

AC 2007-1929: STUDENT SELECTION OF INFORMATION RELEVANT TO SOLVING ILL-STRUCTURED ENGINEERING ECONOMIC DECISION PROBLEMS

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Student Selection of Information Relevant to Solving Ill-Structured Engineering Economic Decision Problems

Abstract

Engineering economic decision problems encountered in practice are embedded in information-rich environments, where large volumes of data are available from multiple sources. However, the information that is most relevant to solving the problem may be unavailable, inaccessible, inaccurate, or uncertain. In contrast, typical engineering economy textbook problems present only the relevant information in a convenient format. To help bridge the gap between textbook and practice, we engage student teams in a series of ill-structured problems. Teams work in an online Problem Solving Learning Portal (PSLP) that provides access to a variety of information resources containing both relevant and irrelevant information. In one problem instance, some information relevant to the solution must be obtained from an external resource that is not available or mentioned in the PSLP.

Student work in the PSLP is organized into successive stages of specifying decision criteria, stating assumptions, expressing their solution in a spreadsheet file and written rationale, and conducting a sensitivity analysis on a single variable they judge to be critical. In addition, they cut and paste information from the resources they see as relevant into a “working memory” repository. We explore different methods for assessing students’ ability to select which information is relevant. Direct measures include simple counts of “hits” and “false alarms” in the working memory that are assessed as part of the grading rubric and analyzed using signal detection theory. Their choice of the parameter(s) on which to conduct the sensitivity analysis can be considered as an indirect measure because the most relevant information is that which provides the best prediction of the most critical parameter (i.e., the parameter that will have the greatest impact on the decision criterion). The online environment also tracks the information resources visited by the student teams and the time of visitation. Data collected from a large engineering economy course are used to evaluate the effectiveness of these assessment methods.

Introduction

Making good engineering decisions is a critical skill for every engineering discipline. The complexity of decision making is tied to multiple criteria which can often be in conflict. Large volumes of information from multiple sources of real-time and historical electronic information are a source of additional complexity. Informal information infrastructures (e.g., mobile communication or instant messaging) increase the immediacy and volume of information available. Both the formal and the informal information infrastructures can drown an individual or team of problem solvers in a sea of data. In addition, information elements that a problem solver perceives as necessary may be unavailable, inaccessible, inaccurate, or involve uncertainty.

Engineering economic decisions involve both technical data and estimates of economic impacts, which frequently extend far into the future. The decision maker must gather and combine

information from both the engineering and the business sides of the organization, as well as from external suppliers and customers, forecasts of economic trends, and projections for future technological innovations. Extracting the information necessary to estimate alternative project cash flows is the difficult and essential prerequisite to conducting a present worth or internal rate of return analysis (a typical basis for these types of decisions).

Irrelevant, redundant, or conflicting information

When ample information is available, a problem solver must select which information to use. In some cases the task relevant information may be available from multiple sources and may appear in multiple representations. When redundancies occur, a problem solver must make a decision about which source is most relevant to the problem space. Green and Wright investigated the selection of task relevant information in the context of multiple sources¹. When some of the redundant information is unreliable, then subjects will try another source.

In many real world problems, different sources of information are in conflict. This may be due to unknown phenomena that affect the information and therefore, the information is actually valid. In some cases the information can be in conflict because a source is invalid, inaccurate, or unreliable. When a conflict occurs, a problem solver makes decisions in an attempt to resolve the conflict by checking the sources to assess their validity or by collecting additional data.

Research on information use in problem solving

The problem-solving research literature distinguishes between well- and ill-structured problems. In well-structured problems such as most end-of-chapter textbook problems, all problem elements are presented concisely, a limited number of rules and principles must be applied, and impacts of decisions are known or easily predicted². Common characteristics of ill-structured problems include missing relevant information³, unknown or uncertain problem elements⁴, and multiple evaluation criteria for solutions, creating uncertainty about which concepts, rules and principles (and therefore, which information) are necessary for the solution⁵. Empirical evidence suggests that *working memory*, which plays a central role in human information processing, has limited capacity for both storage and processing⁶. Because of this limited human capacity for attending to and processing information – approximately seven “chunks” in short-term memory – reducing the information set by selecting relevant information is crucial for good decision-making⁷.

Studies by Egner and Hirsch⁸ found that subjects resolved conflicting information by increasing their focus and attention on task relevant information (which they termed as attentional target-feature amplification). In a modified Stroop test, they collected and analyzed data on the ability of subjects to select targets on a computer display. In a standard Stroop test, subjects are supposed to identify the color of a word and ignore the content of the word. The cognitive challenge of the test is that the words are colors (i.e., red, green, blue, etc.), which causes confusion for subjects. Banich used brain scans during Stroop tests and found that there were two modes in which the brain processes the information⁹. In one mode the prefrontal regions focus attention on task relevant information. For the other mode, posterior regions focused the attention on task irrelevant information, perhaps indicating that some processing time is spent

trying to prevent further use of irrelevant information. This suggests that a subject's identification of task relevant and irrelevant information involves some marking or tagging of information during a cognitive task.

Information reduction is the process of differentiating relevant from irrelevant information in a problem-solving context. Haider and Frensch¹⁰ found that with practice, subjects were able to reduce the amount of information that was used in a cognitive task and therefore, reduce task time. They suggested that this can be attributed to a subject acquiring a skill of focusing on primarily task relevant information. The tasks in their studies involved identifying correct and incorrect sequences of alphanumeric strings based on a set of predefined rules.

Lee and Anderson¹¹ used eye tracking for the Kanfer–Ackerman Air-Traffic Controller Task¹² to collect data on the time spent looking at task relevant and irrelevant information for a series of trials. Time spent on both types of information decreased as a function of the number of trials. The time spent on irrelevant information was consistently longer than on relevant information until the number of trials reached 15, at which points the times were equivalent.

As educators, our goal is to prepare students for real-world engineering economic problem solving. Given the large amount of information available and the smaller though still considerable quantity of information that is relevant to estimating future cash flows in a given scenario, this preparation must include the development of information reduction skills. Rigorous cognitive studies of information reduction have been limited to analyzing performance on very simple tasks under controlled conditions. However, assessment of student performance has been defined as “the process of gathering and discussing information from multiple and diverse sources in order to develop a deep understanding of what students know, understand and can do with their knowledge as a result of their educational experiences; the process culminates when assessment results are used to improve subsequent learning.”¹³ From this definition we see that assessment itself is an ill-structured problem, which comes as no surprise to educators and students. In order to design instruction that helps students improve their information-reduction skill, we need to assess students' ability to select relevant information in a realistic problem-solving environment. Therefore, the goals of this study are to:

1. Examine methods for assessing information reduction,
2. Observe changes in information reduction behavior as students solve progressively less-structured problems in an engineering economic analysis course.

Methods

This section describes a web-based system used to administer ill-structured problems and analysis methods for the data collected.

Problem Solving Learning Portal

The Problem Solving Learning Portal (PSLP) is a web-based collaborative environment that was designed to help students improve their problem solving skills using ill structured real world problems¹⁴. Instructors design individual problem modules containing problem solving stages and information resources. Figure 1 describes the basic module structure. The column on the

left contains a menu structure that provides access to information resources, team related items, assessment methods, and help on the PSLP. The problem statement at the top appears in every stage. Below the problem statement is a set of problem stages specified by the instructor. For each stage, specific stage related information is displayed and typically involves entering different types of information by a student.

	Problem statement	Due date
	Problem stages	
Menu Structure Information resources Teamwork Assessments Help	Stage information	

Figure 1. PSLP Module Structure

An example of problem stages for a module is shown in Figure 2. In the engineering economy course, each stage must be completed and submitted before moving to the next stage. However, students can return to previously completed sections and modify them at any time before the whole project is finally submitted. Moving from left to right, students are first presented with a short Problem Description. Next, they specify the Criteria they will use to evaluate alternatives and make a decision. In the Assumptions section, they list assumed conditions and values for unknown parameters. The Solution stage provides a spreadsheet template for them to use when analyzing alternatives. They select their recommended decision using radio buttons or a drop-down menu and type a short justification for it in a text box. The final section on Uncertainty Analysis can vary depending on the problem. It can require them to perform a breakeven or sensitivity analysis on their choice of critical parameter(s); or re-evaluate and modify their decision given additional information revealed at a simulated later date.

Problem Description	Decision Criteria (Submitted)	Assumptions (Submitted)	Solution (Submitted)	Uncertainty Analysis (Submitted)
<p>Balder-Dash Inc.</p> <p>Balder-Dash Inc. (BDI) is a large conglomerate with both manufacturing and service-based businesses. BDI's goal is to provide its customers (OEMs) one stop shopping for a wide range of component parts. BDI's customers will pay a small premium for quality, but are extremely cost conscious. An opportunity to purchase an item it currently produces to sell as part of a bundle of products to one of its major customers has occurred. You have been assigned to recommend a course of action. Should the part in question be outsourced?</p> <p>Record the Resources that you use in the Working Memory. Your Working Memory will be turned in for grading when you submit your solution.</p>				

Figure 2. Example problem stages

Figure 3 shows the corresponding menu structure. The information resources provide access to information which may be relevant or irrelevant to the problem. Given that PSLP problems are intended to be ill structured, information is not provided to students in well defined packages as in traditional textbook or case study problems. The resources can consist of memos, emails, meeting minutes, spreadsheet or database files, engineering drawings, and other types of representations. Students can select items under Resources on the left side of the screen that can contain task relevant or irrelevant information. Higher order cognitive skills¹⁵, such as application, analysis, synthesis or evaluation, must be used to determine which information is useful for this problem. Some of the information can be used directly, while other data must be used to produce information that can be used to solve the problem.

In the Teamwork section, students create documents from templates to describe different aspects of their solution. The assessments section contains a set of rubrics the instructor specifies for evaluating each problem stage.

Working Memory

- Open

Resources

- Correspondence between BDI and Metalworks
- Interoffice memos
- Manufacturing Layout
- Transportation logistics

Teamwork

- Working documents
- Team evaluation

Assessments

- Grading rubric

Help

- FAQs
- Working with documents
- Working Memory Help

Figure 3 Example menu structure

The PSLP has been used continuously with continuous improvements since fall 2002, beginning with the engineering economic analysis course¹⁶, and with subsequent modules added for manufacturing systems, production systems, and optimization courses in industrial engineering. Thousands of engineering students have used it to solve a variety of realistic problems, developed in consultation with industry partners. Notably, U.S. students have worked in teams with their counterparts in Scotland, Mexico and Taiwan to design a global supply chain¹⁷. Beginning in 2006, it was used for administering shorter multi-faceted problems in physics¹⁸ and in an instructional technology design course.

For this project, we created the Working Memory repository for closer observation of the students' information reduction processes. It is an interactive table containing a list of information elements (typically, sentences or individual data values) that a student team determines is relevant to solving the problem. A student copies and pastes the information from an internal resource or an external source into the empty text box in the left hand column and identifies the information source in the second column. Any information item can be deleted if the students decide later that it is not needed. One criterion of the grading rubric specified that in an exemplary solution, "All the information relevant to the problem, and no irrelevant information, is submitted in the Working Memory."



Figure 4 Working Memory

While we intended for the student teams to store all the information they deemed relevant in the Working Memory, some teams included additional information items in the text-box list of Assumptions – these included relevant information that had not been provided in the Resources and irrelevant information that the teams added erroneously. Furthermore, to reinforce sound spreadsheet habits, we set aside a section in each solution template where the teams were to enter all the constant numbers to be used in their spreadsheet formulas. Some teams put information there but not in the Working Memory.

The PSLP supports additional features that are omitted here for the purpose of brevity.

Signal Detection Theory

Signal detection theory (SDT) is commonly used in empirical studies to evaluate the performance of decision makers¹⁹. The basic premise is that a signal (i.e., relevant information) can be present in some information context and a subject makes a decision (yes or no) about whether the signal is present. This decision is based on the amount of evidence perceived by the

subject. In our context the decision corresponds to whether an information element is relevant or irrelevant to solving a problem. The amount of evidence is considered to be a random variable with a normal distribution. The probability distribution reflects the inherent noise (either in the information or a subject's internal decision making process). The decision is modeled as two normal distributions having the same variance. One distribution corresponds to pure noise (no signal present) and the other distribution is the signal with noise. The model is illustrated in Figure 5.

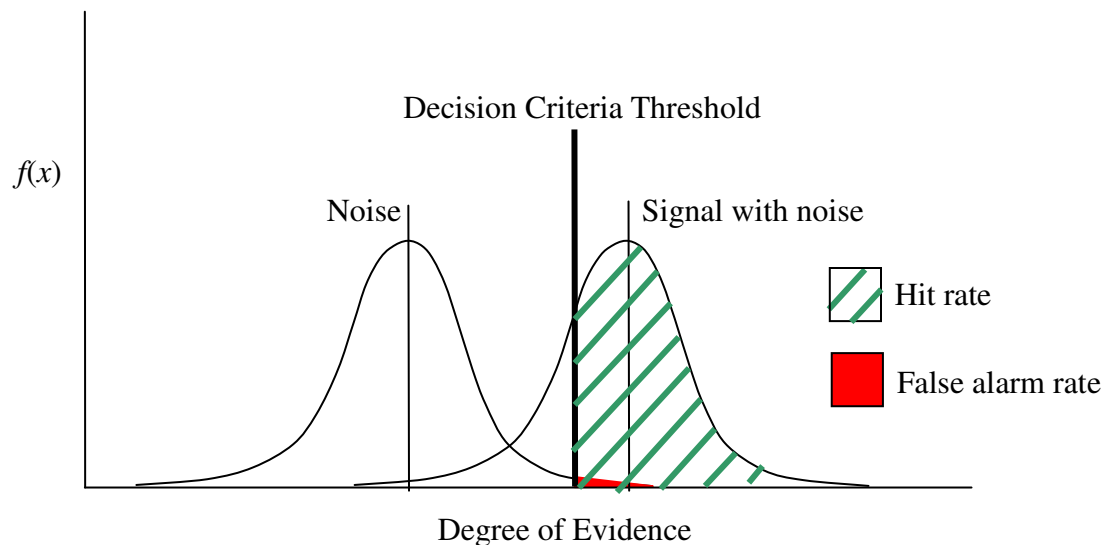


Figure 5 SDT Normal Distributions

The separation between the distributions depends on a subject's expertise, the strength of the evidence, and the amount of noise present. The location of the decision threshold also depends on a subject's expertise. As the expertise of a subject or the strength of the signal increases, the signal with noise distribution should shift to the right and/or decrease its spread.

The area to the right of the threshold under the signal with noise distribution is the probability of making the correct decision given that a signal is present (i.e., a hit). This corresponds to the *hit rate*, H , the number of signals identified correctly divided by the total number of signals present. The area to the right of the threshold under the noise distribution is the probability of making an error given that a signal is not present (i.e., a false alarm). This corresponds to the *false alarm rate*, F , the ratio of the number of false alarms to the total number of instances when no signal is present.

In our context, each unit of relevant information is considered to be a signal. The irrelevant information (if selected) corresponds to false alarms. Given the problem representations with a majority of irrelevant information, the signal to noise ratio is low. To measure a student's ability to select relevant information, we use the separation between the two distributions and the location of the decision threshold (also known in SDT as the *discriminability* and the *bias*, respectively). The separation can be determined by adding the z values from the standard normal

tables corresponding to H and F . The relative location of the decision threshold can be found by the ratio of the z value for F to the separation. The middle of the separation, where $H = 1 - F$, is considered to be an unbiased decision threshold. As it moves to the right, the decision maker is more conservative and requires a higher level of evidence. Moving to the left, the decision maker is more liberal and is willing to accept the information with less evidence.

A non-parametric method for discriminability and bias using H and F was suggested by Stanislaw²⁰. Discriminability, A' , is given by

$$A' = \left(\frac{(H - F)^2 + |H - F|}{4 \max(H, F) - 4HF} \right) S + 0.5,$$

where

$$S = \begin{cases} 1, & \text{if } H > F \\ -1, & \text{otherwise} \end{cases}.$$

The bias, B'' , is given by

$$B'' = \begin{cases} S \left(\frac{H(1-H) - F(1-F)}{H(1-H) + F(1-F)} \right), & H(1-H) + F(1-F) \neq 0 \\ 0, & H(1-H) + F(1-F) = 0 \end{cases}.$$

Open-Ended Sensitivity Analysis

Given the time scale of engineering projects, uncertainty inherent in predicting the future cannot be ignored. To account for this, students learn to perform sensitivity analyses on the economically critical parameters, i.e., those parameters that will have the greatest impact on the decision criterion, which is typically some function of cash flows over a multi-year time horizon. The relevant information provides the best predictions of the critical parameters. Therefore, the identification of these parameters is an indirect measure of how well the problem-solver understands the problem and is able to identify relevant information. The Uncertainty Analysis stage for one case required students to identify a single most critical parameter and report the results of a sensitivity or breakeven analysis on that parameter.

Experience in Engineering Economy Course

In Fall 2006, students in a junior-level engineering economic analysis course completed three progressively more complex and ill-structured group problem-solving exercises.

Loan Analysis

The first problem was adapted from a short case study in the course text²¹. A choice of two car loans was presented: a conventional three year loan or an alternative with lower monthly payments and a final balloon payment. Similar to a financing company's advertising brochure, the problem statement contained a fine print, distracting details and a somewhat misleading claim as to the money saved in the alternative plan. Students working in teams of 3-4 solved the

problem with markers on poster-sized sheets of paper in a 50-minute session. They were instructed to highlight relevant information in the written problem description and show all the steps of their analysis on the solution sheets.

Outsourcing Decision

The second problem was implemented in PSLP. Adapted from a case study text²², it concerned the question of outsourcing production of a small fabricated metal part. Information resources included the details of in-house production, such as various cost components, lead times, and manufacturing layout; also included was information from the vendor's quote with transportation logistics. Of all these resources, the manufacturing layout, with all its associated information about machining times, was irrelevant to the outsourcing decision based on costs. So also, the transportation logistics and lead times quoted (by the vendor and the company itself) were not required to make the outsourcing decision. The Uncertainty Analysis stage for this problem was an open-ended breakeven analysis: students were asked to choose the most critical parameter and describe how much that parameter's current estimate would have to change in order for their recommendation of whether or not to outsource the part would change.

Mortgage Selection

The third problem, also implemented in PSLP, concerned the choice of mortgage financing plans. As in the text supplement²³, student teams were presented with three alternatives for financing the purchase of a specified home: a 30-year fixed rate mortgage, a 15-year fixed rate loan, and a 15-year adjustable rate loan with a rate cap and the interest rate fixed for the first three years. They had to research current interest rates and terms for these three alternatives and choose the one to maximize their net worth at the end of five years. Resources included details of house in question with its final price, a realtor's estimate of the price inflation in the area where the house is located and regulations regarding the property tax in that area. Some concerns raised by the spouse such as the monthly budget for the mortgage payment were also provided. Sample calculations regarding different types of mortgages were included as guide to students. Lastly, an array of related resources available in the public domain were given which included a statement from the Chairman of the Board of the Federal Reserve and a recent government report regarding growth in the housing sector. The only information relevant to the problem was the information about the mortgage rates, available savings rate, the price of the house and its projected inflation over the duration for which the house would be owned. After the solution was submitted, the Uncertainty Analysis section presented students with the additional alternative of refinancing the adjustable rate loan to a fixed rate after the initial three year period. However, the fixed rate available at that time was presented as unknown.

A long term capital investment analysis problem has also been implemented in PSLP¹⁶ but was not used in the study reported on here.

Signal Detection Results

The values for H and F were calculated for each team of students for all three problems, based on all the information highlighted in the pen-and-paper problem, or included in the Working

Memory, Assumptions, and information sections of the solution spreadsheets in PSLP. The results are shown in Figures 6 and 7 as the Receiver Operating Characteristic plots. By plotting the z values from the standard normal distribution for H and F , we can see the discriminability and bias. These values are computed from the relationship $P = \Pr[Z > z_p]$ as $z_p = \Phi^{-1}(1 - P)$, where P equals F or H , respectively, and $\Phi(\cdot)$ is the standard normal cumulative distribution function. We approximated z_1 as -3 and z_0 as 3. The diagonal from the lower left to the upper right corresponds to distributions with no separation. As we move to the upper left corner, the separation increases. The bias is indicated by the distance from the diagonal passing through the upper left corner. This diagonal corresponds to a decision with no bias.

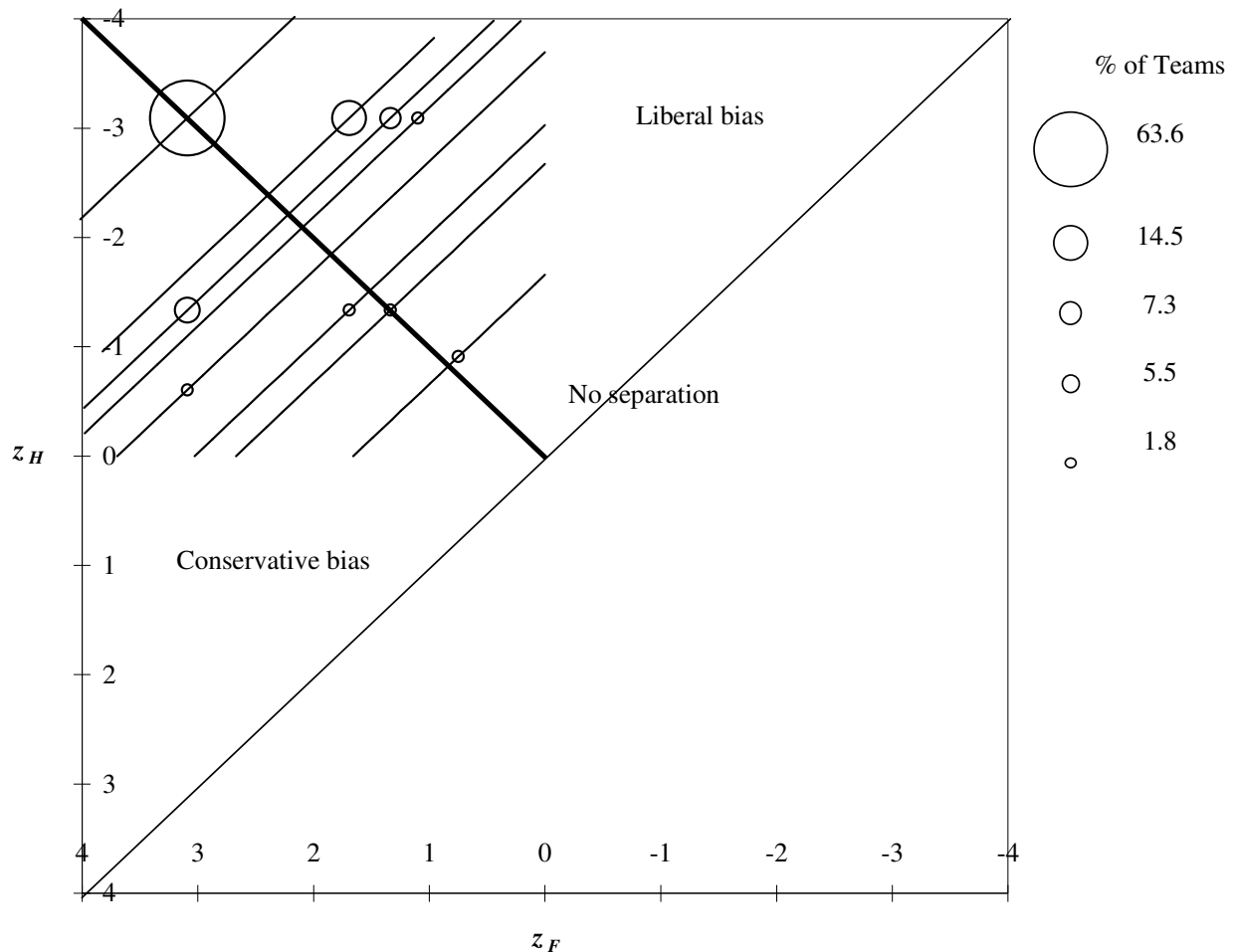


Figure 6. Receiver operating characteristic for Outsourcing Decision problem.

As seen in Figure 6, in the Outsourcing Decision problem, the majority of the teams had the highest possible discriminability and no bias as indicated by the largest bubble in the upper left corner. This corresponds to a hit rate of 1 and a false alarm rate of 0. The next group of teams has less discriminability and shows significant bias in both directions. More teams are willing to accept false alarms (i.e., a liberal bias). A small number of teams show poor discriminability and

therefore, poor information reduction skills. Given the relatively small number of resources and the relative simplicity of the Outsourcing Decision problem, these results are not surprising.

In contrast, the simpler Loan Analysis problem shows a pronounced liberal bias (Figure 7). The majority of teams (55%) had a perfect hit rate but also a substantial false alarm rate ($z_F = 1, z_H = 3$), and all the teams had hit and false alarm combinations on or above the “no bias” diagonal.

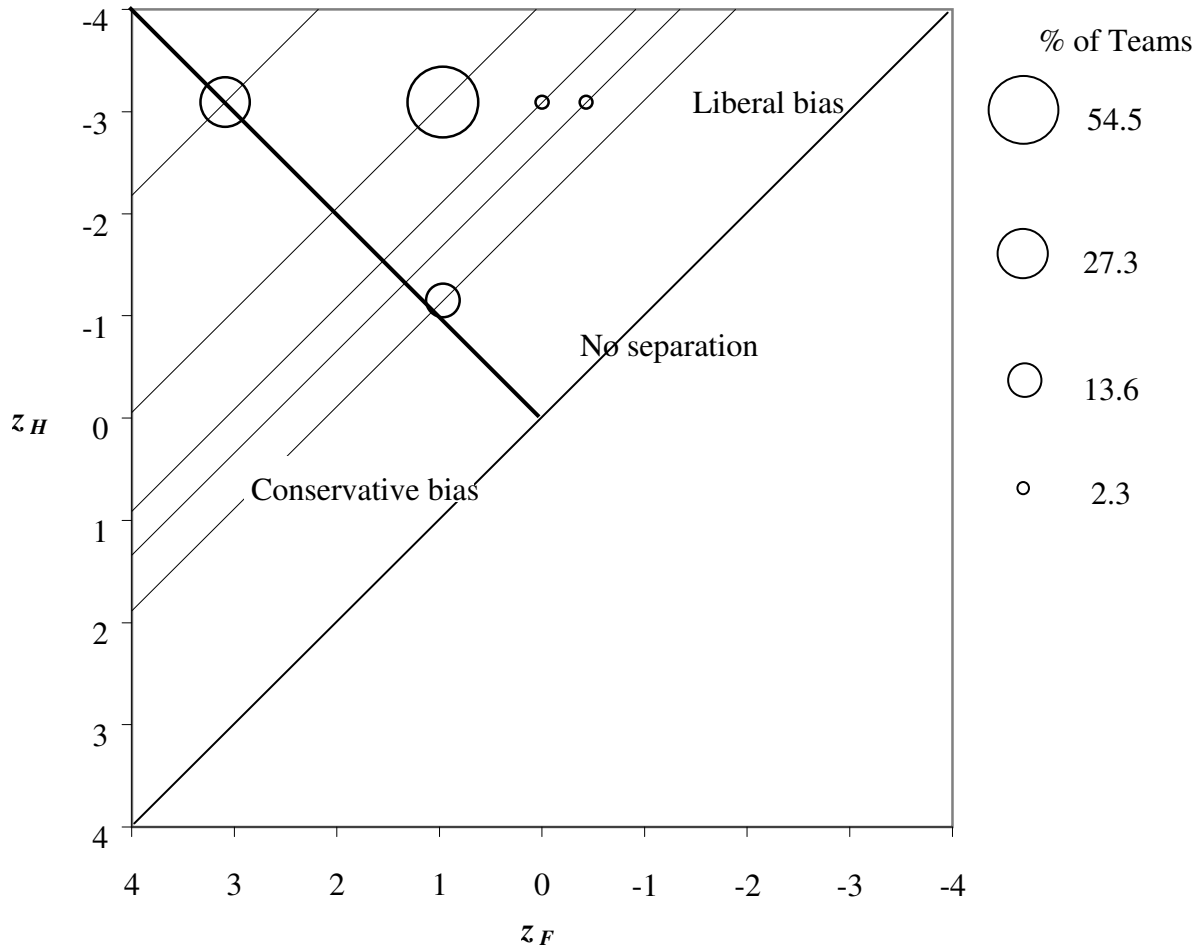


Figure 7. Receiver operating characteristic for the Loan Analysis problem.

In the Mortgage Selection problem, the results in Figure 8 show a wider range of information reduction skills as indicated by the spread of teams throughout the discriminability range. The largest percentage of teams indicated strong discriminability (again as indicated in the upper left corner). There is a major shift of teams into the conservative bias and these teams also show relatively low discriminability as compared to the previous group. The bias may indicate that students did not fully explore the information resources, had confusion about their problem formulation, or that they had less confidence in their selection process. This problem had more

information than the previous problems which may have contributed to the information reduction difficulty level.

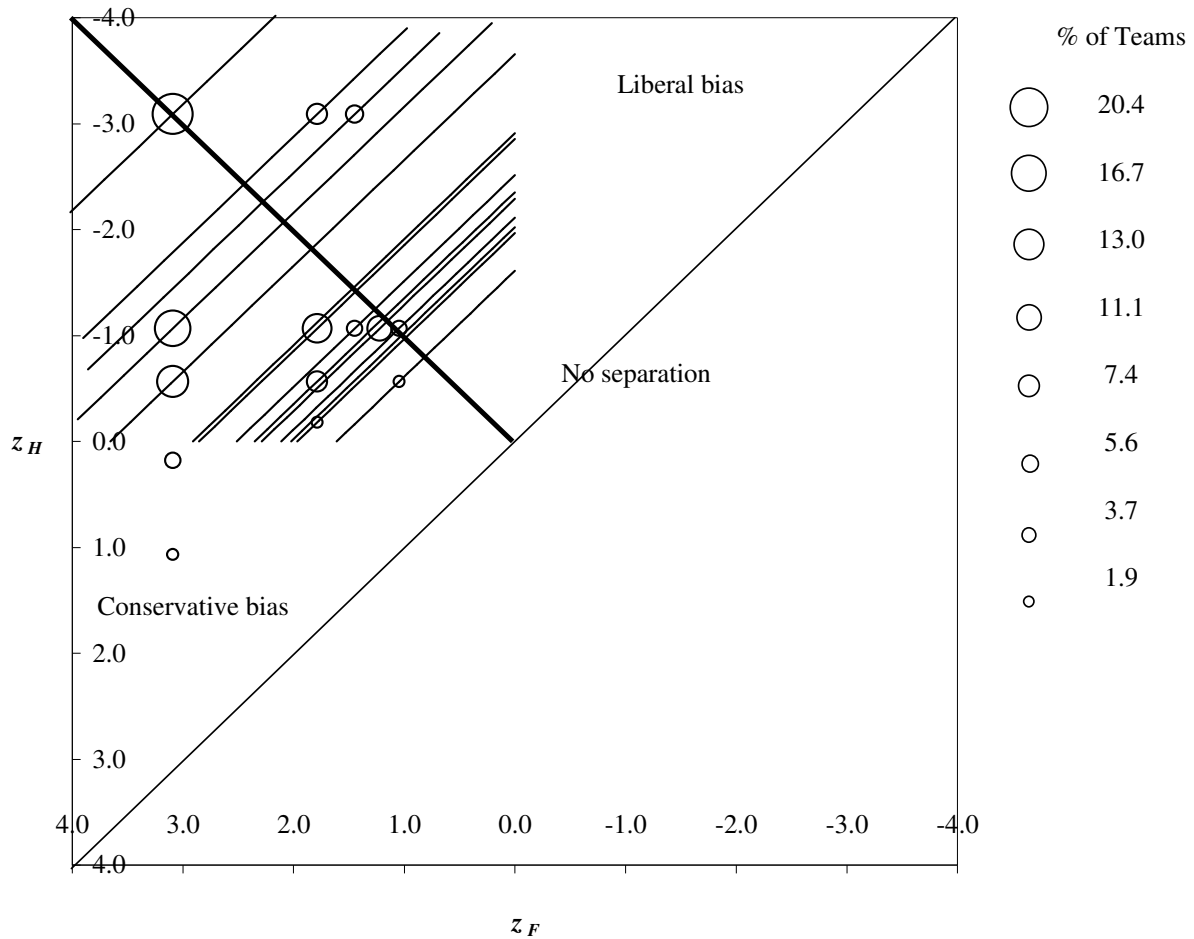


Figure 8. Receiver operating characteristic for Mortgage Selection problem

Do information reduction skills contribute to overall problem-solving performance? For the Mortgage Selection problem, we performed a regression analysis on the team scores versus the A' (discriminability) values, which we consider to be a measure of information reduction skill. The team scores included scores for individual problem stages up to the solution stage, but not the rubric criteria for evaluating assumptions or working memory. We obtained an R^2 value of 0.17 as seen in Figure 9. As would be expected there is considerable noise in the results, indicating that in addition to errors, more than one skill is in use here. Nevertheless, this is a good indication that the information reduction skill level plays a role in overall problem solving performance.

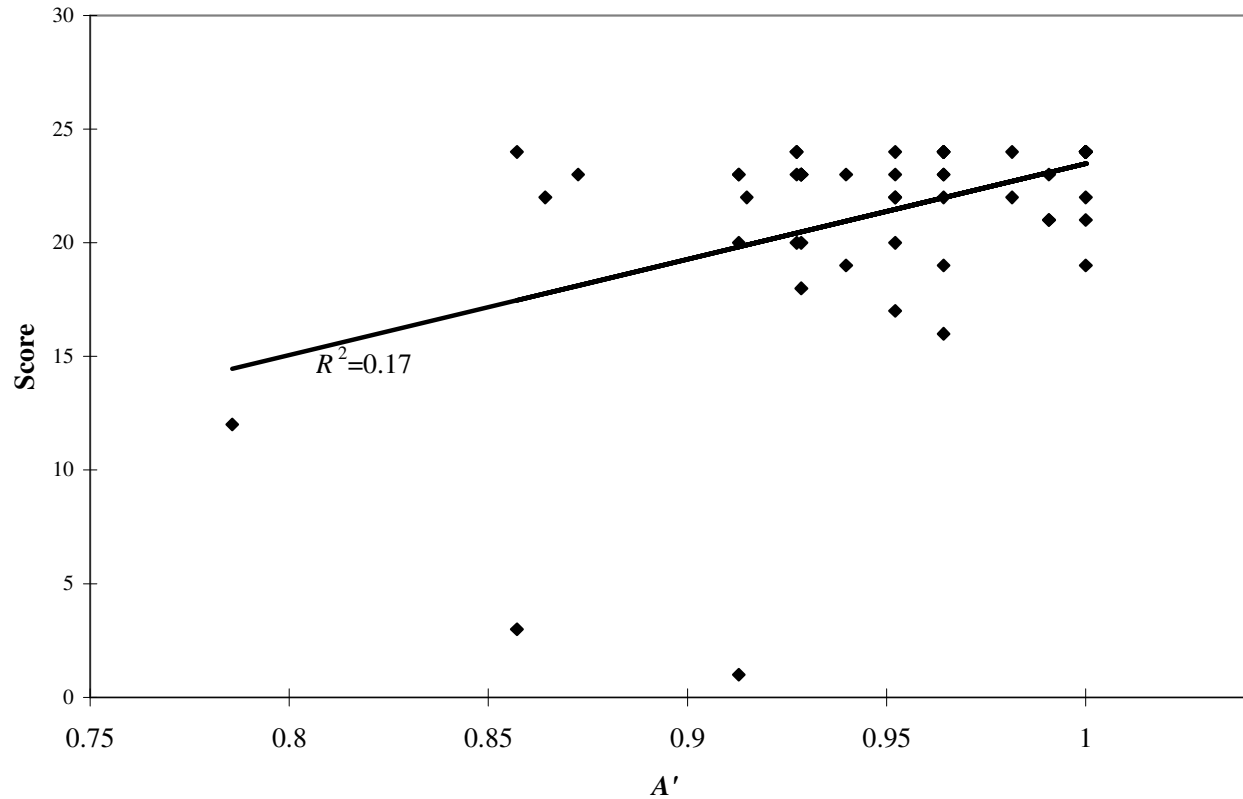


Figure 9. Regression Analysis of Score versus A' for the Mortgage Selection Problem

Choice of Critical Parameter

In the Uncertainty Analysis of the second problem, student teams chose a single parameter on which to report the results of a breakeven analysis. Table 1 shows the five parameters most frequently selected in descending order of frequency, the number of teams that selected each one, and the true absolute percentage change that would be required for that parameter to change the optimal decision. Thus, a Pareto analysis would identify outsourcing cost as the most critical parameter because it has the smallest percentage value needed to affect the results (also the most relevant single piece of information), followed closely by demand. Most student teams chose to report the impact of changing demand, and an equal number of teams chose labor cost as chose outsourcing cost, even though labor cost would need to change proportionally by nearly twice as much to change the optimal decision. Note that in the appropriate short-term or steady state analysis, the MARR and inflation rate are actually irrelevant so that only assumed values were used by a few student teams.

The choice of parameter to analyze may have been influenced by the ways in which the different pieces of information were presented. The demand rate given was accompanied by a statement that the product was in a mature phase of its lifecycle and its demand was expected to hold constant for the next few years. A memo from the supplier stated the outsourcing cost as the best unit price they could offer. Labor cost was communicated in an inter-office memo from HR Management to Central Management Services. The text explanations explaining the teams'

choices of parameters to evaluate suggested that the decisions were influenced by the perceived level of uncertainty associated with the different parameters; i.e., demand was chosen partly because its given value was merely a forecast whereas the supplier's "best price" offer and the current labor cost were deemed unlikely to change. Using sensitivity analysis to select the most critical parameter, e.g., by computing the values in the third column of Table 1, may not have occurred to students because formal sensitivity analysis had not yet been covered in class.

Table 1. Parameters selected for exploration in Uncertainty Analysis.

Parameter	No. of Teams Selecting as Most Critical	% Change Req'd to Change Decision
Demand	24	15.6
Outsourcing Cost	8	14.0
Labor Cost	8	26.9
Facility Planning & Maintenance (FPM) Cost	4	29.8
MARR/Inflation Rate	4	∞
Other (each selected by a single team)	5	-

Teams selecting demand as the most critical parameter had, on an average, greater separation between the signal and noise means ($A' = 0.994$) than other teams; their average B'' value of -0.014 indicated a bias towards the *yes* response (meaning that, on average, they picked a higher number of resources as relevant, even though some of them were irrelevant). On the other hand, teams selecting outsourcing cost as the most critical parameter had on average slightly smaller separation than the previous group ($A' = 0.992$) and a slightly larger bias towards *yes* signals ($B'' = -0.125$). The eight teams that selected labor costs as the most critical parameter had the lowest Hit and False Alarm rates compared to the previous two groups, resulting in a slightly smaller separability ($A' = 0.991$) and a net bias towards the *no* response ($B'' = 0.125$). While the small differences between the A' values probably is not significant, the more liberal bias of the teams who correctly identified either demand or outsourcing cost as most critical is consistent with previous observation of experienced problem solvers being more liberal than novices²⁴.

Student Actions

PSLP tracks student actions (e.g., selecting an item or submitting a response) and stores the data in a relational database. By analyzing the actions for a group, we can obtain some general insights into the student problem solving process. The majority of students appear to solve the problem in multiple sessions as shown by student actions in Figure 10 for a typical group. The actions correspond to accessing information resources, adding or deleting information in the working memory, or working in the different stages of the problem solving process. We also

indicate the relevant and irrelevant items added to the working memory. Adding an irrelevant item is coded as a value of -1, while a relevant item is coded as a +1. Initial stages are marked by multiple visits to resources and the problem description along with operations to the working memory, with the dominant visits corresponding to information resources. This stage represents the information gathering and reduction activities.

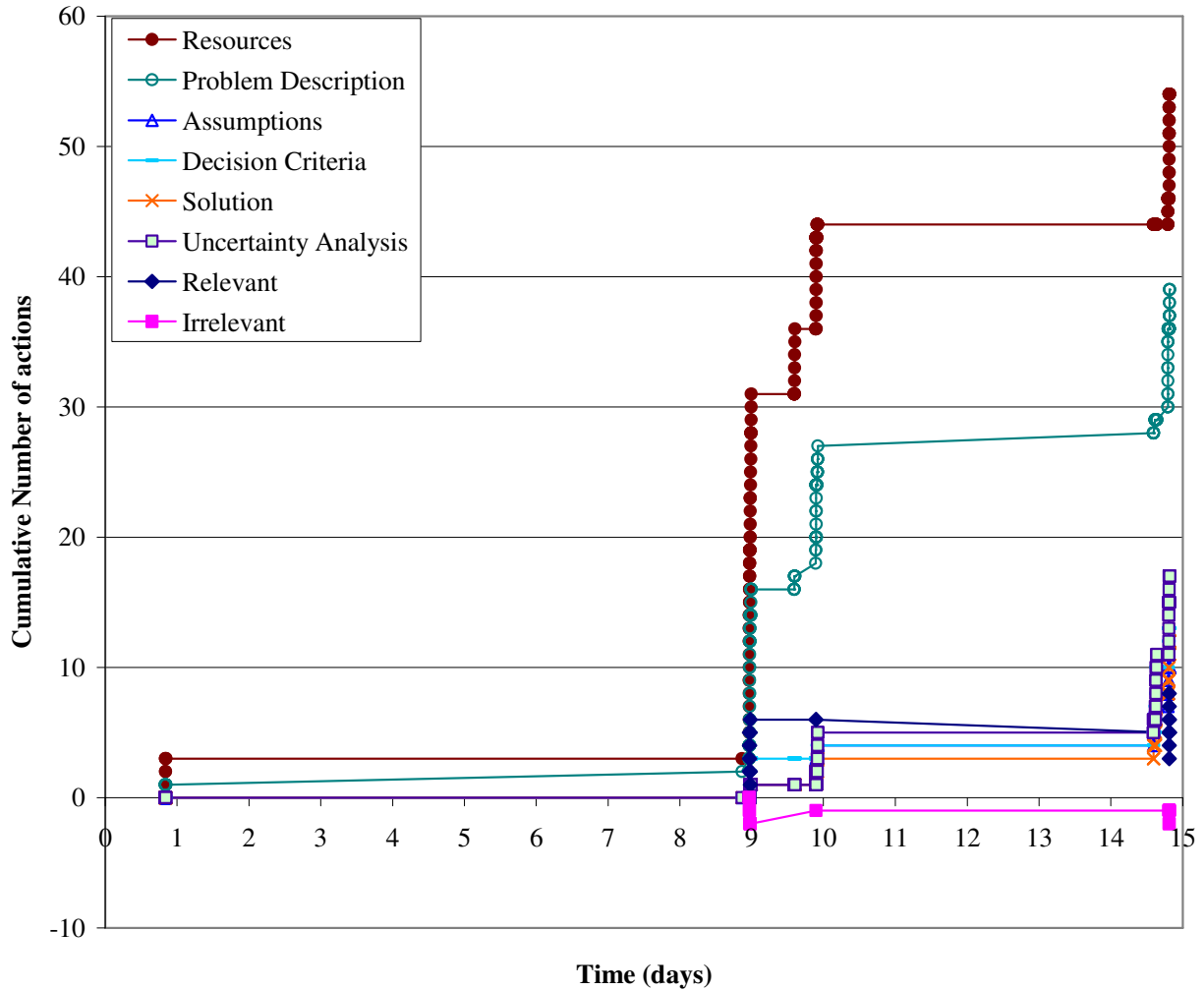


Figure 10. Example of a typical set of actions for a group

The final stage is focused on the solution and uncertainty analysis, but there is considerable refinement of the relevant and irrelevant information. For clarity, this stage has been expanded in Figure 11. There appears to be a relatively uniform distribution of actions across the stages, information resources, and working memory. This may indicate that students are reflecting on their solution to the problem (i.e., engaging in metacognitive activity) and revisiting information sources to either verify their conclusions or perhaps seek out additional information that they missed in the early stages.

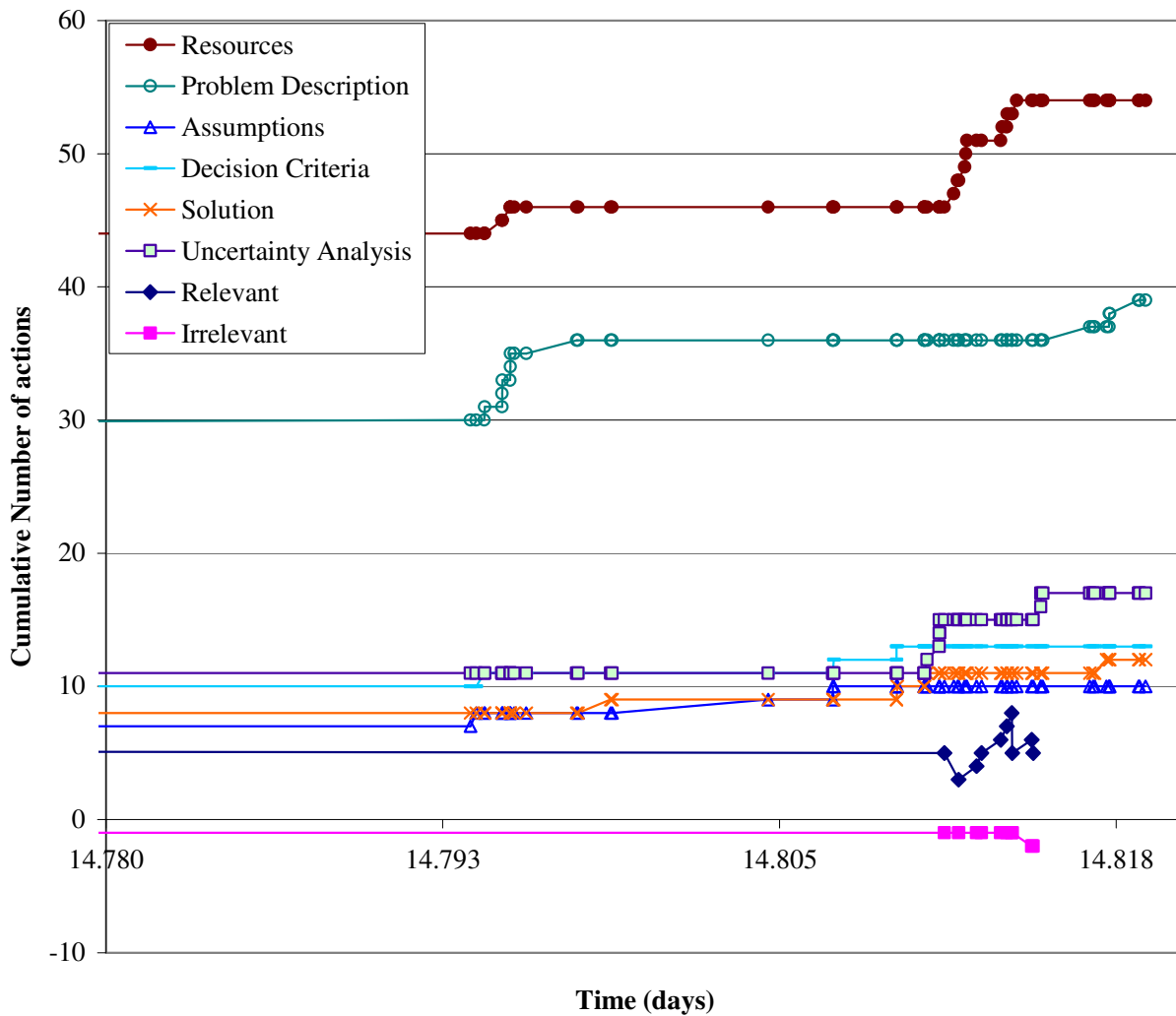


Figure 11. Close-up of student actions

Discussion and Conclusions

In this paper we have reported preliminary results of analyzing the information reduction behavior of engineering students as they solve progressively more difficult and less structured problems. In the loan analysis and outsourcing instances, the basic decision problem was relatively straightforward but students had to sort relevant from irrelevant information and also evaluate the information communicated with varying degrees of uncertainty. They were generally successful at both distinguishing the relevant information and successfully solving the problem. Their signal detection behavior showed a liberal bias, which may reflect their positive level of comfort with the problem-solving task. In the outsourcing analysis problem, the teams who correctly identified the most critical parameter, irrespective of the amount of uncertainty associated with it, exhibited more liberal bias than the other teams. In the mortgage selection problem, where not all the relevant information was provided and the problem was more difficult to solve, students showed more conservative bias. We conjecture that this conservative bias is

evidence of discomfort or lack of confidence when faced with a large and complicated set of information resources, including the external world from where some information had to be gathered. Limiting the amount of information judged to be relevant is one way of simplifying the problem-solving task. The discriminability measure of information reduction skill was positively correlated with overall problem-solving performance on this ill-structured problem.

The online environment provides a wealth of click-stream data that we plan to analyze in depth in the near future. The sample paths of student actions included in this paper give an overview of problem solving strategies over time. By also examining the order in which resources are explored as well as patterns of adding and deleting both relevant and irrelevant items from the Working Memory, it may be possible to identify more or less successful strategies for information reduction. For example, based on data collected from the PSLP in a physics course, Antonenko et al.¹⁸ found that with experience, students accessed more information about underlying principles and more relevant instance-specific information, and the resource requests were interspersed more frequently with other problem-solving tasks. This evidence suggested that early in the course the student teams were indiscriminately exploring all the information resources, but with practice, they guided their information-seeking more by analysis after taking time to understand the relevant concepts. Identifying successful strategies for information reduction could improve pedagogy that prepares students for solving ill-structured problems in professional practice.

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