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Solving Ill-structured Problems: Student Behaviour in an Online Problem-solving Environment

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Abstract
The ability to solve complex, real-world problems has become essential in our increasingly globalized society. Environmental issues like climate change and deforestation, economic issues associated with global economies and linked markets, and social concerns like hunger and AIDS present major challenges that must be addressed. However, schoolteachers rarely provide the kinds of experiences that will help students learn to solve these kinds of complex ill-structured problems. Students, who are typically taught using well-structured algorithmic problems, often struggle when confronted with the multiple challenges of more complex problem-solving tasks. They tend to approach an ill-structured problem by searching for an algorithm that might work (the “plug-and-chug” method), or flounder along with little planning, direction or monitoring. In the present study we examined the problem-solving behaviours of eight student teams (college students – 2 or 3 students per team) as they worked to solve conceptually complex physics problems in an online problem-solving environment. Results suggest that students spent the majority of their time conceptualizing the nature of the problem, solving equations and typing in information, and reading from the computer screen. Little time was spent strategizing about how to solve the problem, monitoring progress, or reflecting on the viability of solutions.

Keywords
learning, problem-solving, real-world problems.

INTRODUCTION
Early problem-solving research typically focused on how people solved well-structured problems (logic puzzles, algorithmic problems, etc.) in an effort to generate universal problem solving strategies (e.g. Ernst & Newell, 1969; Newell & Simon, 1972; Polya, 1954, 1957). However, skills developed by solving these context-dependent problems rarely transferred to solving real-life contextualized problems (Glaser & Chi, 1988; Spiro, Feltovich, Jacobson, & Coulson, 1991; von Glasersfeld, 1995) – yet solving these real-life day-to-day problems may be the most important “learning outcome” in human life (Gagne, 1985; Jonassen, 2000).

Problems typically encountered in everyday life are ill-structured and multifaceted (Minstrell, 1989). These complex real world problems differ from the typical well-structured end-of-the-chapter textbook problems that have been pervasive in science and mathematics instruction. Students solve these types of problems by applying strategies and algorithms from the chapter – simply plugging in the numbers provided in the problem set. In contrast, ill-structured problems have more loosely defined goals and parameters, multiple solution paths, and may not have a single "right" answer. Various solutions are evaluated in relation to benefits and drawbacks rather than being right or wrong. Problems are situated in a context that requires students to draw on deep structural and conceptual knowledge of the topic.

Although several models for solving these kinds of problems (both explicit and implicit) have been proposed (e.g., Hmelo-Silver, 2004; Miao, Holst, Haake, & Steinmetz, 2000; Stepien, Gallagher, & Workman, 1993), we found little empirical work that validated these models relative to specific behaviours of individuals engaged in solving complex, contextualized real-world problems. In the present study we examined problem-solving behaviour as teams of college students worked to solve conceptually complex physics problems in an online problem-solving environment. Our goal was to begin to identify patterns in students' problem-solving activity relative to time spent in the problem-solving process.

METHOD

Participants and Context

Participants were drawn from a 360-student sophomore-level calculus-based physics course at a large Midwestern university. Each week students met for three lectures, one recitation, and one lab. Lecture sessions typically included approximately ten minutes of content presentation, followed by a conceptual question which the students answered via radio-frequency clickers; first individually, then in a group discussion, and finally, recommitting to their solution as a group. The recitations used a mixture of Physics Tutorials (McDermott & Shaffer, 2002), and context-rich, multi-faceted problem solving activities (Heller, Keith, & Anderson, 1992) designed to increase ill-structured and multi-faceted problem-solving skills.

Each topic in the course followed approximately the same sequence: An introductory tutorial during recitation to address the main concepts, two to three lectures, a lab, and two problem sets. The first problem set was due early in the instructional sequence and contained mainly conceptual questions. The second problem set focused on standard end-of-chapter problems designed to reinforce and assess the basic procedural knowledge in the topic area.

Multifaceted problems activities were periodically used during the 50-minute recitation session as a capstone event for major course topics. These problems provided students with an opportunity to develop connected understandings of concepts from different topic areas as they solved complex contextualized physics problems. Groups of two or three students (a "team") worked on problems under the supervision of a teaching-assistant, with approximately 20 students per recitation.

Students worked on six multifaceted problems during the course of the semester: two on thermodynamics, one on waves, two on magnetism and magnetic induction, and one on optics. Half of the recitation sections solved the problems in a pen-and-paper format, and half used the online Problem Solving Learning Portal (PSLP) problem-based learning environment described in the Materials section below (Niederhauser, Antonenko, Ryan, Jackman, Ogilvie, Marathe, & Kumsaikaew, 2007; Antonenko, Jackman, Kumsaikaew, Marathe, Niederhauser, Ogilvie, & Ryan, 2011).

PSLP recitation sections met in a twelve-station computer classroom with student teams sharing a single computer. Students self-selected onto teams, and while some teams stayed together during the semester, others periodically reformed; and every student did not attend every recitation session. Student teams were video- and audio-taped while working on the problem and eight teams with clear and complete data were included in the analyses. We also collected server-log data on sequence and timing of screen access – allowing us to map observed behaviours onto server-log data from the hypertext system. Scores on a problem-solving-based examination covering the content addressed in the recitation session were used as a measure of performance.

Materials

The PSLP software was developed by the researchers to present ill-structured story problems in an on-line environment (see figure 1). The software was designed as a template that could be populated with problem-scenarios from any content area. When beginning work on a problem, students saw the Problem Statement presented on an initial screen. Required tasks for completing the assignment were displayed on a menu bar across the top of the screen:

- *Qualitative analysis*: textual information written by students, in which they described the physics processes that were apparent in the problem.
- *Relevant concepts*: a set of check boxes where students selected concepts that they believed directly applied to solving the problem.
- *On-going monitoring*: a text box where students described any checks they made during their solution.
- *Solution*: a set of radio buttons which typically included 15 different numerical values as possible answers to the problem.
- *Problem review*: a text box where students described what checks they have made after they obtained their solution.

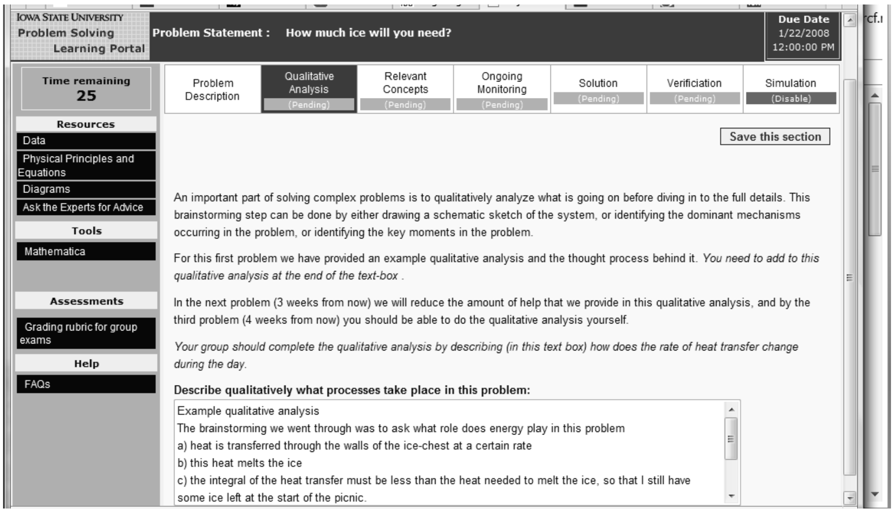

Figure 1: Screen-shot of qualitative analysis task.

A menu bar on the left listed resources (data, principles and equations, diagrams, and expert advice), tools (Mathematica), and the scoring rubric that would be used to grade the assignment. Students were allowed to determine the sequence for completing tasks, and when (or whether) to access resources, the scoring rubric, and tool.

Tasks were opened in the main window when selected. For each task participants were required to enter relevant information and submit their response (with resubmission allowed). Accessing resources, scoring rubric, tools, and working documents spawned a new window – allowing participants to view several windows on their screen. Resources included text or image files with charts, tables, and figures. Consistent with principles of solving ill-structured problems, multiple resource documents were available to students, but only half contained information that was relevant to solving the problem. The Scoring Rubric provided context sensitive grading criteria for the current task.

Analysis

Video and audio data were used to determine the nature of student activity as they worked to collaboratively solve the multifaceted physics problems. Server-log data provided a sequential record of each screen accessed during a session. This information (e.g., what information was being presented on the screen while students were silently reading) supplemented video and audio data, allowing us to be more precise in determining what students were actually doing as they engaged in the problem-solving activities.

Categories of student problem-solving behaviour were established by repeatedly viewing videotapes and server-log data to determine the kinds of activities in which students engaged. After several passes through the dataset the following categories of behaviour were identified:

- *Reading* information from the computer screen (e.g., *Problem statement*, *Resources*, *Tasks*, etc.) When students read silently server-log data were used to determine what was being read.
- *Conceptualizing* the problem and solution strategy (e.g., brainstorming, questioning, explaining, etc.).
- *Gathering information* needed to solve the problem (e.g., seeking specific information, browsing through resources, etc.).
- *Working* to solve the problem (e.g., drawing a diagram, performing calculations, solving equations, etc.)
- *Monitoring* solution strategies (e.g., asking “Are we on track?,” “What do we do next?,” justifying the solution, etc.).

Each team’s video and audio data were then coded to produce an activity transcript, providing a sequential, multi-category, overlapping record of team behaviour during the problem-solving activity. Student activity was coded minute-by-minute for the time that they were engaged in solving the problem. Server-log data were then mapped on to the activity transcript to provide additional insights into student problem-solving behaviour.

RESULTS AND DISCUSSION

Results address the distribution of activity within the problem-solving teams, that is, the kinds of behaviours students engaged in while working toward a viable solution to the problem.

Distribution of Activity

As can be seen in Figure 2, Students spent the majority of their time working, conceptualizing, and reading. They tended to stay on task, and spent a relatively less of their time getting help from the teaching assistant, monitoring their work, and gathering information. This finding was consistent with previous research that showed students spent most of their time working and conceptualizing – little time monitoring and reflecting (Schoenfeld, 1987).

We then examined students’ specific behaviour while engaged in these activities (see Table 1). Teams spent the majority of their working time performing calculations to solve mathematical equations (both with paper and pencil, and with the available Mathematica software) and typing their answers into the computer (110/154; 71%) – not a surprising finding given that they were working on calculus-based physics problems and were required to enter their answers into the computer, Teams spent comparatively little time searching the available resources for relevant equations and information, taking notes, or drawing diagrams to help them visualize their solutions.

Conceptualizing the problem, or “defining the problem space” is widely recognized as an essential step in solving complex ill-structured problems (Newell & Simon, 1972). Our findings provide empirical evidence for this claim in that students’ efforts to negotiate a shared understanding of the problem constituted the second most pervasive behaviours during the problem-solving activity. Conceptualizing behaviour was primarily concerned with "thinking aloud," questioning, and explaining one's ideas (99/119; 83%). Thinking aloud involved one student talking through what he or she saw as the relevant relationships among concepts to frame the problem and define the problem space. This think aloud behaviour often prompted questions from other students on the team (the second most pervasive conceptualizing behaviour), in turn eliciting a direct response to the question – which we coded as explaining. Surprisingly little time was spent explicitly planning solution strategies and/or brainstorming (two behaviours that are often included in the defining-the-problem-space phase of the ill-structured problem-solving process. Perhaps the think aloud/questioning/explaining cycle provided enough insight into the problem that unstructured brainstorming and explicitly stated plans were unnecessary.

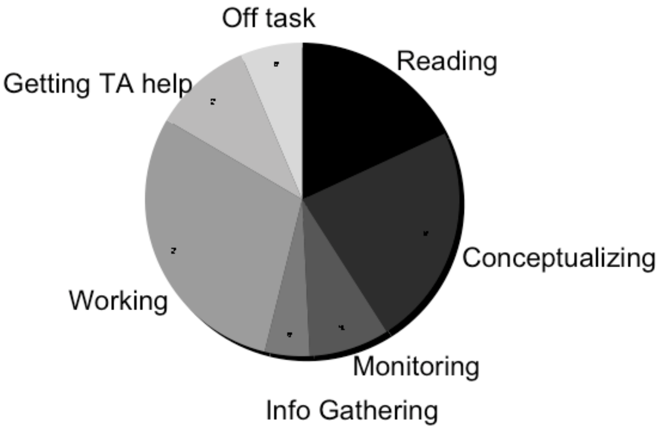

Figure 2: Percentage of time engaged in various activities for all groups.

Table 1: Instances of observed behaviours arrayed within problem-solving activities.

Reading		Conceptualizing		Monitoring		Gathering		Working		TA help	
Resources	28	Think Aloud	41	Do next?	15	Purposeful	19	Solving equations	82	Gives information	19
Creating Teams	19	Questioning	32	Check solution	11	Not purposeful	4	Typing	28	Asks leading questions	16
Scaffold Quest	16	Explaining	26	Justify solution	9			Finding equations	15	Monitor student work	10
Tasks	15	Planning	12	On track?	6			Formulating solution	15	Give answer	7
Prob Statement	14	Brainstorming	8					Drawing diagram	7	Technical issues	3
								Notetaking	7	Listening as TA helps others	2

Students also spent a relatively large amount of time reading from the computer screen – again, not surprising given the context. Instructions, the problem itself, tasks to be completed, resources for solving the problem, and logistics for setting up and using PSLP all required students to read information that was available only through the computer. While reading behaviour was fairly evenly distributed across categories, students spent most of their time reading the resource information that was provided (28/92; 30%). Designers of ill-structured problems typically include both relevant and irrelevant resources in an effort to mirror the complexity of real-world problems. Thus, part of the time students spent reading resources actually involved sifting through the available information to determine which of it might be of value.

Creating teams simply involved reading login and team formulation information – necessary for the assignment, but not essential to the problem-solving task. Students also spent time reading scaffolding questions, which prompted students to analyse the problem, and reading instructions for the tasks that needed to be completed. Finally, server-log data revealed that the problem statement was displayed on the computer screen for what seemed to be an inordinate amount of time – a finding that was consistent with our previous research (Niederhauser, Antonenko, Ryan, Jackman, Ogilvie, Marathe, & Kumsaikaew, 2007; Antonenko, Jackman, Kumsaikaew, Marathe, Niederhauser, Ogilvie, & Ryan, 2011). However, when we reconciled the server-log data with the video data, we found that, although the problem statement was displayed for considerable amounts of time, students were often engaged in other tasks and were not actually reading the problem statement. The use of video data allowed us to more accurately determine the nature of student reading behaviour, thereby providing insights into a previously puzzling result.

Students spent comparatively small proportions of their time getting help from the teaching assistant, monitoring problem conceptualizations and solution strategies, and gathering information; and they tended to keep on task for the most part, In most cases TA intervention involved giving students information, asking students leading questions, and "looking over their shoulders" to monitor student work. Monitoring included deciding what to do next, reflecting on whether their solution made sense, rationalizing the solution, and determining whether or not they were on the right track. Finally, students spent time gathering information (looking back to verify information from the problem statement or tasks, or seeking information in resources). In some cases information gathering was purposeful (students were looking for a specific piece of information or formulae), other times students just looked through the information to see if they had missed anything, or scanned through the content to see if anything that might be useful "popped up."

CONCLUSION

These findings support the idea that defining the problem space, or imposing structure on an ill-structured problem, is central to solving these types of complex multi-faceted problems. While working to solve equations, typing in answers, and reading information constitute procedural activity, the higher-order thinking behaviours associated with developing strategic and tactical approaches to solving the problem were largely addressed through conceptualizing behaviour. That is, students tended to negotiate a shared understanding of the problem through discussion, which allowed them to establish an overall solution strategy, and implicitly guided tactical decisions about what to do next. Further, once students had developed a strategy, they tended to spend minimal time explicitly discussing what to do next, or monitoring their strategy to determine whether their efforts were reasonable and viable.

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Biography

Dale Niederhauser is Associate Professor and Director of Undergraduate Education in School of Education at Iowa State University. Research interests include technology-using teacher development and learning from linked text. Formerly served as President of ISTE-SIGTE and Chair of AERA TACTL SIG.