The Role of Student Tasks in Accessing Cognitive Media Types

Michael Byrne†, Mark Guzdial, Preetha Ram**, Richard Catrambone†,*
Ashwin Ram, John Stasko*, Gordon Shippey*, Florian Albrecht**
*College of Computing
†School of Psychology
Georgia Institute of Technology
Atlanta, Georgia 30332
**Emory University
Department of Chemistry
Atlanta, Georgia
byrne@cc.gatech.edu, guzdial@cc.gatech.edu, chempr@emory.edu, rc7@prism.gatech.edu, ashwin@cc.gatech.edu, stasko@cc.gatech.edu, shippey@cc.gatech., florian@cc.gatech.edu

Abstract: We believe that identifying media by their cognitive roles (e.g., definition, explanation, pseudo-code, visualization) can improve comprehension and usability in hypermedia systems designed for learning. We refer to media links organized around their cognitive role as cognitive media types [Recker, Ram, Shikano, Li, & Stasko, 1995]. Our hypothesis is that the goals that students bring to the learning task will affect how they will use the hypermedia support system [Ram & Leake, 1995]. We explored student use of a hypermedia system based on cognitive media types where students performed different orienting tasks: undirected, browsing in order to answer specific questions, problem-solving, and problem-solving with prompted self-explanations. We found significant differences in use behavior between problem-solving and browsing students, though no learning differences.

Introduction

Hypermedia is typically oriented around physical media types, for instance, text, video, graphics, and audio. The World Wide Web's use of Mime types, which are based on physical characteristics, is a good example [Berners-Lee, Cailliau, Luotonen, Nielsen, & Secret, 1994]. We believe that identifying media by their cognitive roles (e.g., definition, explanation, pseudo-code, visualization) can improve comprehension and usability in hypermedia systems designed for learning. We refer to media links organized around their cognitive role as *cognitive media types*. In a recent study, students using a hypermedia system organized around cognitive media types performed better on a post-test on the content in the system than students using a hypermedia system organized around physical media types [Recker, et al., 1995].

However, we also believe that the goals that students bring to the learning task will affect how the students will use the hypermedia support system [Ram & Leake, 1995]. Certainly, the system can be tuned to different tasks. Researchers working on the Superbook hypermedia system found that different interfaces better supported either browsing activity or searching for a particular kind of information [Egan, Remde, Gomez, Landauer, Eberhardt, et al., 1990]. Our question was whether setting different tasks for students (and thus, different goals) would affect (a) how students utilized cognitive media types and (b) student learning.

In particular, we explored two kinds of task differences:

- *Problem-solving vs. browsing:* We hypothesized that students who had a specific problem to solve would access the hypermedia organized around cognitive media types differently and would learn more than students who were more or less simply browsing for interesting content.
- *Self-explanations:* The work of Chi and others [Chi, 1992] [Chi, Bassok, Lewis, Reimman, & Glaser, 1990] suggests that students who self-explain the content and their actions learn more effectively than those who do not self-explain. We hypothesized that we might be able to prompt students to self-explain based on their activity in the hypermedia system to achieve gains in learning. Our efforts here are similar to those of [Bielaczyc, Pirolli, & Brown, 1991] [Bielaczyc & Recker, 1991] who also engineered prompts to encourage and teach self-explanation behavior. Our additional question was whether students prompted for self-explanations would access the cognitive media types differently than students without such prompts.

Self-explanation prompts are less interesting in a browsing condition than in a problem-solving condition because there is less student activity to explain. Therefore, we only used self-explanation prompts as a second problem-solving condition. We note, however, that the prompts in a self-explanation condition can also serve to direct student exploration.

To explore that role, we had two browsing conditions – one without direction, and one directed to answer specific questions.

Methods

In an attempt to test some of our ideas about cognitive media types, students' tasks, and self-explanation, we designed instructional software for teaching students how to solve problems involving the determination of molecular shape. This subject is particularly difficult for introductory Chemistry students so the potential benefits in this domain are considerable.

The software, which we called ChemLab, is based on an outline of the problem solution procedure developed by our domain expert (P. Ram). The steps in the procedure are laid out in a map that students can follow to arrive at a solution. There are 22 steps in the procedure that the students could examine. Each step contained up to four cognitive media types:

1) *Definitions*. Key concepts relevant to this step and the operations required at this step of the procedure were presented here.

2) *Examples*. Concrete examples of this step in the procedure or the key concept in the step were presented here.

3) *Worked problems*. This was generally a "before and after" presentation in which the students saw a partial solution before the step was performed and then after it was performed. Explanations for the operations were also present.

4) *Problem sets*. This was similar to a worked problem but provides an opportunity to test one's knowledge. The screen presents a "before the step" situation and asked the learner to execute the step in their head or on scratch paper. The learner could request that the solution then be shown to verify their solution.

Because this particular domain is very visual, ChemLab makes extensive use of figures along with the text [see Fig. 1]. However, use of other physical media types were limited. The semi-public computer cluster environment constrained our ability to make use of sound and time constraints made construction of animations impossible. Future versions of ChemLab will make more extensive use of animation to illustrate the more dynamic content, though the use of sound is still an unresolved issue.

Subjects

The subjects in the ChemLab experiment were approximately 80 undergraduates who were taking an introductory Chemistry course at Emory University. They participated in the experiment for extra-credit. Subjects had attended lectures (scattered over a two week period) in their course which addressed the material covered in ChemLab.

The participant sample was a strong group of students with a self-reported grade-point average of 3.4 out of 4.0 and mean SAT scores of 571 on the Verbal scale and 663 on the Quantitative scale. Thus, it was a very capable group that used the ChemLab software. Random assignment procedures were effective in that there were no mean group differences on any of these participant variables.

Apparatus/Materials

Subjects were given paper guides to help them navigate the ChemLab software. The software itself was run on Macintosh Centris personal computers and developed in Apple's HyperCard (version 2.3).

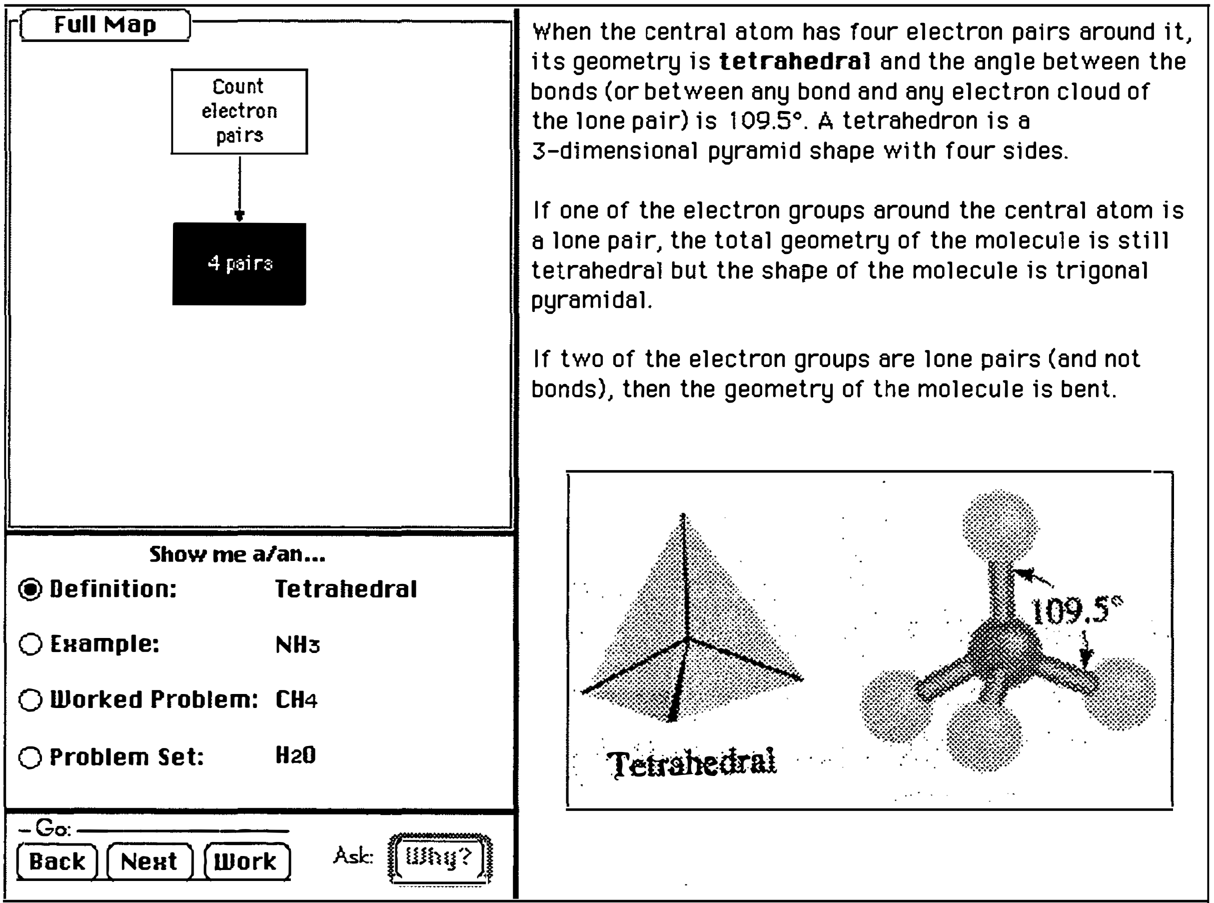

Figure 1: ChemLab screen shot

Design

All subjects had access to the same instructional material in the software and were given the same post-test after using the software. The post-test was a short quiz designed by the regular Chemistry instructors for the course. The ChemLab software also kept a log of mouse clicks so it was possible to analyze browsing patterns for the subjects.

The presentation of the ChemLab software was in slightly different contexts for different subjects. There were four presentation groups:

1) *Passive watching.* In this condition, subjects were given access to the ChemLab instructional material and little guidance. They were instructed to "work through the materials until you are pretty sure you are prepared to solve some problems." This is, in essence, the control condition.

2) *Directed watching.* In this condition, we wanted to give the subjects some learning goals while browsing through ChemLab. Thus, subjects were given a series of questions to answer to help guide their browsing. These questions concerned different aspects: some were oriented towards the procedure (e.g. "how do you do X?" or "what do you do after step Y?"), some were oriented toward specific content (e.g. "what's the chemical formula for Hydrazine?"), some were definitions, and many were purposely obscure things that subjects would have to find as distractors.

3) *Problem solving.* Subjects in this condition could not only browse ChemLab, but were asked to solve two specific molecular shape problems. As they were doing so, they were allowed to use ChemLab as a resource to help them solve the problems. This condition was included to encourage subjects to spontaneously generate learning goals directly relevant to solving real problems.

4) *Problem solving with prompting.* This condition was identical to condition 3 with one addition: at various points while subjects solved the problems, they were prompted to explain what they were doing and why. It was hoped that this manipulation would increase reflection and self-explanation.

Subjects in the two problem-solving conditions were asked to use special software called the Molecule Construction Kit to solve the problems [see Fig. 2]. This made the whole environment more self-contained and gave us the opportunity to examine partial solutions.

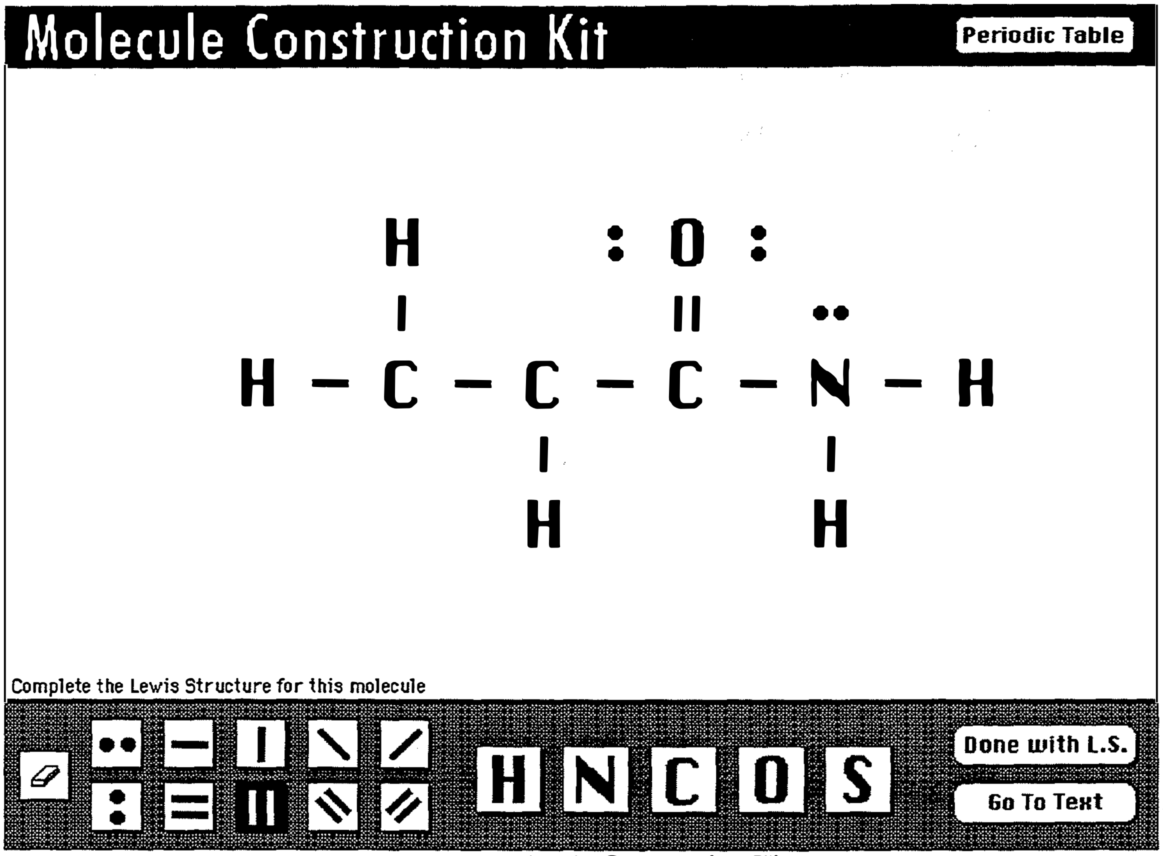

Figure 2: Molecule Construction Kit

Procedures

Participants first filled out the consent form. After this, they were allowed to spend as much time as they wanted with the ChemLab software. The software also prompted them to report their grade-point average and SAT scores. Once they were satisfied with the time they had spent using ChemLab, they received a brief questionnaire asking them to rate their confidence in their ability to solve molecular shape problems. Once they had completed the questionnaire, they were given the post-test on paper. They were proctored during the post-test and given unlimited time to solve the problems on the quiz.

An example problem on the post-test was: *Arrange the following species in order of decreasing F--A--F bond angles, where A is the central atom: BF3, BeF2, CF4.* The correct solution was BeF2, BF3, CF4.

Results

Browsing patterns were clearly affected by the condition to which subjects were assigned. Subjects in the problem-solving conditions visited an average of only 5.4 of the 22 steps, while subjects in the browsing conditions visited an average of 17.6 of the 22 steps, and this difference is reliable ($F(1,74) = 82.70, p < 0.001$). This is an extremely large difference; on average, subjects in the problem-solving conditions saw less than one-fourth of the steps in the procedure while browsing subjects saw 80% of the steps. This difference carried into the number of visits to the different media types; for all four media types, subjects in the browsing conditions had more visits than subjects in the problem-solving conditions.

This may have been compensated for by the amount of time subjects spent looking at the screens when they were presented. An average visit to a screen for the subjects in the browsing conditions lasted 36 seconds, while for the problem-solving subjects the average visit lasted 86 seconds. Again, this difference is reliable ($F(1,43) = 12.10, p = 0.001$) and is quite large; subjects in the problem-solving conditions spent almost two and a half times as long looking at a screen of information than subjects in the browsing conditions. The average total time (not including reading the initial instructions) for the experiment was 17.85 minutes. This was weakly related to post-test score ($r(77) = 0.62, p = 0.058$).

While there were clear effects on browsing patterns for problem-solving vs. browsing, there were no effects associated with prompting except the total amount of time spent using ChemLab. The source of this difference is probably the extra typing subjects in the prompted condition did in answering the prompts. In any case, the difference here, though reliable, was not large.

Unfortunately, there were no reliable differences in post-test scores between the groups. Table 1 summarizes the four groups' post-test scores. Overall, subjects did reasonably well on the post-test, averaging 8.15 points of a possible 10. Interestingly, self-reported confidence (the rating taken right before the post-test) was only weakly correlated with the actual quiz scores, $r(80) = 0.20, p = 0.07$; self-reported confidence was more highly correlated with SAT Quantitative scores $r(69) = 0.28, p = 0.02$ even though SAT scores were not correlated with quiz performance.

Group	Average Score	Standard Deviation
1	8.34	1.91
2	8.34	1.26
3	8.00	1.52
4	7.96	1.59

Table 1: Summarizing Four Groups' Post-Test Scores

Discussion

The lack of differences between groups' post-test scores are surprising – our hypotheses predicted differences both in browsing behavior (which was observed) and in learning performance (which was not). However, this lack of difference might be attributed to the complexity of the task (or rather, lack thereof) and student ability. The students were very capable, and even those who received relatively little support from the hypermedia system (i.e., the problem-solving group students who saw less than 25% of the steps in the procedures) performed very well on the post-test (8.15 out of 10 points, with a standard deviation of less than 2.0 – almost nobody got less than half the quiz right), which may also suggest a ceiling effect. The students were doing so well that there was little opportunity to discover group differences.

More interesting is the dramatic differences between use patterns among the groups. Students who were trying to solve a problem visited fewer cognitive media types but spent more time studying the media that they did visit. It may be that if the task were more complex and the students needed more of the information in the hypermedia system to solve the task, as opposed to having seen much of the information in class already, the differences in use behaviors might result in greater differences in performance on the learning task and on the post-test.

The observation that problem-solving students spent more time studying the screens is in marked contrast with prevailing wisdom in hypermedia design. Generally, hypermedia designers reduce the amount of text in their systems in favor of more "glitzy" media, such as graphics, sound, and video, arguing that users are not willing to spend the time reading text. In fact, some researchers have even claimed that reading will become an obsolete skill as multimedia computers become more common [Papert, 1993]. While the case and value of "glitz" is real and important, our data suggest that if users are actively trying to problem-solve and use the content in a hypermedia system, they will invest the time on the content, perhaps even reading the text.

Our results offer no insights on the question of self-explanation prompts. We have no evidence of differences in learning performance nor of differences in use behavior due to self-explanation prompts, other than the time differences required to respond to the prompts. It may be that if we were to repeat the experiment with a more complex task and with more necessary hypermedia content, then students might be more motivated to respond to the prompts more thoughtfully, resulting in greater learning differences.

Conclusions

While we have not been able to support our hypotheses about self-explanation and about learning effects, our results do support the hypothesis that a difference in user task will cause a difference in browsing behavior. Thus, there are several paths of interest for future work:

- Certainly, repeating the experiment with a more complex task where hypermedia support is more critical might provide useful insights on the learning question. Since the problem-solving students spend more time studying content but view less of the overall system, good navigation mechanisms that lead these students to the necessary content will be a critical feature of future systems [Shippey, Ram, Albrecht, Roberts, Guzdial, et al., 1996].
- Time spent on the content suggests an interesting avenue for an exploration where the relative amounts of

different cognitive media types are varied to investigate further the relationship between media types, task, and learning.

- Varying the kinds of physical media corresponding to cognitive media and varying the kinds of interaction with the system offers another interesting interface component whose use may vary with task.

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