Cognitive Tools, Individual Differences, and Group Processing as Mediating Factors in a Hypermedia Environment

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Abstract

Much research exists on how problem-solving in hypermedia is assisted through the use of navigational aids. However, as hypermedia becomes more pedagogically rich, the structural characteristics of hypermedia no longer serve merely as navigational aids, but often as cognitive tools. When cognitive tools are embedded in problem-solving hypermedia environments, the objective is the continuous active manipulation of cognitive tools in the problem space in order to gather information, test hypotheses, and develop a solution. The purpose of this study was to investigate cognitive tools, individual differences, and group processing as mediating factors when learners were engaged in problem-solving in a hypermedia environment. We specifically examined group patterns of cognitive tool use to determine in what ways the group patterns of tool use may affect students' individual performance and experience of the problem-solving process. The findings provided some evidence to support a more contextual approach to individual cognition and learning; and emphasized the notion that a system of instructional variables interact to create optimal conditions for learning

(Keywords: cognitive tools, individual differences, group processing, hypermedia technology, problem-solving)

Hypermedia technology has come to secure a more central role in learning after several generations of its ancestors (e.g. drill and practice computer based instruction) provided supplemental instruction (Cunningham, Duffy, & Knuth, 1993; Bangert-Drowns & Pyke, 2001). Recently research has turned its attention to how problem-solving in hypermedia is assisted through the use of such structural characteristics as navigation tools (Beasley & Waugh, 1995; Beasley & Waugh, 1997; Boechler & Dawson, 2002; Calvi, 1997; Chiu & Wang, 2000; Dabbagh, 2002; Dias & Sousa, 1997;) and interface design in general (Chen & Chai, 2002; Saxena, Kothari, Jain, & Khurana, 2002). Given recent theoretical, pedagogical, and technological advances in the area of hypermedia the question we must continue to ask regarding hypermedia design is not "Does learner attitude and performance improve?" but "Under what conditions do learners develop a stronger knowledge of content and fulfilling educational experience as they navigate a hypermedia environment?" (Hannafin & Land, 1997; Land, 2000; Park & Hannafin, 1993).

Problem-solving in general, and hypermedia problem-solving in particular, is a delicate interaction between problem variations, those representations provided within the problem space, and individual differences (Jonassen, 2000). As Jonassen states, "problem-solving requires some activity-based manipulation of the problem space....We cannot act without thinking or think without acting in some way" (p. 4). According to Dillon and Vaughn (1997), "comprehension is not something 'other than' navigation, some form of task that is independent of the process of moving through the information space" (p. 99). Theoretically, the structural and semantic properties of hypermedia are inseparable for the learner as she performs a problem-solving task in a hypermedia environment. The ways in which a learner navigates a hypermedia environment and her meaning making co-exist and co-determine each other. A student cannot navigate a hypermedia environment without learning something. However, a study by Dillon and Gabbard (1998) revealed that the learning outcomes of educational hypermedia are minimal. It appears as if comprehension is independent of navigation. Apparently students are navigating such environments quite well, and yet in the process learning little. What can hypermedia designers do to address this issue?

Cognitive Tools

As educational theory and research continues to inform hypermedia design, these learning environments are becoming more pedagogically rich. In order to combat the "navigation without comprehension" issue, a design technique is for learners to navigate hypermedia by using the tools embedded in these virtual environments. In other words, the hypertextual capabilities of hypermedia environments, although they theoretically mimic the way knowledge is structured in human memory, do not in and of themselves serve a cognitive function. Rather, as Sugrue (2000) suggests, "to qualify as a cognitive approach to instruction, strategies for supporting the cognitive processing of the information have to be embedded in either the structure of the hypertext or the activities that constrain and focus students' exploration of information" (p. 135). The role of the students is not simply to navigate through hypermedia, but rather use a range of tools to explore the environment, gather information, test hypotheses, and generate solutions. In a design scheme where the tools are the navigation, these tools are designed to support cognitive processes, and are thus cognitive tools (Jonassen & Reeves, 1996; Kozma, 1987; Lajoie, 1993; Pea, 1985; Salomon, Perkins, & Globerson, 1991). Cognitive tools are designed to engage specific cognitive processes that are more and less relevant at particular stages of problem-solving associated with a hypermedia lesson (Liu, Williams, & Pedersen, 2002; Pedersen & Liu, 2002). Increasingly, the structural characteristics of hypermedia no longer serve merely as navigation aids, but as cognitive tools.

Cognitive tools are computer-based tools that can “amplify, extend, or enhance human cognition” (Kozma, 1987). Jonassen (1996) defined cognitive tools as, "computer-based tools and learning environments that have been adapted or developed to function as intellectual partners with the learner in order to engage and facilitate critical thinking and higher-order learning" (p. 9). In discussing factors that could inhibit learning such as limited capacity of work memory, difficulty in retrieving needed information from long-term memory, and ineffective use of cognitive strategies to restructure information, Kozma (1987) suggested using computers to facilitate the learning process and assist learners in accomplishing complex cognitive tasks. He believed computers could provide such aids as making large amounts of information immediately available for use to supplement limited short-term memory, enabling learners to retrieve prior knowledge and apply it more efficiently in a new situation, and allowing learners to represent ideas in multiple forms. Lajoie (1993) identified four types of cognitive tools according to the functions they serve. These include tools that: (a) support cognitive and metacognitive processes; (b) share cognitive load by providing support for lower level cognitive skills so that resources are left for higher order thinking skills; (c) allow learners to engage in cognitive activities that would be out of their reach otherwise; and (d) allow learners to generate and test hypotheses in the context of problem-solving. In short, cognitive tools are instruments that can enhance the cognitive powers of learners during their thinking, problem-solving, and learning (Jonassen & Reeves, 1996; Pea, 1985; Salomon, Perkins, & Globerson, 1991).

In the context of using cognitive tools as a form of navigation and problem representation, the design of cognitive tools can allow the elements of a problem to productively interact, and hence facilitate learners' processing of the problem (Sweller & Chandler, 1994). This distribution of navigational and representational resources influences a student's processing of information. In examining students' tool use patterns in a hypermedia environment, Liu and Bera (2003) found some evidence to support the notion that cognitive tools in the form of navigational and representational resources can guide, constrain, and determine cognitive behavior. The issue is no longer one of enabling a learner to navigate to a particular node in order to access instructional content. Rather, with tool-rich hypermedia learning environments the objective is for learners to engage in continuous active manipulation of (cognitive) tools in the problem space in order to gather information, test hypotheses, and progressively develop a solution (Jonassen, 2000).

While much literature exists on the definitions and classifications of cognitive tools and their benefits, little empirical research is available to answer such questions as: In what way do cognitive tools scaffold learners' information processing? What are other factors that can influence learners' use of cognitive tools? Iiyoshi and Hannafin (2002) stated that "we need to better understand the use of multiple tools; we also need to learn more about how creative users actually use the tools we provide" (p. 835).

Individual Differences

As researchers are reflecting on and beginning to empirically examine how specific kinds of computer tools affect learning processes and outcomes, they consistently acknowledge that the magnitude of such processes and outcomes often relies on students' desire to exert cognitive effort (Kozma, 1987; Pea, 1985; Salomon, 1993; Salomon, Perkins, & Globerson, 1989). A central tenet of learning is that the greater the amount of mental effort exerted during knowledge acquisition, the more accessible the knowledge is over time (Salomon, 1984; Schmidt & Bjork, 1992). Hoffman and Richie (1997) found the interactive capabilities of hypermedia allowed students to access information according to their own learning needs and presented multiple related problems. A study by Oliver and Hannafin (2000) suggested that building cognitive tools into a hypermedia environment does not ensure that learners will actually use them when they are needed, and in the way they are intended to be used. In their research, they investigated middle school students' use of cognitive tools to help them collect, organize, annotate, and evaluate complex information during an authentic scientific inquiry. They proposed that using these tools to manipulate hypermedia resources in a manner consistent with higher order thinking (e.g., organize, integrate, evaluate) would help students solve complex open-ended problems. However, their results revealed that the tools mostly supported lower-level information gathering and thinking rather than higher order reasoning for which they were designed. The students failed to use the tools to the full potential and the tools were rarely used to develop evidence-based arguments to justify the new ideas. Some researchers have suggested looking at students' need for cognition (Cacioppo, Petty, & Kao, 1984) as they are engaged in hypermedia learning environments in an effort to identify cognitive requirements for effective use (MacGregor, 1999). Problem-solving ability is not solely a function of cognitive ability, affective and conative factors such as the inclination to act purposefully and persistence also play an important role (Jonassen, 2000).

Group Processing

Individual differences have been elicited as just one mediating factor among a variety of mediating factors when one takes a more contextual approach to individual cognition and learning (Pea, 1993; Salomon, 1993). Considering that hypermedia learning environments are often also a collaborative enterprise, the question arises as to the extent to which individual attitude and performance is normalized in such tool-rich and group-mediated learning environments. In an effort to identify optimal ability groupings for computer mediated collaborative learning groups, Hooper (2003) found that although students' level of persistent mental effort did not affect their achievement, it did affect their interactions with group members. Gonzalez, Burke, Santuzzi, and Bradley (2003) found that in computer mediated collaborative learning, group members' sense of efficacy impacted group cohesion, presumably because such environments are more task focused thereby reducing the functionality of interpersonal cues; they found this to be the opposite of face to face collaborative learning groups, where group cohesion impacts group members' sense of efficacy. In response to the convergence of collaborative learning and computer mediated learning, new methods of analyzing group processes in computer mediated environments are now surfacing which isolate and trace individual contributions to collective solutions (Avouris, Dimitracopoulou, & Komis, 2003). With regard to the proliferation of various converging forms of learning environments, some researchers raise the question whether ability and talent is an internal characteristic of learners or an emergent property engendered by the system of mediating factors which circumscribe the individual learners (Barab & Plucker, 2002). Viewed this way, talent is democratized and becomes an emergent property of ecological variables rather than solely an internal characteristic of individuals, as a host of mediating environmental factors interact to support individual cognition and learning.

Purpose of the Study

The purpose of this study was to investigate how such mediating factors as cognitive tools, individual differences, and group processing affect students' ability to learn in a problem-based hypermedia learning environment. Research has examined differences in individual tool use patterns and the problem-solving process (Liu & Bera, 2003). However, no research has examined group tool use patterns in relation to individual performance. Therefore, we were interested in examining group patterns of cognitive tool use to determine in what ways the group patterns of tool use may affect students' individual performance and their experience of the problem-solving process. We sought to clarify these contextual relationships by asking the following questions:

(1). When groups of students work collaboratively in a tool-rich hypermedia environment, does the functional utility of cognitive tools differ among groups? That is, can we identify different types of tool-using groups?

(2). If different types of tool-using groups exist, do differences exist between groups in terms of their performance?

(3). If different types of tool-using groups exist, do differences exist between individuals within similar tool-using groups in terms of their experience?

Method

Participants and Context

Participants were 164 sixth graders from a middle school in a mid-sized southwestern city. Most students had used computer programs such as games and word processing programs prior to the study. Two experienced science teachers, though novice computer users, taught the sixth grades science classes. They went through a two-day training workshop, during which the philosophy and different attributes of the student-centered hypermedia learning environment for use in this research were discussed in depth. The two teachers did not do any direct teaching. Instead, they walked around the room answering students' questions and led regular but short class discussions at the beginning and end of each class session.

The hypermedia environment used in the research is called Alien Rescue, a problem-based hypermedia lesson designed for sixth graders. Guided by the theories and research on problem-based learning in its design, Alien Rescue engages 6th grade students in scientific investigations aimed at finding solutions to complex and meaningful problems. The software is CD-based, and designed to be used as the science curriculum for approximately fifteen 45-minute class sessions. It begins with a video presentation of an ill-structured problem for students to solve. A group of six species of aliens, different in their characteristics, have arrived in Earth's orbit, due to the explosion of their home planets. Students work collaboratively in groups of 3-5 to find new homes for the aliens that can support their life forms or they will die. In this rescue operation, the students act as scientists to determine the most suitable relocation site for each alien species. To solve this problem, students must collaboratively engage in a variety of problem-solving activities. They need to research the aliens' needs as well as planets in our solar system to find possible homes. Groups of students must also engage in planning and decision-making as they determine how to use the resources of the solar system effectively. More information about the software can be found on its web site http://www.alienrescue.com and in an article by Liu, Williams, and Pedersen (2002).

To assist the students' learning, different cognitive tools are provided in the program that students can use to navigate the problem space and solve the problem. These tools can be classified into Lajoie's four categories (1993): (a) tools that share cognitive load, (b) tools that support cognitive processes, (c) tools that support cognitive activities that would be out of reach otherwise, and (d) tools that allow hypotheses generation and testing. Table 1 provides a description of each tool under each category. Figure 1 provides screen shots of some tools.

----------Insert Table 1 and Figure 1 here-----------

The four databases provided in Alien Rescue are examples of tools that share cognitive load. These are carefully constructed and well-organized knowledge databases enhanced through graphics, animations, and 3-D videos. If a student wants to know what a species looks like, where it lives, the atmosphere and gravity on a planet, or about past NASA missions, he or she can find such information in the alien database, solar database, and mission database. If a student comes across a scientific concept that he or she is unfamiliar with, it can be looked up in the concepts database, where various science topics are visually illustrated. Such tools help reduce the memory burden for the students and put the multimedia-enriched information at their fingertips.

The notebook tool is an example of a tool that supports cognitive processes. It allows students to take notes and organize them into different sections that can both help relieve the memory burden as well as assist students in processing the information. The probe builder and launcher rooms are two tools that support cognitive activities that would be out of reach otherwise. They allow students to equip probes with various scientific instruments, such as mass spectrometers, thermometers, and infrared cameras. Each of these instruments can provide the students valuable information about the worlds they are interested in. The launcher room allows the students to launch their probes to an intended planet or moon. Finally, the control room and solution form are examples of the tools that allow hypothesis testing. In the control room, students study the data coming back from probes to test their hypotheses and then write up their solutions using the solution form.

Using the tools in categories A and B, students locate helpful resources, search and research existing knowledge databases, select relevant information, and make effective comparisons and decisions. With the tools in categories C and D, students collect new data, interpret and organize data, build the rationales for their decisions and present their solution plans. As Lajoie (1993) pointed out these categories are not mutually exclusive. For example, the probe builder can both support cognitive activities that would be out of reach otherwise, and allow hypotheses generation. Although students have access to all the tools and information needed to develop a solution plan, the program is structured in such a way as not to suggest solutions. Students are encouraged to explore the environment and select appropriate tools as they determine for themselves the information they need and the process they will use to develop a solution plan.

Students from this study worked in groups in a computer lab equipped with Dell desktop computers with Pentium 4 processors. Each student had a computer for his or her use, with groups of students working at adjacent computers. Since all the necessary tools for students to work on the problem were embedded in the hypermedia environment, it was possible for the teachers to spend most of the class time interacting with the students individually as requested. The two teachers provided scaffolding to the students through daily questioning, answering, and discussion. Two researchers attended most class sessions and helped with technical problems.

Sources of Data

To address the three research questions, we used the log data to identify the types of tool-use groups and examined students' science knowledge test scores for these types of tool-use groups. We also used individual students' level of need for cognition and examined students' factor scores related to their experience of hypermedia problem-solving for these levels of need for cognition. The data sources are as follows.

Log data. Students' actions while using Alien Rescue were logged to a data file. The log file consisted of time and date stamped entries for each action. In this study, the log data were used to identify group tool use patterns. One hundred sixth-four students worked in groups of 3-5, and they logged on as a group. The data set consisted of the number of times a group member accessed each cognitive tool, and the amount of time the group member stayed in each tool for each day of use over a fifteen-day period. Group members collectively decided how to proceed from day to day and task to task. The log files for all group members within a particular group were combined to calculate the average number of times a group accessed each of the 11 cognitive tools, and the average amount of time a group stayed in each tool. The log files of 48 groups were included in the analyses. The log files were collected at the end of the study.

Given the nature of the central problem to solve, the primary task(s) a group might perform during the entire process consists of (a) exploring to get familiar with the environment and to define the problem, (b) conducting research and refining the problem, (c) continuing to research and generate hypotheses, (d) testing their hypotheses and conducting further research, and (e) ultimately finalizing their solution to the problem and writing up their rationale.

Need for cognition questionnaire. To assess the mental effort typically exerted by the students during their learning, the students were asked to complete a *Need for Cognition* questionnaire (Cacioppo, Petty, & Kao, 1984) prior to using Alien Rescue. For each of the eighteen statements in the questionnaire, students were asked to rate how well each statement describes what they think, on a 9-point Likert-type scale ranging from "Not at all true (1)" to "Extremely true (9)." Sample statements include “I would like difficult problems better than simple problems,” “I like to have the responsibility of handling a situation that requires a lot of thinking,” and “Thinking is not my idea of fun.”

Experience of hypermedia problem-solving questionnaires. To understand students' experience working with Alien Rescue, toward the middle of using the program, students were asked to respond to a nine-item open-ended questionnaire elaborating on their experience. Sample questions include “Describe your best experience with the Alien Rescue software. What made that experience so good?,” “Describe a hard or difficult experience with the Alien Rescue software. What made that experience so hard?,” and “Do you learn anything from the Alien Rescue software? What do you learn?” Similar responses mentioned by at least 20 students were retained for a revised nineteen-item questionnaire. At the end of using Alien Rescue, the students were asked to complete the revised nineteen-item questionnaire by rating how well each statement describes what they think, on a 5-point Likert scale ranging from "Not at all true (1)" to "Extremely true (5)." These statements include “Alien Rescue was fun because you had to figure it out yourself, the teacher didn't do it for you, “ “Sometimes I don't know what to do because there are so many things to do,” “ I like that Alien Rescue involves computers,” and “A difficult part was that you had to search through every subject (magnetic fields, craters, etc.) to find an answer.”

Science knowledge test. At the end of using Alien Rescue, each student completed a science knowledge test. Twenty-five multiple-choice questions were constructed that measured factual knowledge and applied knowledge of astronomy concepts introduced in Alien Rescue. This test reflects what the designers and subject matter experts consider as important for the students to acquire after using Alien Rescue. It has been used in other studies (Liu, 2004) and has an internal consistency reliability of .73. The twenty-five questions address factual knowledge (*n*=15) and application (*n=10).* Examples of the questions follow.

Factual: Which of these worlds is a planet (not a moon)?

a. Charon

b. Io

c. Phobos

d. Uranus

Application: You need to design a probe to go to Titan to find out if it has a magnetic field or earthquakes. Which of the following would you choose to include on your probe?

a. a battery and a solar panel

b. an infrared camera and a magnetometer

c. a barometer and a seismograph

d. a magnetometer and a seismograph

Analyses of Data

Types of tool-using groups. We examined whether particular patterns of tool use emerged between groups as shown in the log files. A group's navigation through the environment is based entirely on how the group members used the tools. The statistical procedure we used to identify tool use profiles was cluster analysis. Cluster analysis is a data reduction technique that classifies variables. It is often used when no a priori groups are known to exist. In this study cluster analysis was used to classify the total number of groups into a smaller number of navigation clusters. Literature has shown that cluster analysis is useful in identifying navigation profiles choices (Barab, Bowdish, & Lawless, 1997; Lawless & Kulikowich, 1996). The navigational choices of all 48 groups can be reduced to a few general profiles to account for the variation in frequency of navigation. We could then begin to define the clusters based upon how they used the tools.

For the cluster analysis the eleven navigational variables were the tool choices of each group. These variables comprised the dependent vector of scores in a Ward's hierarchical cluster analysis. All the variables were standardized prior to the analysis. Since the scale of measurement was identical across all variables, the method used to compute similarities in tool use was Rosenberg's profile dissimilarity distance (Davison, 1992; Rosenberg & Jones, 1972).

Differences between types of tool-using groups. We examined if there were any differences between overall tool use patterns with respect to groups' science knowledge test scores. After we performed the cluster analysis to cluster groups based on how they navigated through the environment, a one-way MANOVA was performed with cluster membership as the independent variable, and individual students' scores on the two types of science knowledge test questions (factual and applied) as the dependent variables.

Differences between individuals within tool-using groups. Given different clusters of groups emerged we examined whether there were differences within similar groups between individuals in terms of their experience of the hypermedia lesson and their need for cognition. Factor analysis was used to identify underlying dimensions explaining students' responses to the revised questionnaire in an attempt to understand students' experience of working on Alien Rescue. Students' factor scores were then used in connection with students' need for cognition to examine any differences between individuals within similar groups. Students' need for cognition scores were separated into three levels: high, average, and low, by dividing the range of scores into thirds. Then a one-way MANOVA was performed with level of need for cognition (high, average, low) as the independent variable, and students' hypermedia experience as indicated by their factor scores as the dependent variables.

When post-hoc analyses were performed to identify which dependent variable was contributing to the significant multivariate difference in the MANOVA analyses, independent t-tests were conducted on the dependent variables separately and the ∝ was adjusted to take into account of the number of analyses performed (Stevens, 1997).

Results

Types of Tool-Using Groups

Interpretation of the appropriate cluster solution should be based on parsimony (Aldenderfer & Blashfield, 1984). To determine the number of clusters to extract, we used the information presented in the agglomeration schedule to graph a scree-plot, a graph of the distance between the clusters by the number of clusters (Barab et al., 1997). Greater distances between clusters indicate dissimilar clusters are being merged. Smaller distances between clusters indicate relatively similar clusters are being merged. We inspected the scree-plot to identify the point at which the distance between subsequent numbers of clusters decreased. This "elbow" in the graph (Stevens, 1997) indicates a cluster solution where the distance within clusters is minimized and the distance between clusters is maximized, in other words maximizing the similarity of within clusters and minimizing the similarity between clusters.

We extracted three clusters using the method described above. The clusters we identified provided insight into how different types of groups used the tools available in Alien Rescue. Three types of tool-using groups emerged (see Figure 2). Cluster 1 consisted of 13 groups, cluster 2 consisted of 15 groups, and cluster 3 consisted of 20 groups. Generally, the groups in cluster 2 accessed all four categories of cognitive tools most, the groups in cluster 3 accessed all four categories of cognitive tools least, and the groups in cluster 1 accessed all four categories of cognitive tools moderately (see Table 2). There were two exceptions to this general pattern, and this was between cluster 3 and cluster 1; compared to the groups in cluster 1, the groups in cluster 3 accessed the concepts database and the notebook more often. For ease of interpretation we will henceforth refer to cluster 1 as the Average Frequency of Access, or "Average" cluster, cluster 2 as the High Frequency of Access, or "High" cluster, and cluster 3 as the Low Frequency of Access, or "Low" cluster.

----------------Insert Table 2 and Figure 2 here------------

Differences Between Types of Groups

In order to validate emergent clusters we chose students' individual performance on the science knowledge test as an external criterion. We wanted to investigate whether group tool use was in any way related to individual test scores. The data were analyzed with a one-factor (cluster membership) MANOVA. The results indicated a significant multivariate difference in the fact and application test scores based on cluster membership ($F(4,272) = 6.58$, $p < .001$). Post hoc univariate analyses showed that there was a significant difference between the Average cluster and the Low cluster ($t(103) = -3.57$, $p < .001$) and the High cluster and the Low cluster ($t(111) = -4.46$, $p < .001$) with respect to fact test questions, and between the High cluster and the Low cluster with respect to application test questions ($t(111) = -3.43$, $p < .001$). The Low cluster outperformed both the Average and High clusters on the factual knowledge test questions, and that Low cluster outperformed the High cluster on the applied knowledge test questions. No such differences existed between the Average and High clusters ($t(60) = .36$, p= .72) for the fact test questions, or between the Average and High clusters ($t(60) = 1.19$, p= .24) or between the Average and Low clusters ($t(103) = -1.85$, p= .07) for the application test questions (see Table 3).

------------------Insert Table 3 here--------------

The results on performance as indicated in the science test and the tool use for each of the clusters showed that the while the groups within the Low cluster accessed the four categories of cognitive tools the least, students within these groups scored the highest on both factual and applied knowledge test questions. On the other hand, while the groups within the High cluster accessed the four categories of cognitive tools the most, students within these groups scored the lowest on both factual and applied knowledge test questions. Given such results, we then investigated how groups within the three clusters accessed the tools. Specifically, we examined how long groups within the three clusters stayed in the cognitive tools every time they accessed them. We divided the entire use of Alien Rescue into two halves, examining the average amount of time groups within the three clusters spent accessing four categories of tools during the first half of use (approximately 7-8 days), and then during the second half of use (approximately 7-8 days). During the first half of use, there was not much difference in the average amount of time the three clusters stayed in the cognitive tools every time they accessed them. Groups in all three clusters stayed about one minute in a tool every time they accessed tools that support cognitive processing, about three minutes in a tool every time they accessed tools that support cognitive load, about 30 seconds in a tool every time they accessed tools that support activities otherwise not possible, and about 30 seconds in a tool every time they accessed tools that support hypothesis testing (see Figure 3). However, during the second half of use, there was a difference in the average amount of time the three clusters stayed in the cognitive tools every time they accessed them. The results indicated groups within the three clusters varied by about one minute every time they accessed tools in the four categories (see Figure 4). Compared to groups within the Average and High clusters, groups within the Low cluster spent less time in tools that support cognitive processing every time they accessed these tools, and spent more time in tools that support cognitive load, support activities otherwise not possible, and support hypothesis testing, every time they accessed these tools.

--------------Insert Figures 3-4 here-------------

Differences Between Individuals Within Types of Tool-Use Groups

For the factor analysis, intercorrelations among the 164 students were computed across the 19 items of the revised questionnaire. To derive the factors we applied maximum likelihood factor analysis followed by a varimax rotation. Since this was an exploratory factor analysis, and for purposes of parsimony, any item which failed to load significantly on any factor was removed. Consequently seven questionnaire items were removed. A second factor analysis was conducted on the remaining twelve questionnaire items, and intercorrelations among all the students were computed across these items. Again, we applied maximum likelihood factor analysis followed by a varimax rotation. To determine the optimal number of factors, a scree test was used (Stevens, 1997). For this sample of 164 students, a three-factor solution accounted for nearly half (48%) of the variance, a relatively high percentage. After varimax rotation the first factor accounted for 24% of the variance, the second for 14%, and the third for 10%. To examine the degree to which the varimax rotation achieved simple structure, we classified the questionnaire items into three non-overlapping groups based on their factor loadings. Items were considered clear exemplars of a factor only if they met three criteria: (a) their highest loading on one factor was greater than or equal to .40, (b) the next highest loading was at least .20 below the highest one, and (c) if the subjects' loadings did not exceed .30 on more than one factor. Questionnaire items not meeting these criteria were not included in the interpretation of factors.

We then interpreted the resulting empirical factors in terms of Yang's (2002) taxonomy of cognitive processes. In studying how hypermedia can be used as a tool to guide students' cognitive behavior, Yang (2002) studied learners' cognitive processes while solving an ill-structured problem using a hypermedia learning environment called <u>Perseus</u>. Based upon the findings, Yang created a multidimensional taxonomy to describe the specific cognitive processes that learners used. The eight categories of processes in the taxonomy are (1) executive control; (2) information-seeking; (3) interpreting; (4) intertextuality; (5) reflexivity; (6) reasoning; (7) structuring; and (8) affective responses. Each category consists of additional processes. The results showed that cognitive processes can be task specific and therefore “although there were some core functional characteristics of the cognitive process involved, the scheme is contingent upon a variety of thinking processes” (p. 62).

The attributes of the first factor in our analysis fell into Yang's (2002) *affective* category. Items in the first factor include "Alien Rescue was fun because you had to figure it out yourself, the teacher didn't do it for you," "I like that Alien Rescue involves computers," and "It is easy for me to find things on the computer because all I have to do is click on things, and it will bring things up for me to read." Yang's affective category of cognitive processes refers to students' feelings, motivations, and self-perceptions, such as: expressing emotion, appraising and evaluating the software, concentrating, positive or negative commenting, and evaluative commenting on the software. The attributes for the second factor fell into Yang's *reflexivity* category. Items in the second factor include "Alien Rescue helped me become more responsible and organized" and "I learned to slow down and take my time with computers." Yang's reflexivity category of cognitive processes refers to the process students engage in when they reflect on their problem-solving by questioning or temporarily accepting their solutions pending further problem-solving, such as: self-monitoring, maintaining awareness of needed information, withholding interpretations, altering interpretations in the face of new information, and refraining from making conclusions based on insufficient evidence. Finally, the attributes for the third factor fell into Yang's *information-seeking* category, as evidenced by the following items: "Sometimes I don't know what to do because there are so many things to do," "A difficult part was that you had to search through every subject (magnetic fields, craters, etc.) to find an answer," "Finding which aliens go where was hard because a lot of the planets didn't have what most aliens needed," and "I was good at finding out which planets the aliens could live on because it was easy to match up the information between planets and aliens" (negative factor loading). Yang's information seeking category of cognitive processes refers to the process of searching for, evaluating, gathering, and managing relevant information. In our study all the items which loaded on to our information seeking factor were phrased in a negative direction, emphasizing the difficult aspects of information seeking behavior, with the exception of one item; thus we refer to this factor as *poor* information seeking.

We then proceeded to investigate whether students' Affective, Reflexivity, and Poor Information-seeking factor scores differed as a function of their level of need for cognition. We investigated this for each of the three clusters. A one-way MANOVA was performed for each cluster with students' level of need for cognition (High, Average, Low) as the independent variable, and students' factor scores as the dependent variables (Affective, Reflexivity, Poor Information-seeking). The results showed that within the Average cluster there was a significant multivariate difference in students' factor scores based on their level of need for cognition ($F(6,60) = 2.60$, $p < .05$). Univariate results indicated that students with different levels of need for cognition differed significantly from each other only with respect to the Reflexivity factor ($F(2,32) = 7.48$, $p< .01$). Post hoc tests showed that this difference was significant between students high in need for cognition and those low in need for cognition ($t(19) = 4.125$, $p< .001$), and between students average in need for cognition and those low in need for cognition ($t(23) = -3.21$, $p< .01$) (see Figure 5). Within the High cluster, the results indicated a significant multivariate difference in students' factor scores based on their level of need for cognition ($F(6,72) = 2.45$, $p < .05$). Univariate results indicated that students with different levels of need for cognition differed significantly from each other only with respect to the Poor Information seeking factor ($F(2,38) = 6.71$, $p< .01$). Post hoc test showed that this difference was significant between students high in need for cognition and those low in need for cognition ($t(30) = -3.46$, $p< .01$) (see Figure 6). For the Low cluster, the results did not indicate a significant multivariate difference in the factor scores based on level of need for cognition ($F(6,158) = 1.12$, $p =.35$). For students in low frequency of access groups, students with different levels of need for cognition did not differ significantly from each other with respect any of the three factors (see Figure 7).

----------------Insert Figures 5-7 here-----------

Discussion

The analyses on group tool use patterns indicated three distinctive patterns of tool use by the groups: a Low Frequency of Access cluster, an Average Frequency of Access cluster, and a High Frequency of Access cluster. We used students' individual performance on the science knowledge test, in connection with frequency of access to the tools, to assist us in the interpretation of the three emergent clusters. Given the three types of tool-use groups, the results showed that the while the groups within the Low cluster accessed the four categories of cognitive tools the least, students within these groups scored the highest on both factual and applied knowledge test questions. On the other hand, while the groups within the High cluster accessed the four categories of cognitive tools the most, students within these groups scored the lowest on both factual and applied knowledge test questions.

In an effort to identify possible factors contributing to the relationship between frequency of access and performance on the science knowledge test, we examined the amount of time the groups within the three clusters spent with the tools at two time periods. During the first half of using Alien Rescue, the results indicated that overall there was not much difference in the amount of time the groups spent with the cognitive tools across the three clusters. There was one exception: during the first half of the lesson, groups within the High cluster, on average, spent less time than the other two clusters with the tools that support cognitive load each time they accessed these tools. In general, the groups that visit and re-visit tools often (High cluster) are spending less time with the knowledge intensive tools (i.e. four databases) during the first half of the lesson, whereas the groups that visit and re-revisit tools with less frequency (Low cluster) are spending more time with the knowledge intensive tools. Overall tools in this category are used much more than any other category of tool during the first half of the lesson; indeed these are some of the most essential tools during the early stage of problem-solving when students are identifying the needs of the alien species, and searching the knowledge databases for the requirements of possible homes. Why then do we find high frequency of access groups spending the least amount of time with these tools? One possible explanation may be that for these high frequency of access groups, the "content becomes trivialized and incidental" (Tufte, 1997, p. 148). The action-oriented nature of problem-solving within a tool-rich hypermedia environment is what these types of students may be most drawn to, where manipulation of the tools becomes an end in itself rather than a means to an end. These types of groups may have become preoccupied with the entertainment value, rather than the instructional value, of the tools, a characteristic for which students have been variously labeled as "resource junkies" or "feature explorers" (Barab et. al., 1997; Niederhauser, Reynolds, Salmen, & Skolmoski, 2000).

During the second half of the <u>Alien Rescue</u> lesson, the results indicated that there was a difference in the amount of time the groups spent with the cognitive tools across the three clusters. The Average and High clusters followed the same general pattern but to varying degrees. The general pattern they followed was: they spent the most amount of time with tools that support cognitive processing (bookmark, notebook), followed by tools that support hypothesis testing (control room), followed by tools that support activities otherwise not possible (probe builder, probe launcher), and finally spending the least amount of time with tools that support cognitive load (mission database, concepts database, solar database, alien database, spectrogram, and periodic chart). The general pattern followed by the Low cluster, on the other hand, was: they spent the most amount of time with tools that support hypothesis testing, followed by tools that support activities otherwise not possible, followed by tools that support cognitive load, and finally spending the least amount of time with tools that support cognitive processing.

Ideally, during the second half of the lesson students are interpreting data gathered from probes and continuing to develop and test hypotheses by launching probes, having spent the first half of the lesson with the knowledge intensive tools identifying the needs of the alien species and possible homes. This is consistent with the general requirements of the lesson given the nature of the central problem to solve. But groups in the Average and High cluster did not follow this pattern. It was the groups in the Low cluster that spent the most time with tools that support activities otherwise not possible and tools that support hypothesis testing, whereas groups in the Average and High clusters spent the most time with tools that support cognitive processing. One possible explanation may be that, as opposed to groups that visit and re-visit tools with more frequency (Average and High clusters), groups in Low cluster rely more on each other rather than the tools. Individuals in groups in the Low cluster collaborated in order to integrate information across multiple sources along with the prior knowledge gained previously. When compared to groups within the Average and High clusters, groups within the Low cluster also scored higher on both factual and applied knowledge test items. Collectively, these findings suggest that during the second half of the lesson groups within the Low cluster began to tap the distributive potential of problem-solving in an environment rich with social and technological resources.

In addition, the individual students that comprised all the groups in the Low cluster did not differ significantly from each other with respect to their affective experience, experience of reflexivity, or poor information-seeking experience, as a function of their level of need for cognition. On the other hand, for students that comprised groups in the High cluster, their experience of the hypermedia lesson did vary as a function of their level of need for cognition. Those students with less desire to exert mental effort appeared to experience difficulty in seeking information. For students that comprised groups in the Average cluster, their experience of the hypermedia lesson also varied as a function of their level of need for cognition. Those students with less desire to exert mental effort experience difficulty with self-monitoring. This finding on the relationship between students' experience of hypermedia learning and their desire to exert mental effort within different types of collaborative groups is preliminary. More research is needed to replicate and further investigate this issue.

Complex learning environments such as hypermedia are likely to have embedded within them different cognitive tools to enhance learning. In response to the need for contextualized use of cognitive tools as an integral part of instruction (Jonassen & Reeves, 1996; Kozma, 1987; Pea, 1985; Lajoie, 1993; Salomon, Perkins, & Globerson, 1991), a set of task specific cognitive tools are embedded in the problem-based hypermedia program used in this study. Distributed theories of cognition are encouraging researchers to view cognitive tools as only one instructional variable, among several, which create the conditions for learning (Salomon, 1993). Salomon (1993) posits that learning is far more of a distributed process than we have conceded in the past. Whether or not a student performs well may not necessarily be traced back to the independent contribution of one instructional variable (i.e. cognitive tools), but how a system of instructional variables may or may not combine to support group learning and individual cognition. Pea (1993) stated that intelligence is distributed and supported through the tools, modes of representation, and other artifacts we create to off-load what would otherwise be a heavy and error-prone cognitive burden. The findings of this study offered some empirical evidence to show that cognitive tools, individual differences, and group processing can interact for sixth graders during their problem-solving. The results revealed that cognitive tools interacted with group members to create different types of tool-using groups, and that the same type of students (i.e. students with a low level of need for cognition) functioned differently depending on the type of work group they were associated with. It appears that for students working in groups where less distributed use of social and technological resources was possibly practiced, individual differences that may be a liability surfaced. Whereas for students working in groups where more distributed use of social and technological resources was possibly practiced, individual differences that may have been a liability surfaced less. Such results provide some support to Salomon's (1993) suggestion:

> If social and possibly other "external" processes are to be taken as integral parts of the cognitive process, maybe the whole concept of cognitions ought to be reexamined. Are they perhaps distributed rather than located in the head? And if intellectual processes and products can be seen as being distributed among individuals or between individuals and culturally provided implements, may it not also be the case that intelligence is an emerging quality rather than a "possession." (p. xiv)

This study responds to the call to better understand the use of multiple cognitive tools (Iiyoshi & Hannafin, 2002), and to better understand the interaction of multiple instructional components. The question this line of research wishes to address is how different instructional variables operate as scaffolding mechanisms. Scaffolding cognitive skills involves distributing the burden of cognitive load of any one social and/or technological resource and leveraging the combined potential of these resources, freeing students to engage in and practice higher order cognitive skills (Lajoie, 2000). The interaction of social and technological resources can allow the elements of a problem to productively interact, and hence facilitate learners' information processing. In a complex instructional system cognitive tools are only one component that interact and can go beyond their individual utility collectively. To better understand the potential benefits of systems of instructional components researchers need to take into account the distributed nature of students' interaction with hypermedia programs that involves various contextual factors.

The findings of this study may be useful to a variety of educational professionals. First, the designers who design such instructional environments will be able to make determinations as to ways in which cognitive tools can be more effectively integrated into various hypermedia applications in light of contextual effects. Second, indications of contextual instructional needs, should they appear, could give meaningful direction to future hypermedia instruction. Third, determination of how individual difference and group processing variables interact and contribute to students' hypermedia learning experience could be used to heighten the awareness of many involved - teachers, instructional designers, and educational researchers - as to the impact of such interactions on student performance.

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