# Scaffolding Transfer Activities Through the Use of Concept Maps to Enhance Adaptive Problem Solving in an Introductory Engineering Technology Course

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## Introduction

In the industrial age "knowing what" and "knowing how" to transfer well-structured problem solving skills learned in one context to another context was sufficient for most job positions. With the movement to an information age, problem solving has expanded into the required ability to transform domain-dependent problem solving skills learned in one context into domain-independent skills capable of solving ill-structured problems [1]. Becoming an expert problem solver within this new environment means adding, "knowing why" to what and how knowledge. The typical instructional solution to enhance the student's problem solving skills is to add a "messy" end of course project, based on the faculty member's industrial experience or consulting work. Depending on the nature of the problem and the student's familiarity with the project context, student success can be limited. Spiro delineated this condition, stating "cognitive and instructional neglect of problems related to content complexity and irregularity in patterns of knowledge use leads to learning failures that take common, predictable forms (failure to transfer)"[2]. This investigation addresses the underlying theory and evidence advocating concept maps as a method for scaffolding problem solving transfer. In order to minimize the failure to transfer, both the problem solver's factors and the instructional factors must be addressed.

The instructional factors addressed in this investigation include the nature of the problem and instructional interventions that support the application of a problem solving process. Jonassen in 1997 defined a problem's nature by the attributes of complexity, domain specificity, and structuredness [3]. In an instructional environment, the prescribed objectives or stated competencies control the attribute of complexity, while the level of abstractness defines domain specificity. For the third attribute, structuredness, Jonassen in 2000 proposed a taxonomy of problems based on structuredness [4]. Typical ill-structured problems include design and diagnosis-solution problems, while well-structured problems include story and algorithms. Figure 1 illustrates the continuum for these three variables of complexity, abstractness, and structuredness. Obviously, an abstract, complex, and ill-structured problem provides greater cognitive load to the student than a contextual, minimally complex, and well-structured problem. Cognitive load is defined as "the amount of effort-demanding, controlled processing that is imposed on a learner's cognitive system"[5]. The greater the cognitive load the greater the likelihood of student frustration and failure, however on successful completion the greater the developed skill in problem solving transfer.



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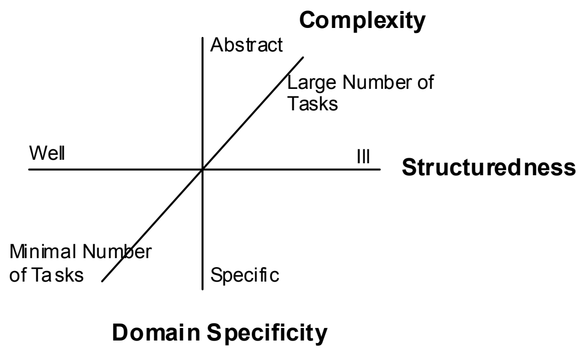


Figure 1. Problem's nature.

Possible instructional intervention strategies used to reduce cognitive load could include: verifying prerequisite skills [6, 7], practicing and providing feedback [8, 9], using guided discovery [10], collaborating [11, 12], presenting the problem [13], and selecting scaffolding macrostrategies [10, 12]. While all these intervention strategies should be considered in the development of instructional materials, the focus of this investigation is on the use of concept maps to reduce the cognitive load inherent in the transfer of problem solving skills.

Problem context

Sinclair Community College, through the Advanced Integrated Manufacturing (AIM) Center, received grant funds from the National Science Foundation (NSF) for the creation of a National Center of Excellence for Advanced Manufacturing Education (NCE/AME) currently known as the National Center for Manufacturing Education (NCME). A key deliverable of the Center is the development and implementation of a novel, activity-based, competency-based, contextual, industry-verified, modular curriculum in manufacturing engineering technology to be completed by June 2004. This curriculum supports the broad NSF educational goal as stated by Lane, former Director of the NSF, of "reaching all students at every level by promoting inquiry-based, hands-on learning experiences in science, mathematics and engineering" [14]. In order to accomplish the inquiry-based, hands-on learning goal, the Center's Project Development Team (PDT) proposed a new instructional systems design model during the summer of 1995 [15, 16]. An essential element of the design is the use of a transfer activity that allows the students to reinforce and extend competencies mastered in previous learning tasks to a new problem solving context. Transfer is defined as "the ability to perform an acquired skill in new, unfamiliar situations" [5]. The purpose of the transfer activity is to provide integration of the competencies introduced through the module's previous learning events and to provide an opportunity to apply the learned skills to a real world problem. The real world problem is based on a virtual company, a macrocontext, Robotic Grippers, Inc. This transfer activity also encourages teamwork, and it hypothesizes that the learning is extended because it stimulates students to make connections and generalizations about the competencies learned after applying them in a new way [17, 18]. The application of the product realization process to the making of a robotic gripper provided the instructional sequence. The use of this macrocontext is supported by Spiro's Cognitive Flexibility Theory. Spiro, Feltovich, Jacobson, and Coulson stated "the central claim of the Cognitive Flexibility Theory is that revisiting the same material, at different times, in rearranged contexts, for different purposes, and from different conceptual perspectives, is essential for attaining the goals of advanced knowledge acquisition" [19]. Anecdotal comments from students support the supposition that solving a variety of problems, using the same macrocontext from different perspectives, helps students integrate and transfer the skills to the workplace [20]. This student observation concurs with the conclusion of the Cognition and Technology Group at Vanderbilt (CTGV). The CTGV concluded that elementary school students, who used *The Adventures of Jasper Woodbury Series* macrocontext, demonstrated superior transfer to new analogous problems within the class, between classes, and outside the school setting [21]. The use of real world problems increases student motivation and enhances the student's ability to apply the learned skills. Formative evaluations of pilot tests reveal that significant student learning and student satisfaction occur when utilizing the instructional materials; no research studies have been done, however, to measure the student's ability to transfer acquired skills. Possible adopters have questioned the educational necessity of the transfer activity and have requested supportive research data.

The NCME advocates that adopting organizations customize the transfer activities in order to reflect macrocontexts found in their own learning communities. While the instructional system design model/template specifies the task complexity through the specified competencies, it currently does not provide guidelines for the problem abstractness or problem structuredness. A second issue is that the instructional design does not provide for a specific scaffolding technique to enhance the transfer of the student's problem solving skills to a new context. In order to improve the quality of the NCME instructional materials and to aid in the adoption of the materials by potential customers, these questions and concerns were addressed in the study.

## Purpose of the Study

This research investigation answers the primary question: What scaffolding effect does the application of a problem solving process to the solution of a well- or ill-structured activity have on transferring those competencies learned to the solution of a new problem? As the nature of work shifts from repetitive task skills to solving ill-structured problems, the importance of this research is evident. How do we design and scaffold curriculum that reduces the cognitive load and at the same time maximizes adaptive problem solving? This research question tests the NCME module architecture model and the use of a scaffolding intervention as a potential solution to these stated problems [20]. Answering this question about the NCE/AME model will allow for the generalization of the results to a very similar instructional design model, the vanMerriënboer 4C/ID [5]. Based on Jonassen's 1997 criteria, both of these models use ill-structured activities, which are designed to integrate and transfer the desired subskill tasks [3]. The activity in the NCME model is called a "transfer activity;" in the 4C/ID model it is referred to as a "whole-task practice." Both of these models also support "subtask mastery." It is clear that the two models mirror each other in the approach to instructional design. VanMerriënboer advocates the need for research to test the claim that the "appropriate design of whole-task practice is critical to reaching the goals...of problem solving and transfer of the non-recurrent aspect of complex cognitive skills as an overall learning outcome" [5]. The results of this research will aid in the decision as to which instructional combinations are the most effective, will provide guidance as to the classification of activities as to their structuredness, and will verify the effectiveness of concept maps as an instructional intervention.

## Review of the Literature

The literature review focuses on three areas: cognitive domain knowledge representation;

effectiveness of concept maps; and characteristics of well- and ill-structured problems and problem solving models. The first two topic areas focus on the learner's ability to acquire, to classify, and to use knowledge. The last topic area focuses on the types of problems and their corresponding solution processes.

Cognitive domain knowledge and representation

This section reviews various cognitive domain taxonomies, starting with Bloom, and then develops the relationship between structural knowledge and supportive cognitive theories. Bloom and his colleagues developed a taxonomy for classifying cognitive educational objectives; these objectives "deal with the recall or recognition of knowledge and the development of intellectual abilities and skills"[22]. Since that formative work, additional taxonomies have been proposed. Reigeluth and Moore synthesized those various proposed cognitive domain taxonomies and included metacognition as an intellectual skill. The synthesized taxonomy includes four cognitive levels: memorizing information, understanding relationships, applying skills, and applying generic skills [1]. Table one below presents a modified instructional taxonomy that addresses Bloom's, Anderson's, and Reigeluth's taxonomies, and includes the inclusion of Jonassen's emphasis on the need for structural knowledge and the author's characterization of the categories.

Table 1. Comparison of Taxonomies

| Bloom | Anderson and Jonassen | Reigeluth |
|---|---|---|
| Knowledge | Declarative knowledge (knowing what) | Memorizing information |
| Comprehension | Structural Knowledge (knowing why) | Understanding relationships |
| Application | Procedural knowledge (knowing how) | Applying skills |
| Analysis<br>Synthesis<br>Evaluation | Metacognitive knowledge (knowing knowing) | Applying generic skills |

Anderson defined declarative knowledge as knowledge about facts and things, the ability to define or describe an object [23]. Anderson further described procedural knowledge as the knowledge about how to perform, use, or apply declarative knowledge. Declarative knowledge is also described as "knowing that." If a learner can describe or define an object, but at the same time may not understand or be able to apply that knowledge, then the knowledge is declarative in nature. This declarative knowledge is typically stored as a schema or information packet [23].

Reigeluth's apply skills and Bloom's application taxonomy are equivalent to Anderson's procedural knowledge, the knowledge of "knowing how" [1]. Anderson defined procedural knowledge as how to perform various tasks; a related term, proceduralization, is "the process by which learners switch from explicit use of declarative knowledge to direct application of procedural knowledge" [23]. As is apparent, understanding relationships and applying generic skills have no equivalent designations under Anderson's taxonomy. Jonassen et al. (1993) proposed the concept of structural knowledge as a necessary addition to Anderson's taxonomy of declarative and procedural knowledge [24]. This new knowledge structure appears to be equivalent to Bloom's comprehension or Reigeluth's understanding relationships.

This structural knowledge, also known as cognitive structure, means "knowing why" and describes how declarative knowledge is connected. The cognitive structures evolve from the assignment of attributes, by association or implication, to objects, thus creating a structural relationship among concepts. The object-attribute model originates in Kelly's personal construct theory (as cited in Jonassen et al., 1993), which focuses on the creation of attribute-based personal constructs. These constructs allow individuals to interpret their own reality. These constructs are changed or modified based on new or conflicting information [25]. The higher order thinking skills category, defined by Bloom and by Reigeluth, is not explicitly defined under Anderson's criteria. Applying a broader interpretation of the definition of structural knowledge based on Kelly's personal construct theory expands structural knowledge to include these higher order skills the author characterizes this metacognitive knowledge as knowing knowing. Given the importance of structural knowledge, which tools and corresponding instructional strategies support the learning of structural knowledge? This question was answered in part by the efforts of Jonassen et al. to document the steps necessary for the eliciting, conveying, and assessing structural knowledge [24].

Jonassen et al. provided instructions and confirming theoretical support for eleven explicit and implicit models that can convey structural knowledge. One of these models, a concept map, has received wide spread support as a practical instructional tool [26, 27]. A concept map illustrates relationships among objects or ideas using a two dimensional diagram. As illustrated in Figure 2, the concepts are linked by arrows and labeled to identify the relationship between the objects or events.

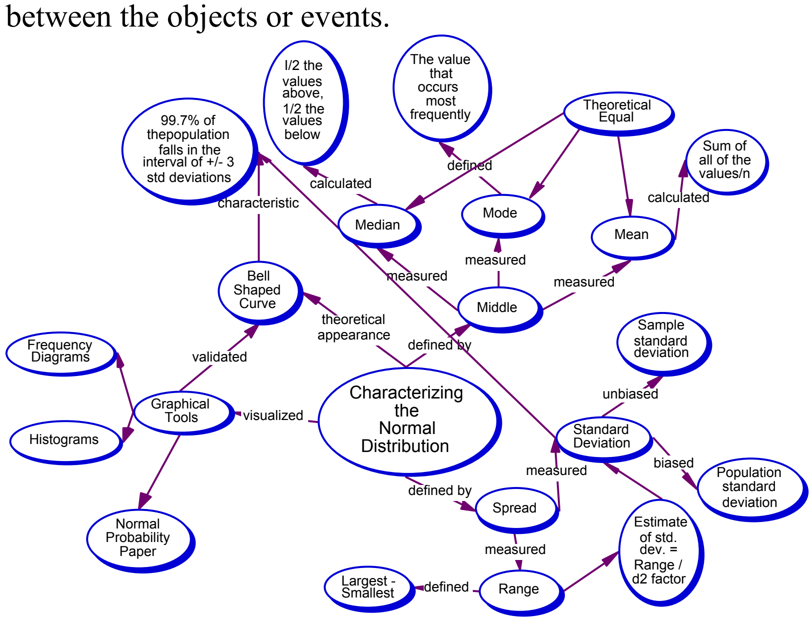


Figure 2. Example Concept Map

The maps are hierarchical or heterarchial in nature with the broadest concept at top or in the center. The subordinate concepts of the maps are below or around the broadest concept. Ausubel's Assimilation Theory provided a theoretical basis for concept maps: "The result of the interaction that takes place between the new materials to be learned and the existing cognitive structure is an assimilation of old and new meanings to form a more highly differentiated cognitive structure" [28].

The use of concept maps to enhance a student's structural knowledge can also affect a student's attitude by reducing the cognitive load. Clark addressed the importance of the right balance of cognitive load in order to motivate the learner [29]. Overall, the use of concept maps is expected to improve the student's domain knowledge and form, cognitive and metacognitive skills, and attitude. The next section reviews the published results of applying the theory of concept maps to instructional situations.

Effectiveness of concept maps

The application of the use of concept maps documented in the literature supports the theory that it improves student performance. This improvement is accomplished by assisting the student in organizing their declarative knowledge and problem solving processes. Horton and his colleagues performed a metanalysis of nineteen studies using concept maps with the results indicating concept maps having positive effects on student achievement and attitudes [30]. Wedge in her investigation concluded that concept mapping within a Computer Aided Instruction lesson can produce measurable gains in achievement [31]. Ferry, Hedberg, and Harper reported on pre-service teachers' use of a concept-mapping tool to create/modify concept maps about science-related elementary curriculum-content knowledge [32]. The process enhanced their skills in planning instruction. Kuhn and Novak in 1971 conducted an investigation in which students who read an "organizer" before studying biological material prior to instruction scored higher on retention tests than students who read an historical passage prior to instruction [33]. Okebukola concluded that concept mapping subjects were significantly more successful at solving biological test questions than control students [34]. Beissner involving 58 freshman and sophomore physical therapy and athletic training majors, determined that students using concept mapping as a study strategy improved their problem solving ability when compared with students in the control group [35]. This conclusion was based on the results from an administered problem solving test analyzed with the use of multiple regression. From the results it is clear that the use of concept maps can significantly enhance student performance. The cited studies all reported enhancement in the participants' cognitive skills due to the use of concept maps. These improvements included increased planning and organizing skills, improved recall of instructional materials, and enhanced problem solving skills.

The pivotal work conducted by Schwartz and Bransford in the systematic development of the protocols for the successful application of concept maps is summarized in the following paragraphs. The stated goal of Schwartz and Bransford's study was "to begin a theoretical and empirical exploration of when to use texts, lectures and explanations within the total repertoire of instructional methods" [36]. One of the major hypotheses guiding the work that differed from previous studies was the use of active comparison of relevant contrasting cases to foster well-differentiated knowledge. Active comparison alone is typically insufficient for students to induce a deep understanding of the domain principles. Three different experiments were conducted with two different college classes. In experiment one the students, twenty-one undergraduate students in two treatments, were provided with two cases as part of a homework assignment, the doctor visit and the balloon passage. In this crossover design the students either analyzed the doctor visit and read the balloon passage, or analyzed the balloon passage and read the doctor visit. Both groups then listened to a lecture on the content. The students were then evaluated on their memory skills (encoding) by judging whether a claim about a target concept was correct; and on their predictive skills (schema) by transferring their learning by making predictions about a hypothetical study. The findings concluded: first, that students who either summarized or analyzed contrasting cases followed by appropriate lecture performed the same on memory concepts; second, students who analyzed contrasting cases followed by appropriate lecture performed significantly better on predictive tasks than students who summarized contrasting cases followed by lecture.

Experiment two followed the same general outline as found in experiment one. Eighteen graduate students in two treatment groups of students were randomly selected and either had to read and summarize the two case problems in a textual format, or read and analyze the two case problems and produce a concept map of the important elements. After the homework assignment was turned in, the students received additional reading materials that covered the elements that would have been developed in the lecture. The students were then evaluated on their predictive schema as in experiment one. The findings for experiment two concluded that: first, students who either summarized or analyzed contrasting cases followed by appropriate readings performed the same on memory concepts; second, students who analyzed contrasting cases followed by appropriate readings performed significantly better on predictive tasks than students who summarized contrasting cases followed by lecture.

The third experiment used a mixed design with all the assignments completed within the classroom setting. As an in-class exercise the students analyzed the balloon cases and submitted the results, followed by a lecture on the topic. Thirty-six undergraduate students were randomly allocated to one of three defined treatments: 1) analyze and lecture; 2) analyze and analyze; or 3) lecture and lecture. The students completed the same predictive evaluation as in experiment two. The findings for experiment three concluded that students who analyzed contrasting cases followed by lecture performed better on predictive assessments than students who analyzed twice the number of contrasting cases or summarized contrasting cases followed by lecture.

These experiments clearly outline the need to use instructional strategies based on contrasting cases. The intent, of the experimental design defined under methodology, is to replicate parts of the Schwartz and Bransford's experiment two using the defined treatments: summary followed by readings/discussion; and analysis (concept map) followed by readings/discussion. Inherent in the proposed instructional design is the ability to transfer the knowledge learned in one context to a new context.

Characteristics of well- and ill-structured problems and problem solving processes

This section provides guidance information on structuredness for classifying and measuring problems and presenting problem solving models or strategies. Typically, problems are classified by domain, type, problem space, or solution. The problem domain classifications describe the concepts, principles, and rules necessary to define the problem elements; for example, the physics domain. Problem type classifications are defined by the application; for example, conservation of energy. A problem space or schema classification includes a definition of the initial state and the process to reach an acceptable solution [3]. More recently, efforts have been directed to examine and define problem types based on a problem's structuredness. Table 2 provides contrasting characteristics of well- and ill-structured problems.

Jonassen proposed and refined a taxonomy of problems and ranking problem types from well- to ill-structured. These taxonomy categories include "puzzles, algorithms, story, rule using, troubleshooting, decision making, diagnostic solution, strategic performance, case analysis, design, and dilemma" [4, 40]. Jonassen's work builds on the Spiro et al. discussion of ill-structured knowledge domains where each knowledge application typically involved multiple conceptual structures such as schemas, perspectives, or organizational principles [19]. Additionally, the application complexity and the interactions among the conceptual structures varied across applications of the same type. Of the eleven taxonomy categories, seven apply directly to business and industry problems, including product or process design, decision-making, troubleshooting, and improvement activities. These seven categories, and their supportive knowledge structures (in parentheses), are easily grouped into four problem categories: algorithmic-story-rule (goal plan hierarchies), decision making (goal plan hierarchies), troubleshooting-diagnosis solution (causal models), and design (conceptual). The choice of appropriate knowledge structure organizers for these problem solving categories could include: hierarchies, cross classification tables, causal interaction maps, cause and effect diagrams, fault trees, and concept maps.

Table 2. Structuredness Characteristics of Well- and Ill-Structured Problems

| Well-Structured Problems | Ill-Structured Problems |
|---|---|
| 1. "Present all elements of the problem" [3] | 1. Lack definition of one or more of the problem elements [37] |
| 2. Have clearly stated goals or outcomes | 2. Have vaguely defined or unclear goals and constraints [38] |
| 3. Have a probable solution | 3. Possess multiple solutions, or no solution [39] |
| 4. Have defined evaluative solution criteria | 4. Possesses multiple criteria for evaluating solutions" [3] |
| 5. Require only a limited number of regular procedural rules and principles | 5. "Present uncertainty about the organization or use of the possible procedural rules and principles" [3] |
| 6. Possess consistent relationships between concepts, rules, and relationships | 6. Possess inconsistent relationships between concepts, rules and relationships |
| 7. Fall within well-structured and predictable domains of knowledge | 7. Fall within unstructured or unpredictable domains of knowledge |
| 8. Possess correct, convergent answers | 8. Possess more than one answer, perhaps divergent |
| 9. Possess knowable solutions where all the problem states are known [37] | 9. Have no general rules or principles for describing or predicting most of the problem's solutions |
| 10. Have a prescribed solution process | 10. Have no explicit means for determining appropriate solution process |
| | 11. "Require learners to make judgements about the problems and defend them" [3] |

Within an engineering environment, well-structured algorithmic-story-rule based problems are known as engineering analysis problems. Howell proposed an examples of a five step problem solving analysis model [41]. Decision making problems can stand alone or can be found as part of greater ill-structured problems, such as design problems, just as algorithmic problems can be found in design problems. The related problem categories, troubleshooting, and diagnosis/solution, fall within the overall problem group represented by the terms troubleshooting or improvement problems. Troubleshooting and diagnosis/solution problems require forms of problem solving processes that move from divergent possibilities to converge on the root cause or causes. Howell also provides a five step model for design, the cornerstone of engineering practice, typically the most ill-structured of engineering problems.

Other models or strategies exist; Gano and the Lumsdanes for example, proposed the use of a four step cause and effect model [42, 43]. Chowdrury and Zimmer presented a five step process improvement model that focused on the importance of irreversible corrective action in step five [44]. Finally, Woods provided over 150 basic strategies or models for problem solving [45]. Additionally, Woods demonstrated that those students receiving practice applying a strategy outperform, on numerous measures, students who did not receive such an experience. Woods also concluded that using a strategy reinforces attributes identified with successful problem solvers: the characteristics of being positive and willing to tackle difficult problems, being systematic and organized.

For domains outside of engineering, Luger and Stubblefield provided an example model for problem solving in the artificial intelligence domain [46]. Bransford and Stein have developed the IDEAL problem solving model for psychology and educational domains [47]. The Jonassen's ill-structured problem solving model provided a different focus when it required that the problem solvers construct supportive arguments and articulate their personal beliefs in support of the conclusion. Hong summarized the process differences in solving well- and ill-structured problems by comparing the problem representation, the solution process, and the monitoring methods [48]. Hong concluded that for well-structured problems the problem solver activated the schema, searched for a solution, and then implemented the solution. For ill-structured problems the problem solver first searched for and selected information and then developed justification for the selection. The solution process involved generating the best solution, then evaluating the solution, monitoring the problem solving process, and finally developing justification.

Recent doctoral dissertations provide insights into scaffolding well- and ill-structured problem solving. Ellspermann tested the question; can creative thinking training have a significant impact on problem formulation of ill-structured problems? The results very significantly supported the hypothesis that "persons trained in creative thinking will generate a larger number of problem statements," $p < 0.01$, and significantly supported the hypothesis that "persons trained in creative thinking will choose higher quality problem statements," $p < 0.05$ [49]. Ellsperman concluded that problem "structuring heuristics, combined with training in creative thinking, is a viable aid to managers and professionals in formulating ill-structured problems" [49]. This research confirms the value of general problem solving training. In a related research investigation the characteristics of high and low student problem solving performance when solving ill-structured multi-step problems were identified. The purpose of the Sterner investigation was to determine "how the utilization of various problem solving processes and analogous problem solving experiences are related to an individual's success at solving complex, multi-step problems" [50]. Sterner concluded that in novel problem solving situations success was associated with a "prepare then attack" process sequence, and in spite of the realistic contexts of the packaged instructional materials, the materials seemed inadequate in terms of serving as a source problem for subsequent transfer to an analogous problem. The next study by Hong produced significant evidence supporting the use of structural knowledge [48].

The purpose of the Hong (1999) study was "to test the theory that the problem solving skills used for well-structured problems are necessary but not sufficient for solving ill-structured problems in the context of an open-ended, multimedia problem solving environment" [48]. The use of two sets of open-ended questions measured the students' abilities to solve well-structured and ill-structured problems involving astronomy contexts. The results for well-structured problems indicate that domain-specific knowledge, structural knowledge, and justification skills were very significant predictors of performance scores, $p < 0.001$. For near transfer ill-structured problem solving structural knowledge, science attitude and justification skills emerged as the significant predictors of performance, $p < 0.01$. For far transfer ill-structured problem solving structural knowledge, justification skills and regulation of cognition emerged as significant predictors of transfer performance, $p < 0.01$. It appeared that general problem solving strategies did not have a significant relationship with any type of problem solving. Hong hypothesized two reasons for the absence of a relationship: first, the inadequacy of the data collection instruments, and second, the lack of assessment questions related to the students' general problem solving knowledge. Hong concluded that although it appeared the students did not use general problem solving strategies to solve problems, it was not known if the students knew "how to use them, and when, and why to use them" [48]. Hong suggested further research on the relationships between the students' problem solving knowledge, declarative, procedural, and structural, and with the observed problem solving skills. These three studies provide mixed support for the use of general problem solving strategies, but very significant support for the importance of structural knowledge. Hong's recommendation for additional research on the effects of general problem solving structural knowledge is answered, in part, in the author's research.

The literature reveals that learners create and organize specific domain declarative knowledge, the "knowing that," into schema. In order to use the knowledge the learners must link the schema by the creation of procedural knowledge, the "knowing how." This procedural knowledge, representing the integration of the schema, is referred to as a performance schema. Structural knowledge, the "knowing why," mediates the integration of schemas into schemata. Learning the knowledge in context significantly enhances recall and performance. The application of cognitive techniques, such as concept maps or semantic networks, is an effective tool for scaffolding the integration process by the use of assimilation and matching. The next section addresses the methods applied in the study.

## Methodology

This section includes a detailed discussion of the experimental variables and design and an outline of the steps followed for completing the research. The experimental model used in this study included a pretest - posttest that measured declarative, structural, and procedural knowledge, this model was based on the Issac and Michael design 4, randomized control-group pretest – posttest [51]. The pretest, given during the eighth week of the quarter, measured the initial knowledge after the completion of the assigned readings, class lectures, and homework assignments related to the course content topics; the posttest measured retention and transfer. A 2x2 factorial design facilitated measuring the effects of the structuredness and scaffolding treatments and their interactions. The experimental variables for this design include the factor variables, response variable, and background variables. As mentioned previously, the two factor variables for this experimental design are structuredness and scaffolding. The response variable for student learning and transfer was assessed using pretest and posttest multiple-choice questions and well- structured story problems. These problems were based on different contexts within the same knowledge domain. Table 3 provides additional information as to the two treatment levels for the design.

Table 3. Factor and Response Variables

| Independent Factor Variables | Treatments Levels | | Dependent Response Variable |
|---|---|---|---|
| | Low | High | |
| Structuredness of transfer activity | Well (T0) | Ill (T1) | Declarative, procedural, and structural knowledge (posttest - pretest) |
| Scaffolding Technique | Summary report (S0) | Concept map (S1) | Declarative, procedural, and structural knowledge (posttest - pretest) |

The background variables included the effects of different instructors and course sections, different student backgrounds, and the assignment of students to the particular treatments. The control method for unknown background variables, and for all of the known background variables except for instructor and traditional versus non-traditional students, was the random assignment of students to their work groups and treatments. The next section provides a detailed outline of the research steps.

Steps and instruments

The first step in carrying out the experimental design entailed participation from the students. The study participants for this research included 79 adult students enrolled in a first year engineering technology course, Introduction to Total Quality Management (QET 101). The students enrolled in either day or evening course sections during the Winter, Spring, or Fall terms in 2002. All of the students were asked to participate in the study, with 68 agreeing to participate and 55 successfully completing both in-class pretest and posttests. These students, varied in age, gender, ethnicity, work experience, ability, and familiarity with technology. The students can be classified as both traditional and non-traditional. This course was chosen because of the match between the course content and the desired outcomes of the study to improve problem solving abilities.

The second step was the administering of an in-class open book pretest of declarative, structural, and procedural knowledge during the eighth week of the term. This sixteen question test included fourteen multiple-choice questions and two well-structured story problems, that address the procedural skills of constructing and analyzing a Pareto chart and an individual and moving range control chart. A concurrent step was the random assignment to teams for the collaborative transfer activity. Within the six course sections involved in the experimental design a total of seventeen student teams were formed.

Two concurrent third steps were the homework assignment; "Integrating your problem solving skills;" and instruction on how to use the available software package *Inspiration*®, useful



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for constructing concept maps. This last step only applied to treatment S1. In the homework assignment the student was expected to read and either summarize (S0) or create a concept map (S1) for the contrasting case problems, *Using SPC in A Mexican Poultry Processing Plant* [52], and *A Quality Process Approach to Internal Complaint System Analysis*[53]. Using Jonassen's taxonomy of problem types, the "Poultry Processing" and the "Internal Complaint" cases are classified as respectively diagnosis-solution and troubleshooting problems.

The fourth step was the team assignment of either the moderately well-structured (T0) or ill-structured (T1) transfer activity for the virtual company Robotic Grippers Incorporated (RGI). The moderately well-structured transfer activity (structructuredness index 55 out of 65) "Quality Problems at RGI," is characterized as a diagnosis-solution problem. The ill-structured transfer activity (structuredness index 40 out of 65) "A Problem at RGI," is characterized as a troubleshooting problem. Students were assigned to review the problem solving materials available within the course textbooks in preparation for a lecture on problem solving methods. In the lecture the author presented problem solving models previously discussed. The author's web-based problem solving materials served as the basis for the lectures, and are located at http://www.carillontech.com/QET_101/CMProblem%20Solving.html

The final steps, during the eleventh week of the term, were the evaluation of the group presentation and team defense of their solution and problem solving method, and the administering of the posttest of domain, procedural, and structural knowledge. This 16 question in-class assessment included 14 multiple-choice questions, with the same topic question distribution as the pretest, and two well-structured story problems.

This study required the development of three instruments, pretest and posttest assessment instruments and a structuredness instrument for assigning an index number to the instructional activities. The pretest and posttest questions and instructions that were used for this study were originally pilot-tested at the college with 10 students during the Fall of 2001. Internal consistency was moderate for both the pretest (Cronbach’s alpha = .59) and the posttest (Cronbach’s alpha = .60). This moderate level of internal consistency still provided sufficient discrimination to test the research. A new instrument was developed to characterize the structuredness of the activities based on criteria found in Table 2 Structuredness Characteristics of Well- and Ill-Structured Problems. This instrument demonstrated a reliability of 0.82 based on a one factor ANOVA among three evaluators and 12 different transfer activities and was able to determine that the difference in structuredness indices between the two transfer activities (T0 and T1) was equivalent to two standard deviations.

In summary, this research study was based on sound statistical approaches. The method for conducting this research study included the use of pretests and posttests utilizing a 2x2 factorial design. The participants include 55 undergraduate students from six different course sections who enrolled in a first year engineering technology course. The results are discussed in the next section.

Results

This section will present summary statistics, t-test comparisons of the treatments, and an ANOVA of the treatment and interaction effects. These statistical tests provide insight into the effectiveness of the selected treatments, and provide the supportive facts for the findings and conclusions reported in the last section.

As discussed in methods, the timing of the pretest is after the participant has completed the necessary classroom instruction, in-class practice, and homework assignments related to topics covered in the pretest and posttests. It would be expected that with two perfectly matched pretest and posttests, the student with no interventions would score the same on both tests. An increase in the score from pretest to posttest typically represents new structural and transfer knowledge. The pretest ($M = 63.07$, $SD = 16.1$) and posttest ($M = 71.82$, $SD = 16.4$) results for the 55 participants indicate an average improvement of 8.75 points. However, this is not a uniform improvement across all treatments; the average increase range from 20.5 for the concept map-ill-structured treatment combination to a decrease of 1.6 for the summary—well-structured treatment combination. Table 4 provides the summary statistics for the population values and treatment combinations.

Table 4. Summary Statistics Paired Data Posttest-Pretest

| Component | Count | Mean | Variance |
|---|---|---|---|
| Scaffold (S) | 29 | 14.66 | 2.30 |
| Structuredness (T) | 26 | 2.16 | 2.72 |
| Concept Map - Ill (S1T1) | 11 | 20.45 | 4.54 |
| Concept Map - Well (S1T0) | 18 | 11.11 | 0.76 |
| Summary - Ill (S0T1) | 18 | 3.82 | 2.63 |
| Summary - Well (S0T0) | 8 | -1.56 | 3.60 |
| Population | 55 | 8.75 | 2.84 |

The first statistical test for determining the impact of the treatments is the t-test for comparison of treatment means. The results are found in Table 5. This test compares the average differences and uses the pooled variances in order to calculate a t statistic. The scaffold comparison between the use of concept maps and summary treatments, based on the Schwartz and Bransford protocol method produced a very significant effect.

Table 5. Treatment Comparisons t-test Results

| Treatment Comparisons | Difference | *df* | Pooled Variance | *t* | *p* |
|---|---|---|---|---|---|
| Scaffold - S1 versus S0 | 12.49 | 53 | 2.49 | 2.929 | 0.005 |
| Structuredness - T1 versus T0 | 2.92 | 53 | 2.88 | 0.637 | 0.527 |

The structuredness comparison indicated no significant difference between the ill- and moderately well-structured treatments. Further analysis is necessary in order to determine if any significant interactions occur among the four combinations.

In order to answer this question and to determine the impact of instructor variation, the use of ANOVA is required. The ANOVA procedure systematically determines and compares assignable causes of variation to the inherent within treatment variability know as the experimental error. The significance of each treatment or assigned cause of variation is compared using the mean squared variation for each cause versus the error term. The corresponding $F$ ratio will determine the significance of the effect. Table 6 lists the sources for variation and the significance.

Table 6. ANOVA Treatment and Interaction Effects

| Source | *df* | *MS* | *F* | *p* |
|---|---|---|---|---|
| Scaffold Treatment (S) | 1 | 21.39 | 11.55 | 0.001 |
| Structuredness (T) | 1 | 1.17 | 0.63 | 0.431 |
| S x T Interaction | 1 | 8.73 | 3.64 | 0.035 |
| Instructor | 2 | 15.76 | | |
| Error | 49 | 1.85 | | |

The scaffold and structuredness tests provide the same indications as concluded in the t-test results found in Table 4. A surprising result is the indication of a significant interaction among the scaffolding and structuredness treatment combinations. This result indicates that a synergy exists between the use of the concept map and the choice of an ill- or well-structured transfer problem beyond what is expected from a linear model. In summary, the ANOVA test confirmed the very significant treatment effects found in the t-test results and surprisingly indicated a significant interaction effect.

Findings

The research results have produced three findings. The first finding is that the Schwartz and Bransford protocols on the use of concept maps versus summary reports as applied in this research provided very significant student performance improvements, $p < .01$, in both the t and ANOVA tests. The second finding is that the use of either an ill-structured or moderately well-structured transfer activity did not produce significant differences in student performance. The third finding is that a significant interaction occurred between the selected scaffold method and the choice of either an ill or moderately well-structured transfer activity.

In order to measure the full impact of the treatments; the response table numbers found in Table 4 have been restated as overall percent improvement in Table 7.

Table 7. Overall Percent Improvement in Performance from Pretest to Posttest

| Treatment Means | S1 | S0 | Overall |
|---|---|---|---|
| T1 | 32.4% | 6.1% | 16.1% |
| T0 | 17.6% | -2.5% | 11.4% |
| Overall | 23.2% | 3.4% | 13.9% |

For example, the use of the concept map protocols (S1 treatment), in conjunction with a transfer activity, produced on average an increase in the mean scores of 14.7, from 63.1 to 78.8. This 14.7 point increase represents a 23.2% overall improvement in student performance. The next section presents conclusions based on the findings and linkages to the previously cited research followed by sections analyzing the strengths, weaknesses, and limitations of the research study.

Conclusions

The first finding that the Schwartz and Bransford protocols on the use of concept maps versus summary reports as applied in this research provided very significant student performance improvements is supported by previously cited works. Two examples include Horton and his colleagues in their metanalysis study, and likewise, Wedge's conclusion that concept mapping can produce measurable gains in achievement [30, 31]. The finding and supportive research lead to the first two conclusions:

1. This study confirms the success of the Schwartz and Bransford concept map protocols as a very effective instructional scaffold with both ill- and moderately well-structured transfer activities (23.2% average improvement).
2. The use of the summary protocol as a scaffold is not as effective as an instructional strategy (3.4% average improvement).

The success of the concept map protocols is attributed to the discovery learning approach, which required the participants to create a relationship map between two contrasting case studies. VanMerriënboer refers to this instructional strategy as inductive-inquisitory and promotes this discovery approach as the best method for reaching a complete level of understanding.

The second finding that the use of either an ill- or moderately well-structured transfer activity did not produce significant differences in student performance is contradicted by the third finding that a significant interaction occurred between the scaffold method and the choice of either an ill- or moderately well-structured transfer activity. Table 7 indicated that the average performance improvement difference between the ill-structured problem and moderately-well structured problem was nearly 5%; however this was not statistically significant. It is clear from tables that the choice of the ill-structured transfer activity produced the highest student improvement performance and that the choice of the moderately well-structured transfer activity produced the lowest result. Possible clues as to the differences between the two transfer activities lie with two characteristics — structuredness (55 and 40 index numbers) and familiarity (near/far and far.

Both familiarity and structuredness affect the acquisition of structural knowledge. Near transfer is governed primarily by procedural and declarative knowledge. Far transfer relies heavily on the use of analogies and is governed by a student's structural knowledge, which aids in the generalization of the concepts. Hong (1999) found that structural knowledge and justification skills were required for both well- and ill-structured problem solving. Additionally, well-structured problem solving required domain-specific knowledge, and ill-structured problem solving required metacognition skills. The ill-structured transfer activity (T1) is characterized as far transfer, while the moderately well-structured transfer activity (T0) is characterized as near transfer as the primary mode. Therefore, one possible explanation for the difference involves those participants that received the concept map protocols (S1) developed greater structural knowledge and consequently greater reinforcement of analogical skills with the ill-structured (T1) transfer activity.

Another possible explanation is the statistical weakness of the ANOVA test given the treatment sample sizes and structuredness index difference between the two transfer activities. The two standard deviation shift might not be sufficient to produce a statistically significant conclusion given the sample size and reliability of the test instruments. Therefore, based on these findings and research the author concludes:

3. Instructional designers should combine ill-structured transfer activities with the concept

map protocols in order to achieve the greatest performance improvements.
4. Additional experimental data should be collected based on the protocols in order to increase the discrimination of the statistical test.

The final two conclusions address the answers to the research questions and support the Jonassen, Beissner, and Yacci concluded that the acquisition of structural knowledge, the "knowing why," is instrumental in the development of a problem solving process [24]. The author concludes:

5. The use of a concept map to scaffold the selection and application of the appropriate problem solving process to the solution of a moderately well- or ill-structured transfer activity proved highly effective in the transferring of those competencies to the solution of new problems.
6. The use of an integrating activity, as described in the 4C/ID or NCME instructional systems design models, significantly enhanced the transfer of complex cognitive skills when used with the concept map protocols, and not with the summary protocols.

This improvement is accomplished by assisting the student's in organizing their declarative knowledge and problem solving processes. The strengths, weaknesses, and limitations of the research are addressed next.

One of the strengths of this study was that it confirmed the Schwartz and Bransford protocols on effective concept map usage. A second strength was the confirmation of the positive impact on student performance of a whole task integrating activity used at the end of an instructional unit. A third strength was an indication that the structuredness of the transfer activity has a performance impact through an interaction effect with the concept map. Another major strength is the development of a structuredness instrument with instrument reliability of .82. This tool can be an important device for designers in the development and characterization of instructional activities.

A weakness of the study was the moderate reliability numbers of .59 and .60 for the content instruments. These instruments did not provide sufficient statistical resolution, given the sample size, to determine the potential weak effects of problem structuredness. A second weakness was the procedural problem that occurred during the winter evening section by the part-time instructor only assigning the ill-structured transfer activity.

Two limitations of the study are the fact that the study was conducted within a single college course at a single college. Another limitation is the students who participated in the study were both traditional and nontraditional in background. Nontraditional students could have obtained course related work experience and thus had an advantage over traditional students by acquiring structural knowledge on the work site, as well as, in the college course.

Research summary

The results of this study contribute to the efforts to measure problem structuredness and to provide research data for choosing well- or ill-structured activities to enhance student learning. The results test the hypothesis that the 4C/ID "whole-task practice" and the NCME "transfer activity" contribute significantly to student learning. Butterfield stated that transfer is "the most important unsolved problem of education and psychology" [54]. The results confirm the effectiveness of concept maps as a tool for developing structural knowledge and provide one additional piece towards solving the transfer puzzle.

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