users from the perspective of individual differences takes into account demographics and other personal attributes. By using individual differences as a guiding theory, the study of the user could provide a more complete view of individuals' embodied behavior, not just a slice from their observable actions.

The theoretical stance of individual differences supports the notion that people are unique individuals that will behave and interact with the environment based upon that fact. This theory rejects notions of behavior based upon static biological characteristics. For example, the thought that women and men, as groups, behave differently in respect to technology, would not hold with respect to this theory. Based upon prior research conducted by Trauth et al. (2004, 2005; Morgan et al., 2004; Quesenberry et al., 2004), it is documented that women display numerous types of behavior in respect to their positions in the IT workforce. Based upon this theory, generalizations about men and women do not adequately represent the diversity of the experiences that occurs within or between each group.

The study of individual differences is important because the further development of technology and more specifically, the Internet should be based upon the actual study of user interactions. Using this theory as a basis for research into user behavior supports a notion of user diversity. It accounts for important characteristics that may influence how a user interacts with his/her environment. In addition, it highlights an important area of interest for those engaged in the development of systems. It illustrates that a number of attributes about a user may influence their interaction with IT, and therefore it is necessary to gather rich information about the users for whom the system is being developed. It may also argue that increased levels of user personalization in systems can have a positive impact on user behavior and interaction with technology.

Solutions and Recommendations

In an effort to encourage the incorporation of the theory of individual differences into the study of user behavior and Internet technology, the following research program outlines our approach to the study of the phenomenon. One goal of this research agenda is to add to digital divide research by investigating another possible facilitator or inhibitor of technology use. In addition, because there is evidence of a disconnect between current models of user searching behavior and actual search engines, we seek to inform design based on the perspective of individual differences. Therefore, research into individual behavior with technology has the possibility to enlighten the development process of search engines. We also seek to support and extend individual differences research and theory by documenting its role in human information behavior.

Research Agenda

The individual differences theory will be the theoretical basis for this research. In addition, we will also work to expand the theory into the realm of Web searching and information retrieval. We believe that Web searching is largely influenced by individual differences. In addition, the theory is applicable to this study due to the possibility of sociocultural influences affecting people's perception of Internet technology and their attitudes toward Web searching.

The Internet has recently been described as being essential to society in a variety of ways (Hoffman, Novak, & Venkatesh, 2004). It is a vehicle for the creation and searching of information as well as being a mechanism for communication. So in the wake of this "Internet age," it is important to understand how the technology can be more usable and beneficial to all people.

Currently, due to the inequity of people with the ability to participate in Internet technology, a digital divide exists among users and nonusers. Although a great deal of research has been carried out to address causes for the problem, there has not been a definitive reason identified. In an effort to continue articulation into the problem of the digital divide, more research must delve into factors that influence the motivation or inhibition of Internet use.

We seek to address this need by researching the role of individual differences in online searching skill and performance. Research has identified that "knowledge of more fundamental and enduring factors that can help us improve people's internet retrieval in deep and lasting as opposed to relatively superficial and fleeting ways" is necessary (Ford et al., 2001, p. 1049). In addition, the investigation into user diversity with interactive systems has also been deemed important to the research community (Borgman, 1987).

The significance of this type of study would provide insight into how users actually search for information and the influences, experiences, and perceptions that shape their attitudes and behavior with Web search engines. This research seeks to further support and expand the theory of individual differences being developed by Trauth. This study would identify that the theory of individual differences is applicable to both genders and is relevant to explaining both the underrepresentation of women in IT and differences in Web search skills. In addition, the results of the study could provide critical design information for creators and administrators of Web search engines. In the event that the results do show a connection between individual differences and online Web searching skill, a case can be supported for more concentrated research effort into the personalization and customization of Web search engines. Also, this research may move the research community closer to finding a theory or framework that links the concept of individual differences to information retrieval. This would be an important contribution because without a guiding theory, the subject area will "continue to proceed as in the past using a shotgun approach" (Saracevic, 1991, p. 85). Another important contribution of this research would be the articulation of an additional obstacle to user participation with the Internet, which also supports further explanation of the problem of the digital divide.

Future Trends

This chapter supports the mission of this book by drawing attention to the importance of understanding individual characteristics with respect to technology. We support the notion that systems should be developed based on cognitive-, behavioral-, and performance-based user models. Due to the increased interactivity and sophistication of systems, understanding users at a superficial level will be insufficient to design effective usable systems. Research into individual differences emphasizes user-based design and development methodologies by stressing the uniqueness of individual users.

Future research into this area could explore a variety of areas. The study of individual differences could be expanded from a micro level look at Web search engine use and performance to overall use of technology. Also, this study could be replicated in different international locations to explore how individual differences may be affected by national culture or environment. The theory of individual differences could also be used to evaluate other user behavior in relation to Internet technology in order to develop a rich user model for the development of other Web-based systems.

Conclusion

Users of technology interact with it in a number of ways, especially in their search for information. When looking to solve a problem or answer a question, users find different methods of formulating that question in the context of their own knowledge. Based on their knowledge, users look for a way to find the information they need in the environment of the Internet. However, the arrangement of information systems is not always based on the way that different individuals organize their search for information. This makes the task of information searching very complex. However, we know that users identify a way to find information in their environment. To better understand the factors that influence different levels of performance with the Internet, the study of individual differences can provide critical insight into users. By incorporating the theory of individual differences into research of online searching skill and performance, we can see what impact that situation has on use of the Internet. This research program looks to extend research on individual differences and information retrieval. In addition, by exploring patterns of usage and performance, we can also address the impact of search engine use on overall technology participation. This may well help to address and provide an additional barrier or motivator to Internet use.

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Chapter XIII

Using Bayesian Networks for Student Modeling

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Abstract

This chapter purveys an account of Bayesian networks-related technologies for modeling students in intelligent tutoring systems. Uncertainty exists ubiquitously when we infer students' internal status, for example, learning needs and emotion, from their external behavior, for example, responses to test items and explorative actions. Bayesian networks offer a mathematically sound mechanism for representing and reasoning about students under uncertainty. This chapter consists of five sections, and commences with a brief overview of intelligent tutoring systems, emphasizing the needs for uncertain reasoning. A succinct survey of Bayesian networks for student modeling is provided in Bayesian Networks*, and we go through an example of applying Bayesian networks and mutual*

information to item selection in computerized adaptive testing in Applications to Student Models. *We then touch upon influence diagrams and dynamic Bayesian networks for educational applications in* More Graphical Models*, and wrap up the chapter with an outlook and discussion for this research direction.*

Computer-Assisted Learning

In the past couple of decades, both the research literature and the real world have seen flourishing studies and applications of computer-assisted learning. (We use *computer-assisted learning* to refer to *computer-assisted instruction* as well.) The increasing capabilities and decreasing prices of personal computers have created an affordable environment for individualized computer-assisted learning. The explosive expansion of the Internet not only provides a rich source of information but also nourishes the studies and applications of Web-based learning systems. To give a few examples, Conati, Gertner, and VanLehn (2002) have studied computer-assisted learning of Newtonian Physics; Mislevy and Gitomer (1996) have investigated the techniques for computer-assisted learning of the troubleshooting of hydraulics systems in aircraft; Mitrovic, Martin, and Mayo (2002) have designed systems for teaching the SQL database language; Horvitz, Breese, Heckerman, Hovel, and Rommelse (1998) look into the possibilities of assisting users of Microsoft Excel with software agents; Anderson et al. have developed a system for learning LISP programming (Anderson, Boyle, Corbett, & Lewis, 1990) and high school mathematics (Anderson, Douglass, & Qin, 2004); Virvou, Maras, and Tsiriga (2000) construct systems for assisting the learning of the passive voice in English; and Brusilovsky et al. have discussed issues such as course sequencing (Brusilovsky & Vassileva, 2003) for Web-based education (Brusilovsky, Schwarz, & Weber, 1996).

Student Modeling for Computer-Assisted Learning

In order to build the software infrastructure that supports computer-assisted learning, researchers are employing techniques for modeling important participants in the learning process. Major participants in learning activities include students, instructors, and the targeted learning/teaching objects. Researchers have studied issues ranging from course material preparation to the eventual course material delivery to students, and have taken diverse approaches to modeling and decomposing the whole learning process. For instance, Virvou and Moundridou (2001) consider student and instructor models in their design of authoring tools; Mislevy, Steingerg, and Almond (2003) set up student, task, and evidence models for the assessment task; and Brusilovsky et al. (1996) places emphasis on making intelligent tutoring systems (ITSs) available on the Web.

Despite the differences in the ITS architectures, a significant portion of the literature focuses on student modeling. This is barely surprising. Students are the major, if not the most important, users of any computer-assisted learning systems, so inferring about the students for choosing appropriate learning activities is a key issue for system designers. Since learning is a cognitive process, modeling students' learning process will have to explicitly or implicitly construct some artificially assembled images of the students' cognition process (Anderson et al., 1990). For instance, Anderson et al. (1990, 1992, 2004) base much of their work on theories of cognition, and by working on computer-assisted learning systems, they examine and refine such cognitive theories as ACT* and ACT-R at the same time. They show how students *apply* and *learn* knowledge with *performance* and *learning* models, respectively. Their systems then apply the *model* and *knowledge* tracing techniques in monitoring students' progresses in the problem domains. Similarly, Brusilovsky (1994) proposes *overlay student*, *error*, and *genetic* models for demonstrating different aspects of student performance. Overlay student models record students' competence in different areas of the learning targets, error models provide an explanation of why students make mistakes, and genetic models capture student performances in executing procedural knowledge.

Besides comparing student models based on how theories of cognition are employed, we find previous approaches differ in how they link students' external performance with their internal state of knowledge. On the one hand, we can assume that there is a one-to-one deterministic relationship, and build student models with either propositional or first-order logics. From here, it is natural to treat the problems of diagnosing students' deficiency in knowledge as the problems of identifying buggy designs in electronic systems (de Kleer & Williams, 1987). For instance, Kono, Ikeda, and Mizoguchi (1994) build their work on de Kleer's truth maintenance system (de Kleer, 1986). Such logic-based approaches face the challenges that students may not perform consistently over time and under different contexts, and researchers have to employ such techniques as nonmonotonic reasoning in their systems. On the other hand, we can accept that inconsistency is part of nature, and adopt reasoning mechanisms that explicitly capture and reason about the uncertainties in applications.

Sources of Uncertainties in Modeling Students

Uncertainties in student modeling come from several sources. The most commonly cited are *slips* and *lucky guesses* (cf. Martin & VanLehn, 1995; Millán & Pérez-de-la-Cruz, 2002; Mislevy et al., 1996; Reye, 2004). Let us assume that students are either competent or incompetent in some concepts and that we rely on test items to gauge students' competences. We can identify students who fail in test items that the students should be able to respond to correctly. Analogously, we can identify situations when students respond to test items correctly by guesswork, although the students do not have sufficient knowledge to know the answers. Researchers call these phenomena *slips* and *lucky guesses*, respectively. An interesting source of such uncertainties comes from the nature of human behavior. After students have learned the correct concepts, they might commit the same errors again. Although such a recurrence of errors is less common in machines, it is quite conceivable in human behavior (Sison & Shimura, 1998). As a consequence, we cannot tell for sure whether students are really competent in a particular concept, given that they may respond to test items correctly or incorrectly.

More generally, uncertainties exist when we are interested in knowing factors that are not directly observable. For instance, even if the relationship between being competent in some concepts and responding correctly to test items is deterministic, we might not be able to exactly judge the students' competences in some situations. When there are multiple ways to solve the test items, we cannot tell for sure which way the students have applied to solve the problems (Martin & VanLehn, 1995).

More challenges come about in computer-assisted learning environments. In an open learning environment, where students are allowed to explore topics of their choices, it is hard to tell the real purposes of students' activities (Bunt & Conati, 2003). In an interactive environment, it is possible that students make deliberate errors to see how the machines will react (Reye, 2004). Hence, we may not want to jump to a specific conclusion after observing students' mistakes.

The uncertain relationships between students' responses to test items and students' competence in learning targets make student modeling a challenging task. Had the relationship been deterministic, we could infer that a student is incompetent in a concept when we observe that s/he failed to answer a test item correctly. This would allow us to employ logics-based methods for student modeling. In fact, the relationships are not deterministic, and logic-based reasoning is not appropriate. Therefore, we would have to resort to other approaches that consider uncertain relationships between the observed and unobservable variables. In the remainder of this chapter, we introduce Bayesian networks for this task of reasoning under uncertainty.

Bayesian Networks

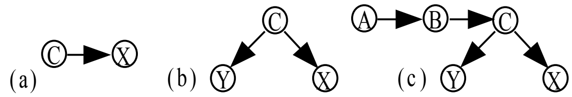
The aforementioned types of uncertainties prompt researchers to employ appropriate techniques for student modeling. More than 10 years ago, researchers began to employ Bayesian networks (Pearl, 1988) for student modeling (cf. Villano, 1992).

Capturing and Reasoning About the Uncertainties

Bayesian networks (BNs) are directed acyclic graphs that consist of nodes and arcs (Pearl, 1988). Nodes represent random variables, and arcs qualitatively denote direct dependence relationships between the connected nodes. Each node can take on its value from a set of possible values, and has an associated conditional probability table that quantitatively specifies the degrees of mutual dependence between the connected nodes. Nodes at the tails of arcs are parent nodes of the nodes that are pointed by arrows. A node without parent nodes should have a table of prior probabilities. A Bayesian network indirectly encodes the joint probability distribution of the random variables in the network, so we can compute any conditional probabilities of interest given a Bayesian network that is constructed for the target application.

We illustrate the basic concepts of Bayesian networks with the examples discussed in Liu (2005). Let C be the random variable that encodes the degree of the mastery of a concept, and X the random variable representing the outcomes of using an item for testing the mastery of C. Assume that variables

Figure 1. Some very basic Bayesian networks for assessing students' competence in concepts



for both concepts and items are dichotomous. A variable for a concept takes the value of either **good** or **bad**, and a variable for the response to an item takes the value of either **correct** or **incorrect**. For simplicity of notation, we use a small letter of the variable to denote the "positive" value of a random variable, and a small letter with a bar to denote the "negative" value of the variable. For instance, $\Pr(x \mid \bar{c})$ denotes $\Pr(X = \text{correct} \mid C = \text{bad})$. We use the symbol *PR* and capital names of random variables to denote the probability values of all possible combinations of the values of the involved random variables. For instance, $PR(X \mid C)$ denotes $\{\Pr(x \mid c), \Pr(\bar{x} \mid c), \Pr(x \mid \bar{c}), \Pr(\bar{x} \mid \bar{c})\}$.

We can use the very simple Bayesian network shown in Figure 1(a) to represent that *X* is a test item for assessing students' competence in *C*. Node *C* will include a table that contains the prior distribution for the random variable *C*, and node *X* will have a table that contains the probability distribution for *X* conditional on the values of *C*. The contents of $PR(X \mid C)$ will capture the probabilities of making slips and lucky guesses when students respond to *X*. Let *Y* denote the response to another test item. The network shown in Figure 1(b) suggests that we have an extra item for measuring the competence in *C*. Again, the contents of $PR(Y \mid C)$ contain the probabilities of making slips and lucky guesses when students respond to *Y*. The network shown in Figure 1(c) expands Figure 1(a) in another direction. We add a node for concept *B* that is directly related to the competence in *C*, and yet another node for concept *A* that is directly related to the competence in *B*. The contents of $PR(C \mid B)$ dictate how the competence in *B* will influence the competence in *C*

A Bayesian network indirectly specifies the joint probability distribution of the random variables, so we can compute any conditional probabilities that involve variables in the network. The very simple network shown in Figure 1(a) indirectly encodes the joint distribution of *C* and *X*, and we can compute the conditional probabilities of interest, for example, $PR(C \mid X)$. Researchers have invented different algorithms for computing conditional probabilities with Bayesian networks (Jensen, 2001), and there are available commercial and free software tools (http://www.cs.ubc.ca/~murphyk/Bayes/bnsoft.html).

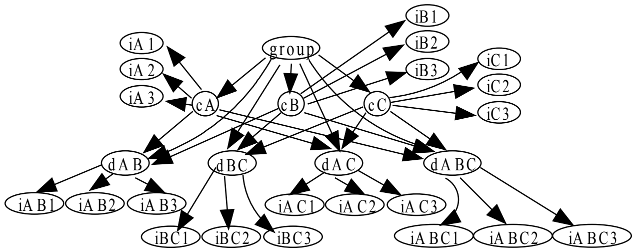
However, before we explore other aspects of applying Bayesian networks for student modeling, we must keep in mind that Cooper (1990) has proven that computing exact probability distributions with Bayesian networks is an NP hard task. Moreover, Dagum and Luby (1993) have proven that computing approximate probabilities with Bayesian networks are also NP hard. Consequently, computational costs can become a design concern for systems that require complex networks (e.g., Martin & VanLehn, 1995; Mayo & Mitrovic, 2000), and Collins, Greer, and Huang (1996) and Reye (2004) discuss the applications of special classes of Bayesian networks for student modeling.

A Running Example

Liu (2005) applies the network shown in Figure 2 for adaptive item selection in student classification. The *group* node is multiple valued, and represents the types of student groups. Nodes named *cX* represent basic concepts, and nodes named *dY* represent composite concepts. Values of nodes that represent concepts are either **good** or **bad**. All nodes named *iZ* represent responses to test items, and the responses can be either **correct** or **incorrect**. For instance, *dAB* is a composite concept whose prerequisites include *cA* and *cB*, and *iA1*, *iA2*, and *iA3* represent students' responses to test items that are designed for evaluating students' competence in *cA*.

Links from concept nodes, for example, nodes named *cX* and *dY*, to item nodes, for example, those named *iZ*, indicate the competence levels in concepts influence the probability of answering correctly to test items. Links from basic concepts to composite concepts indicate that understanding com-

Figure 2. A Bayesian network designed for item selection (Liu, 2005)



posite concepts requires the knowledge of basic concepts. Links from the *group* node to nodes that represent basic concepts indicate that different student types may have different abilities in the basic concepts. Links from the *group* node to the nodes that represent composite concepts indicate that different student types may have different abilities in integrating basic concepts to form knowledge about the composite concept.

The contents of the conditional probability tables quantify the strength of the dependence between nodes that are directly connected. For instance, $\Pr(\overline{ia1} \mid ca)$ and $\Pr(ia1 \mid \overline{ca})$ are, respectively, the chances of making slips and lucky guesses for the test item *iA1*. $\Pr(cb \mid g_i)$ is the probability that the *i*-th type of student is good at concept *cB*, and $\Pr(dabc \mid ca, cb, cc, g_i)$ is the probability that the *i*-th type of student who is also good at *cA*, *cB*, and *cC* can actually learn the composite concept *dABC*.

Given such a Bayesian network, we can conduct predictive and diagnostic inferences. We predict the chances of correctly responding to a particular test item given that we know a student's type. In contrast, we compute the probability distribution over the possible student types given the correctness of students' responses to some test items, and may choose to guess the students' types based on the probability distribution over *group*. In fact, taking advantage of the Bayesian network, we can compute the conditional mutual information between any unadministered test items with the *group* node for selecting the most effective test items which, hopefully, allow us to determine a student's type with as few test items as possible (Liu, 2005).

Learning Bayesian Networks

Obtaining appropriate Bayesian networks for the target problems is a challenge that one must cope with. Researchers such as Heckerman (1999) have done quite a lot of work in learning Bayesian networks from data, and Chickering (1996) shows that learning Bayesian networks is NP complete. Practically, the task of learning a Bayesian network has been split into two stages: parameter learning and structure learning (Neapolitan, 2004), although learning good structures and their parameters are not independent.

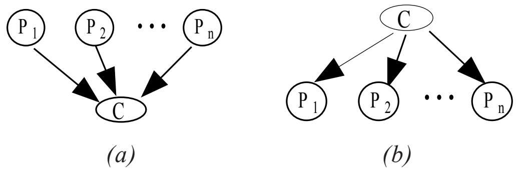
Based on domain knowledge in education and psychology, experts can directly provide structures for the problem domains. For more complex applications, one provides building blocks that model subparts of the whole problem, and the building blocks will be used to dynamically construct a complete network on the fly. This is the so-called knowledge-based model construction approach (Breese, Goldman, & Wellman, 1994). Mislevy, Almond, Yan, and Steinberg (1999) apply Markov Chain Monte Carlo methods to obtain parameters for a given network. Mayo and Mitrovic (2001) initialize Bayesian networks with data collected from a population of students, and adapt the conditional probabilities for individual students with algorithms discussed in Heckerman (1999). It is also possible that system designers employ heuristics for choosing appropriate parameters from a specific set of choices (Conati & VanLehn, 2001).

Relatively, choosing a structure for the problem domain is less straightforward than fitting the joint probability distribution encoded in a Bayesian network to the observed data. On the one hand, we would like to have networks that reflect the dependence relationships among all variables involved in the applications. On the other hand, we also have to consider the computational costs of evaluating Bayesian networks and whether we really can obtain sufficient training data that will be used to train the networks for their conditional probability tables. Mayo and Mitrovic (2001) classify different channels of obtaining student models into three types: *expert-centric*, *efficiency-centric*, and *data-centric*. In the expert-centric approach (e.g., Conati et al., 2002; Mislevy & Gitomer, 1996), experts create student models based on domain knowledge, but have to employ heuristics for obtaining the required conditional probability tables. In the efficiency-centric approach (e.g., Reye, 2004; Mayo & Mitrovic, 2000), people employ relatively simple networks to track students' competence over time. In the data-centric approach, both structures and conditional probability tables are induced from training data.

Millán and Pérez-de-la-Cruz (2002) discuss directions of arcs for aggregation relationships and evidence–knowledge relationships. Different choices of arc directions imply different relationships among the variables, and will also influence the difficulties confronted in model construction. Assume a meaningful aggregation, denoted C, of a set of items, denoted P_1, P_2, ..., P_n. How do we model the relationships between the basic items and the aggregated cluster? (For ITSs, the basic items could represent the prerequisites of an advanced course.) Conati et al. (2002) employ the structure shown in Figure 3(a) for a network that mimics the structure of the domain knowledge, but Mislevy and Gitomer (1996) adopt deductive reasoning and the structure shown in Figure 3(b).

Analogously, for inferring students' competence in concepts, assume that we have three test items, I_1, I_2, and I_3 and two concepts, C_1 and C_2. If responding

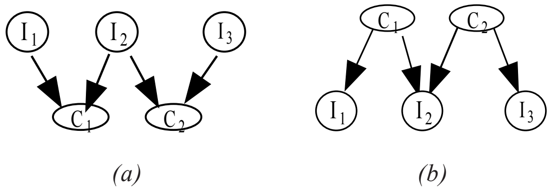
Figure 3. Alternative structures for nodes of an advanced course and its prerequisites



correctly to and respectively, requires the knowledge of only both and and only What is the structure that we should use to model this relationship? In this case, the structure shown in Figure 4(b) will be more natural and appropriate, and many projects adopt this choice (e.g., Guzmán & Conejo, 2004; Millán & Pérez-de-la-Cruz, 2002). In practice, if a student responds incorrectly to this would decrease the possibility that this student will respond to and correctly. This intuition is implied by the structure shown in Figure 4(b) but not so by the one shown in Figure 4(a). When we have no direct evidence about both and nodes and remain independent of in Figure 4(a), due to d-separation (Pearl, 1988).

Despite the advances in computational technologies, it appears that it is very challenging, if not impossible, to create a computer program that fully automatically infers a convincing structure for a specialty domain. As pointed out by an anonymous reviewer for this chapter, "there can be wide disagreement on what constitutes a prerequisite for concept." Consider systems that rely on models that are provided by human experts on one extreme of the spectrum and systems that rely on models that are fully automatically learned from data on the

Figure 4. Alternative structures for nodes representing concepts and test items



other extreme. A middle ground between these two extremes is to allow experts to provide fragments of a complete network and let computer programs to dynamically construct the complete network at run time. Before machines can fully assist the task of model construction, an appropriate intervention of experts may be required. Conati et al. (2002) apply Bayesian networks as the infrastructure for assisting real students to learn Newtonian Physics. They employ a set of fragments of network for domain-general knowledge and another set for task-specific knowledge. At run time, the tutoring system employs fragments from these two sets to compose networks that are tailored for individual students.

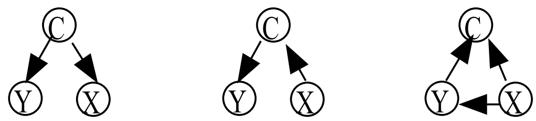
A Note on the Semantics of Arc Directions

Semantics of arc directions is the key issue in our discussion of the structures shown in Figures 3 and 4. It is tempting to interpret directions in Bayesian networks as causal directions. This is evident in that many, including the network shown in Figure 2, choose to implement their systems with structures that are similar to those shown in Figures 3(a) and 4(b). In addition, typical textbooks on artificial intelligence also advise that constructing Bayesian networks based on the causal directions among random variables are more likely to lead to concise networks (Russell & Norvig, 2003).

Despite these facts, arc directions in Bayesian networks do not have to follow causal relationships among propositions which are represented by the nodes. More technically speaking, Bayesian networks are *independency maps* rather than *dependency maps*, meaning that lacking a direct link between nodes in Bayesian networks only implies conditional independence and the directly connected nodes might in fact be independent (Pearl, 1988). Roughly speaking, links in Bayesian networks are more about conditional correlations between random variables. Hence the choices between the networks shown in Figure 3(a) and 3(b) can be subjective, and both can work for the applications as long as the underlying distributions fit the real data.

Let C represent the competence in a particular concept, and X and Y be two test items for assessing the mastery in C. We can apply any of the network structures shown in Figure 5 to carry the joint probability distribution of these three random variables. In fact, it is possible that we reverse directions of arcs in Bayesian networks without changing the underlying joint probability distributions, and we can transform the leftmost network shown in Figure 5 gradually

Figure 5. Alternative structures for concept C and test items X and Y



to the middle network and to the rightmost network with Shachter's algorithm (1986). The directions of arcs do not necessarily carry causal implications in these alternative networks.

Arcs of Bayesian networks as they are defined in most literature (e.g., Jensen, 2001; Pearl, 1988), encode correlations among random variables. Correlations do not necessarily imply causal relationships, although many researchers have interpreted arcs in Bayesian networks as causal links. Many researchers have been working on causal Bayesian networks, and readers who are interested in causal inference are referred to Pearl (1995), Cooper (1999), and Lauritzen (2001).

Applications of Bayesian Networks to Student Models

Research on student modeling is an interesting topic in cognition. Good student models not only reveal how things are learned but also guide ITSs to help people to learn (Anderson et al., 1990). Course sequencing aims at providing individual students with appropriate course material at the right timing (Brusilovsky & Vassileva, 2003). A well-designed ITS should consider students' interests, competence, and learning styles, for presenting course materials of appropriate challenge levels with suitable formats, for example, textual, audio, or video. Conati et al. (2002) employ Bayesian networks for both accessing students' competence and recognizing students' learning plans in helping students to learn physics. More generally, an ITS should choose the best tutorial actions in order to maximize the teaching effects (Murray & VanLehn, 2000).

Computerized adaptive testing (CAT) is another component of ITSs, and relies on good student models to choose the test items that will help us to assess students' competence in an efficient and effective manner. While researchers have laid out a solid foundation for CAT (van der Linden & Glas, 2000; Wainer, 2000), some recent reports look into details about how test items should be selected for assessment. Guzmán and Conejo (2004) emphasize the consideration of content-balanced tests and polytomous response models, and their work has been implemented in a Web-based tool for adaptive testing (Conejo, Guzmán, Millán, Trella, Pérez-de-la-Cruz, & Ríos, 2004). Collins et al. (1996) and Millán and Pérez-de-la-Cruz (2002) propose different criteria that are chosen based on utilities of test items. In this section, we explore the possibility of applying mutual information (cf. Cover & Thomas, 1991) for student classification with the help of Bayesian network-based student models (Liu, 2005).

Mutual Information-Based Adaptive Item Selection

Consider the running example shown in Figure 2 and the competence patterns shown in Table 1. For the basic concepts, denoted by *cX*, we use "1" and "0" to represent the situation of whether typical students of a particular type are competent in that concept. For the composite concepts, denoted *dY*, we use "1" and "0" to represent the situation of whether typical students of a particular type are competent in integrating basic concepts for that composite concept. For instance, students of the third type are competent in *cB*, but cannot integrate knowledge in *cA* and *cB* into *dAB*. As is explained in detail in Liu (2005), "1" and "0" here do not intend to introduce deterministic relationships. When generating Bayesian networks in experimental studies, some limited degrees of uncertainty will be introduced, and we employ the concept of Noisy-And nodes for the composite nodes.

Given the network shown in Figure 2, we can compute the mutual information between a test item and the *group* node, and choose the item that has the highest mutual information with the *group* node as the next test item. Let $MI(X;C)$ denote the mutual information between random variables X and C. We choose from the item pool the test item I that maximizes $MI(I;group)$ in the following MI-ADAPT procedure.

Table 1. Competence patterns for different types of students

student types	cA	cB	cC	dAB	dBC	dAC	dABC
1	1	1	1	1	1	1	1
2	1	1	1	1	1	0	0
3	1	1	1	0	0	1	1
4	1	1	0	1	0	0	0
5	0	1	1	0	1	0	0
6	1	0	1	0	0	1	0
7	1	1	1	0	0	0	0
8	1	1	0	0	0	0	0
9	0	0	1	0	0	0	0

MI-ADAPT: Procedure for Adaptive Student Assessment

1. Select and administer the item that has the largest mutual information with *group*.
2. Select the most probable type in *group* as the student's type, based on the posterior probability distribution over *group*, updated for the results of administering the selected items.
3. Stop the classification task, if every item has been administered; otherwise continue.
4. Compute the mutual information between each available item and *group*, given the results of administering previous items.
5. Select and administer the item that has the largest condition mutual information with *group*, and return to step 2.

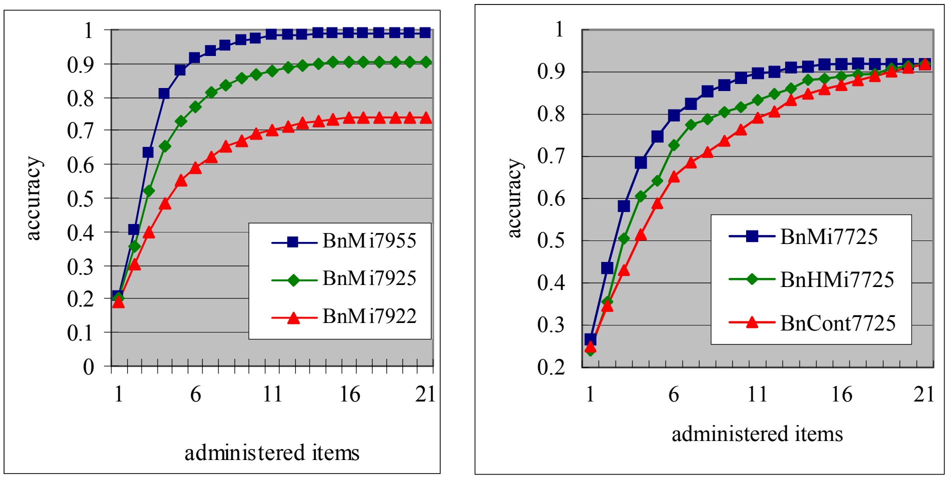
We employ simulated students for evaluating the effectiveness of MI-ADAPT, similarly to previous work (e.g., Millán & Pérez-de-la-Cruz, 2002; VanLehn, Ohlsson, & Nason, 1994). It is clearly not necessary to exhaust all test items in the item pool in assessing a student at step 3. In a practical system, we can and should stop the assessment when a high confidence on the student's truth type is reached. Liu exhausts all test items here just for observing the complete performance profile in his small-scaled experiments. For convenience, we follow VanLehn et al. (1994) and call the simulated students *simulee* henceforth.

In this simulation-based study, we assume the availability of the Bayesian network for modeling the problem domain, and consider chances of students' making lucky guesses and slips when assigning conditional probability tables for the given network. Employing a random number generator, we utilize this Bayesian network to create simulees. In each different experiment, 20,000 simulees were created. Half of the simulees were used to train another Bayesian network that eventually was used to classify the remaining half of the simulees. The structure of the learned Bayesian network was the same as the network that was used to create simulees, but the conditional probability tables were obtained from the training data with Lauritzen's algorithm (1995) that was implemented in Hugin (www.hugin.dk).

Chart (a) in Figure 6 shows the experimental results when we used the network shown in Figure 2 in the simulation. Keys for the curves indicate the setups of the experiments. **Bn** indicates that we applied the Bayesian network to compute probability distribution of the *group* node for student classification. **Mi** indicates that we relied on mutual information for item selection. "**79**" indicates that we have seven concepts and nine different types of students, as shown in Figure 2 and Table 1, respectively. If the second to the left-most digit is **2**, there were at most 20% of the chances of making lucky guesses and slips. If the second to the left-most digit is **5**, there were at most 5% of the chances of making lucky guesses and slips. The left-most digit indicates the chances of students deviating from the stereotypical behavior of a particular student type, and was used to reflect the fuzziness in simulee creation. This left-most digit can be either "2" or "5," implying, respectively, 0.2 and 0.05 in probability of deviation. The horizontal axis shows the number of administered test items, and the vertical axis shows the percentage of correctly classified simulees among the 10,000 test cases. It is easy to see that it became harder and harder to correctly classify simulees when the students' behavior became more and more uncertain, that is, by our increasing the bounds of making slips and luck guesses.

Although using exact mutual information gives us a good guidance for selecting test items, we recall that exactly evaluating Bayesian networks is NP hard. As a consequence, we may have to wait a long time to compute the mutual information between each test item with the *group* node for a realistic large item pool. This may not be satisfactory when responsiveness and computational

Figure 6. Experimental results of using mutual information for student classification



(a) *(b)*

efficiency of ITSs become major concerns. Applying Theorem 1 and Corollary 1 listed below, we can design a heuristic for comparing dichotomous items without requiring the computation of exact mutual information. Let *C* denote a concept and *X* be a test item. The test item that has a larger $\Pr(x \mid c) - \Pr(x \mid \bar{c})$ may have larger mutual information with the concept *C*, therefore might shed more light on the classes of the simulees.

Theorem 1. (Liu, 2005) For a fixed $\Pr(c)$ when $\Pr(x \mid c) \geq \Pr(x \mid \bar{c})$, $MI(X;C)$ is a monotonically increasing function of $\Pr(x \mid c)$ for a fixed $\Pr(x \mid \bar{c})$, and a monotonically decreasing function of $\Pr(x \mid \bar{c})$ for a fixed $\Pr(x \mid c)$.

Corollary 1. (Liu, 2005) Let *C* be the parent concept of items *X* and *Y*. We have if $MI(X;C) \geq MI(Y;C)$ if $\Pr(x \mid c) \geq \Pr(y \mid c) \geq \Pr(y \mid \bar{c}) \geq \Pr(x \mid \bar{c})$.

Again, we employed a simulation-based approach to evaluate the effectiveness of different item selection strategies, and chart (b) in Figure 6 shows the results.

In all three experiments, we used the probability distribution of the *group* node to guess simulees' types. There were seven student types after we removed the eighth and ninth types from Table 1 for the experiments, there were at most 0.2 in chances of making lucky guesses and slips, and there were at most 0.05 in chances of simulees' deviating from the stereotypical behavior of the simulees' types. The middle part of the keys for the curves indicates how test items were selected. **Mi** means that we chose test items with exact mutual information, **HMi** means that we chose test items with the heuristic that is designed based on Theorem 1 and Corollary 1, and **Cont** means that we chose test items purely based on content balancing. Note that we did not have experts to manually provide the relative importance of the concepts when attempting to meet the demands of content balancing as Guzmán and Conejo (2004) did. Instead, we randomly chose an item for a concept, and checked that the number of tested items was balanced as much as possible among the seven concepts. The curves in chart (b) are quite encouraging. Clearly HMi does not perform as well as Mi, but it already provided quite a good performance profile.

The charts in Figure 6 and other charts reported in Liu (2005) indicate that a good strategy for choosing test items will help us to identify types of students earlier. Hence the results of this study (Liu, 2005) and Tsiriga and Virvou (2004) are useful for detecting examinees' initial level in computerized adaptive testing.

A Comparison with Item Response Theory

Item response theory (IRT, cf. van der Linden & Hambleton, 1997) is such a dominant theory for educational assessment that we have to compare the model shown in Figure 2 with IRT models in more detail. There are three IRT models, each including a different number of factors in the model. The three-parameter model considers item discrimination a_i item difficulty b_i and the guess parameter c_i. The model prescribes that a simulee with competence θ will respond to item *I* correctly with the probability provided in (1), where k_i is a constant for normalization.

(1) $$\Pr(i \mid \theta) = c_i + \frac{1 - c_i}{1 + e^{k_i a_i (\theta - b_i)}}$$

For grading simulees, it is common to assume that the probabilities of correct responses to different items are independent given θ. Assume that $\Im = \{i_1, i_2, ..., i_t\}$ is the set of items administered in the test. We estimate the competence Θ of the simulee using the following formula:

$$\textbf{(2)} \qquad \Theta = \arg\max_{\theta} \Pr(\theta \mid \Im) = \arg\max_{\theta} \Pr(\Im \mid \theta)\Pr(\theta) = \arg\max_{\theta} \prod_{i_j \in \Im} \Pr(i_j \mid \theta)\Pr(\theta)$$

It should be clear that formula (2) is a realization of the naive Bayes (NB) models. Although formula (1) is significantly more complex than typical formula used in NB models, there is no essential difference between NB models and IRT models when we use (2) for grading simulees.

From this perspective, we can easily see that the model shown in Figure 2 is more expressive than the IRT models. Given that we know a simulee's type, say *g*, the probability values of correctly responding to different items, for example, *I* and *J*, remain dependent. More specifically, unlike IRT models, the assumption for the equality in (3) is not required in Liu's models. Moreover, the equality will hold only if the parent concepts of the test items are independent given the testee's identity, which generally does not hold in Liu's simulations and in reality.

$$\textbf{(3)} \qquad \Pr(i, j \mid g) ?= \Pr(i \mid g)\Pr(j \mid g)$$

Hence, there are three major differences between Liu's and the IRT models. First, students are classified into types not competence levels in our work, although we may design a conversion mechanism between these two criteria. Second, the responses to different test items may remain dependent given the identity of the simulee in Liu's models. Third, because Liu assumes that all random variables are dichotomous, Liu's simulations use only two parameters for each item, which is not as expressive as the three-parameter IRT models. The role of c_i is undertaken by the parameter for controlling the bound of making lucky guesses, and the roles of a_i and b_i are undertaken by the parameter for controlling the bound of making slips. It should be clear that the MI-ADAPT procedure allows more complex models than the dichotomous ones. Allowing the variables that represent the mastery statuses of concepts to take more than two possible values, we will acquire more expressive power to catch the concepts of discrimination and difficulty of test items, thereby allowing the models to compete even with polytomous IRT models. Paying for the gains in expressiveness, it would become harder to compare test items purely based on their parameters.

More Graphical Models

Besides Bayesian networks, there are other formalisms of graphical models that are useful for student and instructor modeling. We briefly go over dynamic Bayesian networks (cf. Russell & Norvig, 2003), influence diagrams (cf. Jensen, 2001), and qualitative probabilistic networks (Wellman, 1990) in this section.

The network shown in Figure 2 models students' status at a particular moment. Networks of this kind may not meet needs of all kinds. Assume the following situations: (1) we administered item *iA1* at time *T*, and a student responded incorrectly, (2) we administered item *iA1* again at time *T+1*, and the student responded correctly, and (3) we administered item *iA1* again at time *T+2*, and the student responded incorrectly. If we infer the student's competence only based on his/her latest performance, we do not really have to care about the whole history. If not, we may have to employ Bayesian networks in a more complex way (cf. Mislevy & Gitomer, 1996).

Figure 7 shows a segment of a dynamic Bayesian network (cf. Russell & Norvig, 2003). We duplicate the same network structure for each stage in the network. A node that appears in each stage represents the status of a random variable at that stage. It is not necessary to interpret the stages as different time frames, and we can duplicate each frame after each tutorial action (e.g., Murray & VanLehn, 2000; Reye, 2004). Using this approach, we will need different nodes for *iA1* for different time stages for coping with the aforementioned example.

Figure 7. A (partial) dynamic Bayesian network

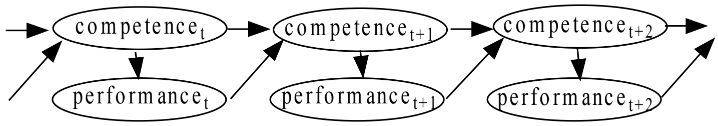
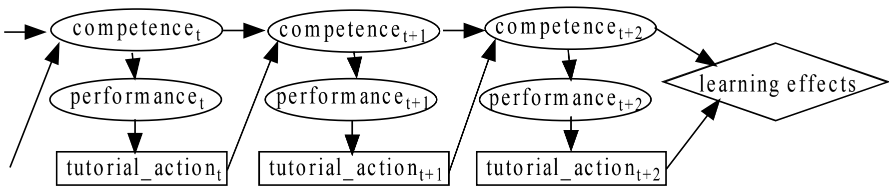


Figure 8. A (partial) multiple-stage influence diagram

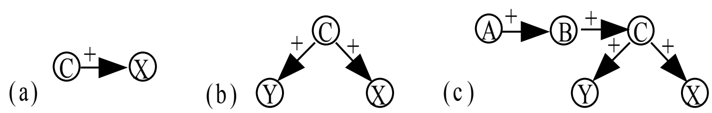


While dynamic Bayesian networks extend the applications of Bayesian networks into temporal reasoning, influence diagrams introduce decision nodes and value nodes so that we can plan tutorial actions for maximizing learning effects. The influence diagram shown in Figure 8 illustrates the basic idea. The diagram models choices of tutorial actions at different time stages by square nodes, and the eventual achieved affects in learning by the diamond node. Murray and VanLehn (2000) employ influence diagrams for determining optimal tutorial actions.

As we employ gradually more complex graphical models for modeling students' internal states and instructors' actions, the computational models capture the real world more faithfully. However, computational costs progressively become a concern as well. This is probably why Millán and Pérez-de-la-Cruz (2002) explicitly employ dynamic Bayesian networks, and later adopt roll-up techniques (Russell & Norvig, 2003, in Millán et al., 2003).

In some particular application domains, we may use a more compact formalism to capture the probabilistic relationships among random variables, and infer qualitative relationships more efficiently. Take a look at the structures shown in Figure 1 again. In practice, we have no reason to assume that the probability of correctly responding to *X* would decrease when a particular student gets a hand on *C*. Therefore, in Figure 1(a), we also have $\Pr(x \mid c) \geq \Pr(x \mid \bar{c})$, and we show this positive influence of *C* on *X* by marking the link between them with the "+" symbol, following the tradition of Qualitative Probabilistic Networks (QPNs) (Wellman, 1990). In a fully fledged QPN, random variables may also have relationships of negatively influence (denoted by "-") and ambiguity (denoted by "?"). One marks the relationship between a concept and an item by "-", when understanding the concept hinders a student from answering the item correctly. This may happen when students learn a new concept that is similar to *C* in nature but might mislead students to respond to *X* incorrectly.

Figure 9. Corresponding qualitative probabilistic networks of the networks shown in Figure 1



Assume that *C* has positive influences on *X* and *Y*, and that *A* and *B* have positive influences on *B* and *C*, respectively. We can enhance the networks in Figure 1 with qualitative signs, as shown in Figure 9.

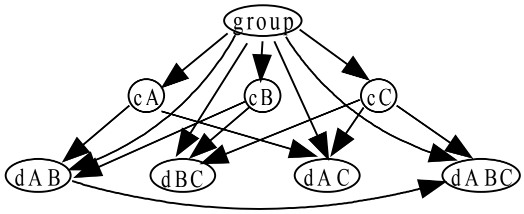
Wellman (1990) and Druzdzel and Henrion (1993) have proposed inference algorithms for QPNs. Given a network such as the one shown in Figure 9(c), we can infer that the competence in *A* positively influences the competence in *C*. We can also infer that the competence in *B* positively influences the values of *X* and *Y*, indicating that competence in *B* increases the probability of responding to *X* and *Y* correctly. Conversely, the chance that a student is competent in *B* is qualitatively increased when s/he respond to *X* or *Y* correctly.

Conclusion

In order to assist students toward efficient and interesting learning, ITSs must find ways to infer internal aspects of students from their external behavior. Whether we infer about students' competence in concepts based on their responses to test items or we infer about students' learning plans based on their explorative actions in an open environment, the problem is about conducting inference under uncertainty. To meet this technical challenge, this chapter provides background information for probabilistic reasoning using Bayesian networks and their extensions.

The applications of Bayesian networks in ITSs have widened in recent years. Breese and Ball (1998) apply dynamic Bayesian networks for modeling the emotion and personality of agents, and Conati (2002) applies Bayesian networks for assessing and monitoring the user's emotion in educational games. Readers who are interested in the effectiveness in modeling real students with Bayesian networks should refer to their work. Wang and Liu (2004) attempt

Figure 10. Mapping learning processes: An alternative for the network shown in Figure 1



to map students' learning processes of composite concepts. Based on students' responses to test items, they apply techniques of learning Bayesian networks for judging the relative genuineness of the networks shown in Figures 2 and 10. (Figure 10 does not include nodes for test items for simplicity of the network structure.) These networks differ in the parent nodes of *dABC*, which indicate different ways of learning the composite concept *dABC* from relatively more basic concepts. Zapata-Rivera and Greer (2004) propose a negotiated assessment process based on inspectable Bayesian student models. With this trend, we may see growing contributions of Bayesian networks to actively assist human users (Kautz, Etzioni, Fox, & Weld, 2003) and even to the theoretical aspect of cognitive systems (Hoffman & Woods, 2005).

Toward this end, one might become interested in a philosophic question. Anderson et al. (1990) have mentioned that one of the main purposes of developing intelligent tutoring systems is to offer human users a relatively economical substitute to human tutors, while examining the validity of cognitive theories. From this viewpoint, it may be interesting to ask whether human tutors employ Bayesian reasoning in their diagnoses of human students. That is, are people Bayesian (El-Gamal & Grether, 1995)?

Acknowledgments

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Section V

A Real-World Case Study

Chapter XIV

The Effect of Technology on Student Science Achievement

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Abstract

Empirical data from a California secondary school was analyzed to determine the direct and indirect effects of technology on student science achievement. Prior research indicates that technology has had minimal effect on raising student achievement. Little empirical evidence exists examining the effects of technology as a tool to improve student achievement by developing higher-order thinking skills. Furthermore, previous studies also have not focused on the manner in which the technology is being used in the classroom to enhance teaching and learning. As a result, the variables analyzed in this study include student computer use, teacher use of computers for instruction, student attendance, *teacher preparation, demographic factors, and final science course grades. The method of quantitative analysis includes a path analysis using final course grades as the ultimate endogenous variable. Key findings include evidence that while technology training for teachers increased their use of the computer for instruction, a student's final science course grade did not improve.*

Introduction

Those inside and outside of education have debated technology use and its effect on student achievement over recent years. With the advent of such federal mandates as the No Child Left Behind Act of 2001, school accountability for meeting state and national standards has become a major concern for not only local school officials but also their state counterparts. As school funding becomes more closely linked to performance on standardized tests, improving student achievement through innovative means, such as technology integration and use, is critical.

In the pages that follow, the steps for an empirical study of the effects of technology on student science achievement are presented. The indirect factors—student access after school, teacher technology preparation and experience, and type of science course (physical vs. life)—may provide more interesting results than the direct effects (teacher use and availability). According to Skinner (2002), "purchasing computers and improving Internet connections are just part of what it takes to make technology an integral part of teaching and learning. Preparing teachers to use and integrate technology into their work in meaningful ways remains a challenge" (p. 53). Means, Wagner, Haertel, and Javitz concur, explaining, "Existing survey data provide a portrait of the distribution of technology resources in U.S. schools and, to a lesser extent, the distribution of different general categories of technology use (e.g., drill and practice on basic skills, games, CDROM reference materials, Internet search). What the data cannot tell us is whether involvement with one or multiple kinds of technology is having a long-term impact on the students who use them" (Means, Wagner, Haertel, & Javitz, 2000, p. 2). The analysis of the data collected will provide more insight into this area.

Objectives

Previous research focused on the initial phase of technology implementation, that is, increasing access and initial professional development, which centered on computer basics. What is now needed is an in-depth look into the effects technology has on student science achievement at a representative school via a quantitative study that focuses on how students and teachers use computers in the teaching and learning process. This analysis will add much-needed information to the knowledge base regarding technology and student achievement.

Background

In December 2000, a national technology plan, *eLearning: Putting a World-Class Education at the Finger Tips of All Children* (U.S. Department of Education, 2000), was released which outlined five goals to improve how technology is used in both elementary and secondary education. With the approval of this plan, a race to connect every classroom to the Internet was underway. According to Cuban, "techno-promoters across the board assumed that increased availability in the classroom would lead to increased use. Increased use, they further assumed, would then lead to efficient teaching and better learning, which in turn, would yield able graduates who can compete in the workplace" (Cuban, 2001, p. 18). Unfortunately, results from the National Center for Education Statistics (NCES) National Assessment for Educational Progress (NAEP) 2000 Results in Science and Mathematics (National Center for Education Statistics, 2002) showed no significant change in student achievement from 1996 despite an increase in computers in the classroom.

The question becomes, "Why is increased access to technology not creating a rise in student achievement?" The answer to this question is not simple and must focus on how computers are used for instruction as well as explore the indirect effects technology has on students and their perceptions of school.

Technology and Student Achievement

Simply because the hardware and software are in place in a classroom does not imply that it is either being used or being used effectively. Hedges, Konstantopoulos, and Thoreson (2000) found that even though teachers have had increasing access to computers for instruction, very few actually use them. Although 84% of all public school teachers said personal computers were available to them, approximately 60% indicated that they used them (U.S. Bureau of the Census, 1998). Analysis of teacher data from the National Education Longitudinal Study (NELS) showed that about half of eighth grade math teachers have students who spend less than 10% of class time working on computers (Hedges et al., 2000), while across subject matter, teachers average only about 4% of all instructional time with computers (Cuban, 1993). A survey of middle school math and science teachers in South Carolina (Dickey & Kherlopian, 1987) also showed that although 70% of these teachers had access to computers, almost half of those with access did not use them. Thus, even though computer technology may be widely available, in general, it is poorly integrated into the classroom curriculum and is underused (Hedges et al., 2000).

An additional concern deals with the accountability states place on technology use and integration in the curriculum. Research has shown that the effectiveness of technology in improving student achievement depends on a match between the goals of instruction, the characteristics of the learners, the design of the software, the technology, and the implementation decisions made by teachers (Padilla & Zalles, 2001, p. 14). Schacter agrees, stating, "Learning technology is less effective or ineffective when the learning objectives are unclear and the focus of the technology use is diffuse" (Schacter, 1999, p. 10). Furthermore, in addition to consistency between what is taught and the goals of the technology, alignment must also occur between what is taught and the tests used to assess and monitor student achievement. If the technology supports higher-order thinking skills and the assessment system evaluates only basic skills, the benefits of the technology may not be evident (Padilla & Zalles, 2001, p. 15). According to Park and Staresina, "All but six states include technology in state academic standards, and of those six states, Georgia is currently drafting technology standards, and Mississippi plans to have standards in place next school year. But only three states—New York, North Carolina, and Utah—actually test student knowledge of technology to see if the instruction is having an impact" (Park & Staresina, 2004, p. 67).

Another concern for educators is the manner in which computers are used in the classroom and the effect it is having on student achievement. The CEO Forum Year 4 Report (CEO Forum, 2001) found that while students frequently use computers at school for research (96%) or to write papers (91%), their actual use for learning new concepts or practicing new skills learned in class was significantly lower (60% and 57%, respectively). Results from the 2003 National Assessment of Education Progress (NAEP) background questions found that "an overwhelming majority of students had teachers who were using computers for basic drill and practice or for math games. Very few were using computers for higher-order-thinking tasks such as simulations" (Park & Staresina, 2004, p. 67).

The effect this use or misuse has on achievement is contradictory. A review of studies by the CEO Forum found that "technology can have the greatest impact when integrated into the curriculum to achieve clear, measurable educational objectives" (CEO Forum, 2001, p. 2). Middleton and Murray (1999) conducted a study on the impact of technology on student reading and mathematics achievement of fourth and fifth graders. Their study found that the level of technology used by the classroom teacher affected student achievement. Analysis of data from the NAEP's 2000 Science Assessment on types of computer use by students revealed that students whose teachers used computers for learning games (grade 4); simulations and models for data analysis (grade 8); and data download, collection, and analysis, use of probes, or exchanging information via the Internet (grade 12) scored higher on the Science Assessment than those whose teachers did not use the computer (National Center for Education Statistics, 2002).

In his report on the effects of technology on student mathematics achievement, Harold Wenglinsky (1998) found that unfortunately, for all of the investment in educational technology, there is a surprising lack of hard data on its effects. Wenglinsky found the types of use to which computers are put varies greatly between fourth and eighth grade. Among fourth graders, 54.5% have teachers reporting learning games as the primary use; 35.9% report drill and practice; 7.5% report simulations and applications; and 2.1% report introducing new topics. Thus, the activity traditionally thought of as teaching higher-order skills, applying concepts or developing simulations to illustrate them, is rarely used. Based on his analysis of the 1996 NAEP Mathematics Assessment, Wenglinsky found that at in all grade-level studies (Grades 4, 8, and 12) teachers who are knowledgeable in the use of computers are more likely to use them for higher-order purposes. When computers are used to perform certain tasks, namely applying higher-order concepts, and when teachers are proficient enough in computer use to direct students toward productive uses more generally, computers do seem to be associated with significant gains in mathematics understanding and skills (Wenglinsky, 1998).

The following section will take an in-depth look, through empirical analysis, at the manner in which the members of the science department at one school attempt to implement technology into their classroom and the effect this implementation had on student achievement. Through this analysis, the ability to evaluate the effectiveness of technology in raising student achievement will be discussed.

Methodology

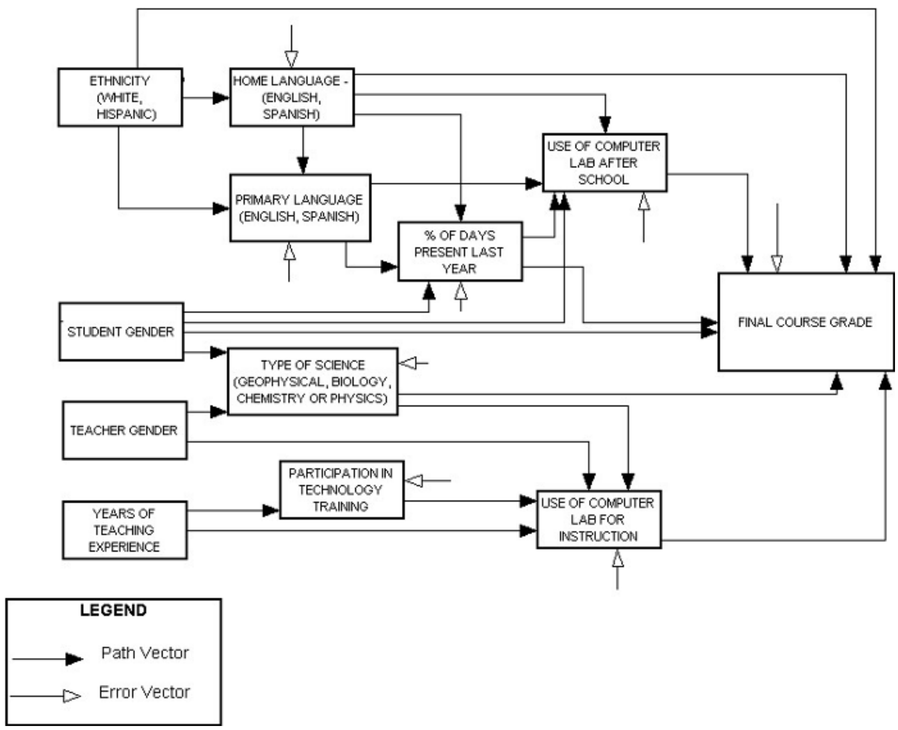
Student Population Data

The data set consists of the 2002 final course grades, student and teacher computer use, and demographic information from students in Grades 9–11 at a high-poverty, comprehensive high school in Western Riverside County, California. The school's enrollment, during the 2001–2002 school year, was 2,752 of which 400 were 12th graders. The final sample size was 1,194 after removing those students not taking science or enrolled in science outside the Science Department (Special Education, Opportunity School, Home Study). The school district supplied information on ethnicity, home/primary language, student gender, 2001–2002 student attendance, final course grade, and the name of their science teacher. Information regarding teaching experience, teacher participation in technology training, and teacher gender was obtained from the Assistant Principal for Curriculum and Instruction. Information regarding student and teacher computer use was determined via computer lab sign-in sheets.

Analysis Methods

This study utilized path analysis to investigate the direct and indirect effects of technology as it relates to Student Science Achievement. Descriptive statistics

Figure 1. Proposed path model of student achievement predictors



for key variables, results from the multiple regressions, calculations involving error vectors, and decomposition tables for bivariate covariation are presented. The proposed path is presented in Figure 1.

Research Questions

This study investigated the direct and indirect effects of technology as they relate to a student's final grade in his/her respective science course. The specific variables studied were categorized as demographics, teacher preparation/experience, teacher instructional practices, and student factors. The ultimate endogenous variable studied was the student's final course grade. The issues about the relationships of these factors can be expressed in empirically testable terms by the following questions:

1. Does technology significantly affect a student's final grade in science?
2. Are the indirect effects of technology significant predictors of a student's final grade in science?

Results

Descriptive Statistics

Descriptive statistics for the variables are given in Table 1. Based on these descriptive statistics, approximately 51% of the students were enrolled in a Geophysical Science course (Sheltered, Regular, or Honors), 28% of the students were enrolled in a Biology course (Regular, Honors, or Sheltered), and 20% of the students were enrolled in either a Chemistry or Physics course (Regular, Honors, or Advanced Placement). Almost two-thirds of the students spoke English at home and as their primary language as designated by the Home Language Survey given to all students when they first enroll in the district. Almost 60% of the students were of Hispanic ethnicity while approximately 40% were of White ethnicity. Student gender was almost evenly distributed between males (47.5%) and females (52.5%). Students demonstrated a 95% attendance rate. The mean final course grade was slightly above a "C". The teachers at the high school averaged almost 10 years of experience, were mostly male (70%), and used the computer lab for instruction approximately 5% of the available time. Of the 11 science department members, 5 (45%) participated in the school sponsored technology training.

Pearson product moment correlations of the key variables are given in Table 2. There are significant positive correlations, identified in bold print, between type of science course taught, either chemistry or physics (C/P C), and years of teaching experience (YTE) (0.429) as well as between teacher use of computer lab for instruction (TUL) and type of science course (BC) (0.415). Significant negative correlations, also identified in bold print, exist between teacher gender (TG) and years teaching experience ("0.356) indicating that males in the department have more years of teaching experience. Other interesting correlations exist between type of science course and final course grade (FCG) (0.259), teacher gender and teacher use of the computer lab for instruction (0.274), and % days present (DP) and final course grade (0.225).

Table 1. Descriptive statistics (N = 1,194)

Variable	% Yes	% No
Geophysical Course	51.0	49.00
Biology Course	28.9	71.10
Chemistry or Physics Course	20.1	79.90
English Home Language	66.2	33.80
English Primary Language	67.2	32.80
Hispanic Ethnicity	57.3	42.70
White Ethnicity	38.5	61.50
Teacher Participation in Technology Training	45.3	54.70
	% Female	% Male
Student Gender	52.5	47.50
Teacher Gender	29.5	70.50

Actual Years of Teaching Experience	Percent
1	10.6
2	12.2
4	9.8
5	6.9
8	9.6
11	23.3
15	13.7
20	3.6
25	10.3
% Teacher Uses Computer Lab	**Percent**
0	13.7
1.7	11.7
3.6	10.6
4.2	9.8
5	6.9
5.9	14.7
6.7	10.3
8.3	1.2
9.2	11.6
10.9	9.6

Table 1. Cont.

Final Course Grade	Percent
A	18.3
B	27.1
C	25.7
D	17.4
F	10.2
Missing Data	1.2
% Days Student Present	**Percent**
100%	5.1
95–99	43.2
90–94	18.7
85–89	6.1
80–84	2.0
75–79	0.8
70–74	0.4
65–69	0.0
60–64	0.1
55–59	0.1
Less than 54%	0.0
Missing Data	24.2

This illustrates the following:

1. The final grade in Biology was lower than in Chemistry/Physics.
2. Female teachers used the lab more often than male teachers.
3. Students with a higher attendance percentage had higher final course grades in their respective science classes.

Correlations (also highlighted in bold) between Ethnicity and Primary/Home Language provide expected results.

Multivariate Path Analysis

After performing the necessary stepwise multiple regressions and bivariate correlations, the estimated model indicates technology has significant direct

Table 2. Pearson correlation matrices for key variables (N = 1,194)

	TPT	YTE	TUL	BC	C/P C	% DP
TPT	1.000	0.291	0.073	–0.142	0.060	–0.004
YTE	0.291	1.000	–0.012	–0.013	**0.429**	0.043
TUL	0.073	–0.012	1.000	**0.415**	0.184	–0.003
BC	–0.142	–0.013	**0.415**	1.000	–0.320	0.015
C/P C	0.060	**0.429**	0.184	–0.320	1.000	0.048
% DP	–0.004	0.043	–0.003	0.015	0.048	1.000
SG	0.050	0.049	0.018	–0.093	0.100	–0.089
HE	0.014	–0.114	–0.059	0.035	–0.065	0.010
WE	–0.008	0.073	0.059	–0.011	0.019	–0.020
EHL	0.016	0.131	0.087	–0.014	0.040	–0.086
EPL	0.009	0.117	0.055	–0.062	0.057	–0.088
TG	–0.124	**–0.356**	**0.274**	0.297	–0.191	–0.085
FCG	0.043	0.156	–0.018	–0.058	**0.259**	**0.225**

	SG	HE	WE	EHL	EPL	TG	FCG
TPT	0.050	0.014	–0.008	0.016	0.009	–0.124	0.043
YTE	0.049	–0.114	0.073	0.131	0.117	**–0.356**	0.156
TUL	0.018	–0.059	0.059	0.087	0.055	**0.274**	–0.018
BC	–0.093	0.035	–0.011	–0.014	–0.062	0.297	–0.058
C/P C	0.100	–0.065	0.019	0.040	0.057	–0.191	**0.259**
% DP	–0.089	0.010	–0.020	–0.086	–0.088	–0.085	**0.225**
SG	1.000	0.050	?0.064	–0.033	–0.033	–0.014	0.097
HE	0.050	1.000	?**0.917**	**–0.566**	**–0.546**	0.120	–0.171
WE	–0.064	–0.917	1.000	0.565	0.553	–0.123	0.151
EHL	–0.033	**–0.566**	**0.565**	1.000	0.825	–0.176	0.089
EPL	–0.033	**–0.546**	**0.553**	**0.825**	1.000	–0.178	0.128
TG	–0.014	0.120	–0.123	–0.176	–0.178	1.000	–0.240
FCG	0.097	–0.171	0.151	0.089	0.128	–0.240	1.000

Legend for Table: TPT = Teacher Participation in Technology Training; % DP = % Days Present; YTE = Years of Teaching Experience; SG = Student Gender; TUL = Teacher Uses Computer Lab for Instruction; TG = Teacher Gender; BC = Biology Course; HE = Hispanic Ethnicity; C/P C = Chemistry/Physics Course; WE = White Ethnicity; FCG = Final Course Grade; EHL = English Home Language; EPL = English Primary Language and indirect effects on student achievement. The analysis of the data revealed that the significant exogenous variables were the ethnicity variable of Hispanic and Student Gender. With the exception of Home Language Spanish, Primary Language Spanish, Student Use of the Computer Lab After School, and Type of Science–Geophysical, all of the proposed endogenous variables remained in the model to predict student science achievement as measured by final course grade. Home Language English, Primary Language English, Teacher Participation in Technology Training, Teacher Gender, and Years Teacher Experience, however, were not direct predictors of the ultimate endogenous variable. Table 3 illustrates significant predictors of final course grade. Tables 4–7 illustrate the significant predictors of the other exogenous variables, which remained in the regression equation.

The calculations of the error vectors as well as the decomposition table for bivariate covariation are given below in Tables 8 and 9, respectively. The path coefficients and error vectors for the estimated model are given in Figure 2.

The results of the estimated model indicate that the variables are moderate to good predictors of student science achievement as measured by final course grade. Two of the seven error vectors (Final Course Grade and Type of Science – Biology) were between 0.85 and 0.95, indicating a moderate causal relationship. The error vectors for the endogenous variables of Primary

Table 3. Prediction of final course grades for students in grades 9–11

Independent Variables	Beta	t	Sig t
Type of Science – Chemistry/Physics	0.284	9.312	<.001
% Days Present	0.196	7.728	<.001
Ethnicity – Hispanic	–0.169	–6.267	<.001
Teacher Uses Computer Lab for Instruction	–0.121	–3.824	<.001
Student Gender	0.103	3.787	<.001
Type of Science – Biology	0.097	2.931	0.003
R = .384			
R^2 = .147			
Adj. R^2 = .143			
F = 34.115			
Sig F < .001			
N = 1194			

Table 4. Prediction of Biology Course for students in grades 9–11

Independent Variables	Beta	t	Sig t
Teacher Gender	0.296	10.734	<.001
Student Gender	–0.089	–3.228	0.001
R = .310			
R^2 = .096			
Adj. R^2 = .095			
F = 63.328			
Sig F < .001			
N = 1194			

Table 5. Prediction of Chemistry/Physics Course for students in grades 9–11

Independent Variables	Beta	t	Sig t
Teacher Gender	–.190	–6.713	<.001
Student Gender	0.098	3.449	0.001
R = .215			
R^2 = .046			
Adj. R^2 = .045			
F = 28.815			
Sig F < .001			
N = 1194			

Language – English (0.556) and Teacher Use of the Computer Lab for Instruction (0.796) indicate a good relationship. The error vector values signify moderate to low residuals for these variables and also correspond to the moderate to good R^2 values (>.10) indicating that these variables account for as much as 69.1% of the dependent variable. The R^2 value of 0.143 (Final Course Grade) indicates a moderate relationship, accounting for 14.3% of the dependent variable. The other R^2 values of .367 (Teacher Use of the Computer Lab for Instruction) and .691 (Primary Language – English) indicate moderate to strong relationships accounting for 36.7% and 69.1%, respectively, of the dependent variable.

Table 6. Prediction of Teacher Use of Computer Lab for Instruction for students in grades 9–11

Independent Variables	Beta	t	Sig t
Type of Science – Biology	0.544	20.641	<.001
Type of Science – Chemistry/Physics	0.465	16.880	<.001
Teacher Years of Experience	–0.209	–7.210	<.001
Teacher Participate in Technology Training	0.202	8.219	<.001
Teacher Gender	0.152	5.838	<.001
R = .608			
R^2 = .370			
Adj. R^2 = .367			
F = 139.468			
Sig F < .001			
N = 1194			

Table 7. Prediction of Primary Language English for students in grades 9–11

Independent Variables	Beta	t	Sig t
English Home Language	0.752	38.569	<.001
Ethnicity – White	0.128	6.581	<.001
R = .832			
R^2 = .692			
Adj. R^2 = .691			
F = 1335.218			
Sig F < .001			
N = 1194			

Analysis of the decomposition table reveals that one-third of the noncausal values (6 of 18) were more than 0.10, indicating a difference between what the model predicts and what the correlation describes. Two of the noncausal values can be considered to show a moderate relationship (between 0.06 and 0.10) while 10 noncausal values (< 0.05) showed a good relationship between the model estimation and the correlation. Thus, it appears that the expected and observed outcomes are virtually the same for about two-thirds of the relationships.

Table 8. Calculation of error vectors

Endogenous Variable	R	R^2	$e = \sqrt{1 - R^2}$
Final Course Grade	0.384	0.143	0.926
% Days Present	0.112	0.011	0.994
Primary Language – English	0.832	0.691	0.556
Type of Science – Biology	0.310	0.095	0.951
Type of Science – Chemistry/Physics	0.215	0.045	0.977
Teacher Participation in Technology Training	0.291	0.085	0.957
Teacher Use of Computer Lab for Instruction	0.608	0.367	0.796

Figure 2. Estimated path model

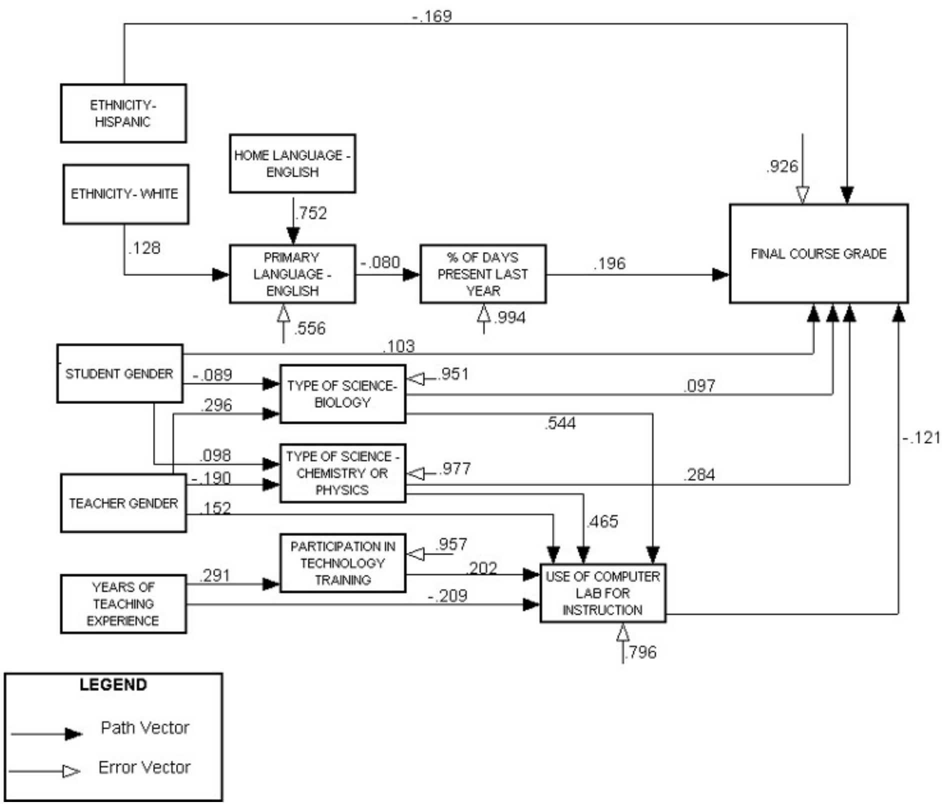


Table 9. Decomposition table

	FG/EH	FG/DP	FG/SG	FG/B	FG/CP	FG/TUL	DP/PLE	PLE/HLE	PLE/EW
Original Covariation	–0.17	0.23	0.10	–0.06	0.26	–0.02	–0.09	0.83	0.55
Direct Effects	–0.17	0.20	0.10	0.10	0.28	–0.12	–0.08	0.75	0.13
Indirect Effects	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00
Total Effects	–0.17	0.20	0.12	0.10	0.28	–0.12	–0.08	0.75	0.13
Non causal	0.00	0.03	–0.02	–0.16	–0.02	0.10	–0.01	0.08	0.42
	B/SG	**B/TG**	**CP/SG**	**CP/TG**	**TPT/YTE**	**TUL/B**	**TUL/CP**	**TUL/TPT**	**TUL/YTE**
Original Covariation	–0.09	0.30	0.10	–0.19	0.29	0.42	0.18	0.07	–0.01
Direct Effects	–0.09	0.30	0.10	–0.19	0.29	0.54	0.47	0.20	–0.21
Indirect Effects	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
Total Effects	–0.09	0.30	0.10	–0.19	0.29	0.54	0.47	0.20	–0.15
Noncausal	0.00	0.00	0.00	0.00	0.00	–0.12	–0.29	–0.13	0.14

Legend for Table: TPT = Teacher Participation in Technology Training; DP = % Days Present; YTE = Years of Teaching Experience; SG = Student Gender; TUL = Teacher Use of the Computer Lab for Instruction; EH = Ethnicity – Hispanic; B = Biology Course EW = Ethnicity – White; CP = Chemistry/Physics Course HLE = Home Language – English; FG = Final Course Grade; TG = Teacher Gender; PLE = Primary Language – English

Two of the 18 variables displayed indirect effects. These variables included Student Gender and Years of Teaching Experience. This shows that the exogenous variable of Student Gender not only affected Final Course Grade directly but also indirectly through Type of Science – Biology or Chemistry/ Physics. Interestingly, while Years of Teaching Experience did not affect Final

Course Grade directly, it did so indirectly through Teacher Use of the Computer Lab for Instruction.

Conclusion

Interpretation and Recommendations

The results of this study indicate that teacher use of technology displayed both direct and indirect effects on student achievement. These effects are detailed below.

Teacher Use of the Computer Lab for Instruction

eacher use of the computer lab (beta = “.121) was a significant predictor of final course grade. Although the negative sign indicates that students whose teachers used the computer lab had lower grades, it does not necessarily imply that teachers should forsake using the computer lab, as their students’ achievement will not improve. It does indicate that teachers using the computer lab were doing so ineffectively, that is, selecting instructional strategies that were not maximizing student achievement. Cuban’s (2001) study of technology use in six preschools, five kindergartens, two high schools, and one university in California supports this finding. Cuban found that in classrooms of teachers who considered themselves serious or occasional users of technology, most students’ use of computers was for completing assignments, playing games, conducting Internet research, or exploring CD-ROMS to gather information (p. 133). It had little to do with the primary instructional task set forth in the teacher’s instructional objectives. This finding coincides with the activities occurring in the computer lab at the study school. The Geophysical Science teachers, who taught over 50% of the students rarely, if ever, used the computer lab. The Biology teachers, who taught 28% of the students, used the computer lab primarily for Internet research on such topics as the cell, mitosis, meiosis, and ecology. The Chemistry teachers, however, utilized the computer lab to develop more advanced skills through the use of a virtual chemistry lab program, online simulations for the Gas Laws, balancing equations, and chemical bonding. The Physics teacher utilized the computer lab in order for students to understand, identify, and explain force pairs via the West Point

Bridge Builder Program and other online simulations. Unfortunately, the number of students enrolled in Chemistry or Physics comprised only 20% of the population. Thus, student activities in the computer lab did not coincide with strategies to increase higher-order or critical-thinking skills

Teacher Participation in Technology Training

A closer look at the indirect effects of technology (teacher participation in technology training) indicates that those teachers who did participate in training were more likely to use the computer lab for instruction—positive beta. While this may seem counterintuitive—teachers used the computer lab but their students' achievement did not increase—it supports the research that stresses how the computer is used for instruction is crucial for student achievement. While teachers who participate in technology training may feel more comfortable taking their students to the computer lab, it does not imply that they have mastered the use of the computer in instruction to develop critical-thinking skills. Smerdon et al. found that elementary teachers were more likely than secondary teachers to instruct students to use computers or the Internet to practice drills and to solve problems and analyze data (Smerdon et al., 2000, p. 104). Other studies found that technology can enable the development of critical-thinking skills when students use technology presentation and communication tools to present, publish, and share results (Cradler, McNabb, Freeman, & Burchett, 2002, p. 48). Christmann and Badgett (1999) studied the effects of computer-aided instruction (CAI) on student achievement in science and found that computer simulations were valuable in learning science as they allowed students to complete experiments that were either too dangerous to perform in a real laboratory or unrealistic due to the expense of the materials.

Effective Use

While the secondary school in this study addressed two important issues of technology use in education—accessibility and professional development—it did not address the issue of effective use. An interview with the Assistant Principal for Curriculum Instruction (personal communication, April 2, 2003) revealed that the type of training teachers received as part of their technology training centered on basic computer literacy skills, not on integration into instruction via simulations, software programs, data collection, and data analysis. This fact supports the finding that teachers who used the computer lab were not necessarily improving the type of instruction their students received in the content area. Instead, emphasis was placed on activities such as word-processing reports or unstructured Internet research rather than on programs that developed higher-order thinking skills or that supported classroom instructional objectives. As Wenglinsky reported, "It seems that for fourth and eighth grades, computers are used for lower-order activities (i.e., drill and practice)" (Wenglinsky, 1998, p. 22). The NCES, in its study of the 2000 NAEP Science Assessment, found that of the two-thirds of the 12th-grade sample taking a science course in their senior year, those who reported using computers to collect data, download data, or analyze data had higher scores than students who reported never doing so (National Center for Education Statistics, 2002, p. 12). Clearly, effective use is the key to increased achievement.

Relationship Between Training and Use

The indirect effect of teachers who received training using the computer lab more frequently is well documented in the literature. Andrew Trotter reports that training seems to make a positive difference to those who received it, particularly when it came to confidence levels, use of digital content, and willingness to experiment (Trotter, 1999, p. 40). Fatemi points out that "A lack of training is the most important obstacle inhibiting the use of digital content. Teachers who received technology training in the past year are more likely than teachers who had not to integrate technology into their classroom lessons and are also more likely to use and rely on digital content for instruction, spend more time trying out software and searching for Websites to use in class" (Fatemi, 1999, p. 7). Trotter also found that teachers who received training were more likely to use software to enhance instruction in their classrooms, to rely on software and the Internet in classroom instruction to a "very great" or "moderate" extent, and to spend time trying out or teaching themselves about software as well as searching the Internet for information and resources to use in the classroom (Trotter, 1999, p. 40). Thus, teachers who received training used the computer lab for instruction, although their attempts at integration did not improve achievement, due in part to insufficient training. As Wenglinsky states, "Technology does matter to academic achievement, with the important caveat that whether it matters depends on how it is used" (Wenglinsky, 1998, p. 32).

Implications and Future Trends

The study provides a piece (effective technology use) to a much larger puzzle (increasing student achievement in science). It indicates that how technology is used in the classroom is more interesting and important than how much technology is in the classroom. It provides business and educational personnel with information on how and where monies should be allocated in local, state, and federal budgets. Teacher training on effective use of technology must become a priority if this puzzle piece is to have a significant effect on student achievement. This study also provides an analysis of ways that teachers and students use technology at the beginning of the 21st century. Although further research is needed in the form of a longitudinal study using the same analysis model, this study offers one possible solution for improving the teaching and learning process and, hence, increasing student achievement.

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