Integrating Knowledge across the Engineering Curriculum

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Abstract: *Graduating engineers are expected to have obtained an understanding of their discipline by the time they graduate. Although the body of knowledge representing the discipline is actually an integrated whole, the students have learned these concepts, by necessity, in separate courses. The hope is that students will integrate the concepts learned in these separate courses into an integrated understanding of the discipline. If this integration does not happen, the result can be an impoverished understanding of the concepts and an inability to use concepts on demand. At the Center for Engineering Learning and Teaching, we are developing an innovative program to respond to these issues. The goal of the program is to help students 1) identify concepts of the discipline they are learning, 2) link these concepts into an integrated understanding of the discipline, 3) determine which concepts represent the core of the discipline, and 4) communicate this understanding to themselves and others. In a pilot version of the program to be completed in the fall of 1999, we will work with Civil and Environmental Engineering students as they develop concept maps and web pages to accomplish these goals. In this paper, we describe the theoretical and practical motivations for the program, identify the principles guiding the design of the program, and sketch out a possible implementation.*

Introduction

Reports on the state of engineering education suggest concerns that students are not able to perform relevant professional activities upon graduation [e.g., 1]. For example, students have difficulty in contributing to design activities and have difficulty in communicating their engineering knowledge and activities to others [2]. Such findings have led to calls for reform in engineering education [3-5].

In response, many innovative programs have been developed to complement engineering education. The emergence of integrated curricula at the freshman year, problem-based learning approaches to professional education [6], the MacMaster problem solving curriculum [7], and freshman-level introduction to design and engineering programs [8] are all attempts to address these problems.

In this paper, we describe a program that offers a complementary approach. In our program, we are focused on helping students develop integrated knowledge, a characteristic of expertise and a feature of knowledge important for effective problem solving and design. In this paper we will describe the program along with the theoretical and practical motivations. At the end of the paper, we touch on the next steps.

Integrated Understanding

Integrated understanding refers to the connectedness of concepts in a person's understanding of a domain. Integrated understanding is a characteristic of expertise, in general, and therefore a goal for engineering education. The development of an integrated understanding can result from processes that underlie all learning. Often such processes are not explicitly promoted in traditional curricula where disciplinary knowledge is divided into courses and taught separately, although more successful students may bring such processes to bear in their own learning approaches. The structure of current engineering curricula provides a baseline for considering how to address this problem.

Integrated Understanding and Expertise

The goal of an engineering curriculum is to develop graduates who can successfully participate in engineering activities upon graduation. Research on expertise provides a basis for understanding what we may expect students to acquire through their education.

Cognitive scientists have been studying the behaviors and knowledge structures of experts for over two decades. Through this research, the following characteristics of experts have been identified: (1) experts can recognize patterns in phenomena more quickly than novices, (2) experts categorize problems based on their underlying structure rather than on superficial characteristics, (3) experts have superior memory for the details of cases in their discipline, and (4) experts frequently perform no better than novices when working on problems outside of their domain [9]. The theory accounting for these findings is that expertise involves the presence of a robust knowledge base to support the performance of these skills [9].

Two features of this knowledge base can be identified. First, research suggests that the central concepts in the knowledge bases of experts and novices differ. For example, Chi studied how experts and novices classify problems in physics [10]. The novices were observed to classify problems based on structural features while the experts classified problems based on underlying physics principles. This suggests that the knowledge base of the expert is organized according to such underlying principles.

Second, the knowledge base of the expert is structured differently than that of the novice [11]. Schvandevedlt and his colleagues have developed a means of representing the relationships of concepts (or integration of concepts) as seen by a person [12-14]. Using various metrics to determine similarity between two concept representations, these researchers have shown that the similarity of these relational structures of concepts is higher among experts than between experts and novices.

In summary, experts structure their knowledge differently than novices and have different central concepts. The implication for engineering education is that a goal of engineering education should be to guide students from a novice state to more of an expert state in terms of knowledge and structure.

The Emergence of Integrated Understanding in Current Curricula

We suspect that students may not be developing as integrated an understanding as they could. If this is true, it may be because of the format of current engineering curricula.

To format an engineering curriculum for a particular engineering discipline, the knowledge of the discipline is typically divided into components that are then taught to students through separate classes, as shown in Figure 1. The expectation is that students will integrate the concepts learned in classes into a coherent disciplinary knowledge structure. However, the students may have few explicitly supported opportunities that facilitate this integration of knowledge across these classes.

The challenge, then, is to develop a strategy for helping students develop an integrated understanding. The existing curriculum provides constraints for achieving this goal. One approach is to change the existing curriculum structure, as the integrated curriculum and problem-based learning initiatives have done [6]. Another option is to assume that the current curriculum will not change and develop an intervention that fits into the current curriculum. Pragmatic reasons for working within the current curriculum including the ease with which the course can be implemented, managing the expected level of teacher expertise, and promoting modularity in the curriculum. Further, individual classes may be superior to integrated curricula or problem-based learning approaches in giving students the support to focus on individual topics and learn that topic (and the associated concepts) at a desired level of detail. So our question is this: how do we develop a program to promote integrated understanding within the constraints of a traditional curriculum?

The KIAC Intervention: Supporting Integrated Understanding Development

The goal of our intervention is to facilitate the processes that lead to the development of integrated understanding of an engineering discipline. In particular, we want to help students focus on (1) identifying the concepts they are learning, (2) integrating the concepts into their understanding of the discipline, (3) differentiating important concepts from concepts of lesser importance, and (4) communicating these concepts to others.

Intervention Design Principles

In designing an intervention that addresses these goals, we have identified four design principles to guide our efforts. These principles are discussed below:

Anchor the activities in the student's development of an external artifact. In the context of our intervention, we are hoping that students will construct an integrated understanding of their discipline. Social constructionism is an educational philosophy grounded in the idea that individual construction of knowledge is facilitated by the student's construction of an external representation of the developing knowledge that is sharable and can be critiqued [15]. Thus, the design consideration is this: What can students construct that will externalize their efforts to develop integrated understanding?

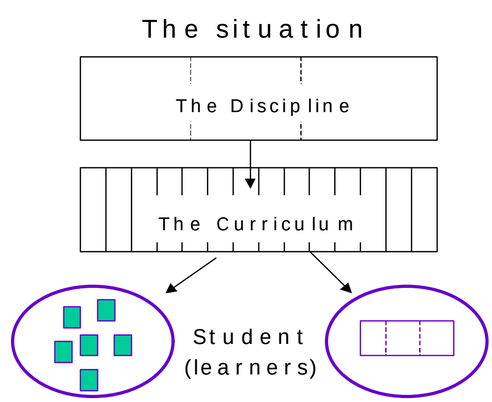

Figure 1. Diagnosing the Situation

Balance individual and group work concerning the artifact. Learning is both an individual and a social process. Learning involves individual effort for the learner to integrate new knowledge into his or her own existing understanding. Learners can also benefit from social interactions, in that other learners can identify problems, bring new ideas, and provide motivation. These thoughts lead to the following design consideration: How can we balance individual and group activity in the design of the program?

Permit individual differences. The development of structural knowledge for a particular discipline involves large individual differences [12]. In the context of engineering education, students will be taking different courses, may have different foci, and may be interested in different aspects of their chosen discipline. As a result, students may develop very different perspectives of a domain. The design consideration is thus: How can the program be created to permit any student to develop their understanding of the curriculum given their potentially unique situation?

Make the program feasible. The program must fit into an existing curriculum. The focus of the student's activity will remain on the discipline courses. The design involves the following challenge – determining how the goals can be met given the small amount of time available. Some ways to make the curriculum feasible include minimizing the necessary demands on the faculty, making the program self-assessing, and having the products of the program be useful elsewhere such as for ABET accreditation.

A Student Enrolls in the Program

The presentation of the intervention design is distributed over the next two sections. In this section, we introduce Ann and follow her as she takes the course through the last two years of her program in Civil and Environmental Engineering. The scenario is hypothetical and idealized and represents our current guess at the details of the intervention. In the section following this scenario, the four design principles will be revisited in order to identify how the described intervention fulfills each.

Ann is a Civil and Environmental Engineering junior, enrolled in the two-year course CE499: Knowledge Integration across the Curriculum (KIAC). She enrolled as a result of an intriguing presentation she attended during the spring of her sophomore year. Over the summer, she received various updates concerning the course. She is now excited to attend the first session and meet the other students. At the same time, she is ambivalent. Did she make a good decision? Will the course really help her? Will she regret signing up? How much time will it take away from her "real" classes?

The first class meeting

Ann attends the first class during the first week of the fall term. The facilitator begins class with an open-ended question – "What is Civil and Environmental Engineering?" Throughout the discussion, the facilitator is busy putting terms on the board as the students brainstorm the question. After about 30 minutes of discussion, the board contains a long list of terms ranging from calculus to ethics to teamwork.

The facilitator transitions into the subject of concept maps. He first draws a simple concept map on the board, as illustrated in Figure 2. Next he demonstrates how the same concept map can be created using a computer program. The facilitator then asks the students to work individually to develop an initial concept map containing the terms listed on the board. Towards the end of the class period, the facilitator instructs the students to print (and save) a copy of the concept map. The facilitator then posts the initial concept maps and asks for comments. After some hesitancy, the students begin discussing. They discuss for about 15 minutes.

The final portion of the first class is devoted to a discussion of the course structure over the next two years. Ann learns that the course will meet once every other week, for two hours. Part of class time will be spent working on the concept maps, as was done in the current class. The rest of class time will be spent developing a web site, something to be introduced during the next class period. The initial class closes with the assignment of a homework – the writing of a reflective essay containing thoughts about the first class and expectations and attitudes toward the course.

To write the reflective essay, Ann uses the web-based computer system as described in a handout. The computer system contains prompts for the essay topics and she notices that there is one that mentions potential ambivalence about the course. Ann writes her first essay concerning this issue, specifically focusing on how the first lecture has helped her to believe that the course may really be valuable.

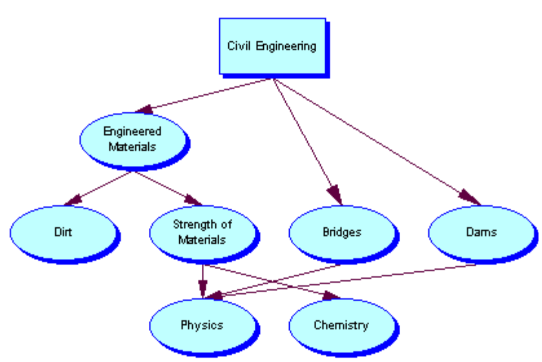

Figure 2. Example Concept Map

Meetings over the next two years

The next meeting occurs two weeks later and lasts for two hours. That session begins with the facilitator having the student list their classes and their assigned homework. This activity is used to identify new terms to add to the concept maps. The students then spend about 30 minutes integrating these new concepts into their concept maps.

In the remaining 60 minutes, the facilitator introduces the students to the web page component of the class, specifically the development of the personal Civil-and-Environmental-Engineering-as-a-discipline web page (the "Personal CEE Web Page"). Ann learns that she will be developing a web site representing her view of the Civil and Environmental Engineering discipline. To get the students started, the facilitator asks students to create a word document. He then shows the students how to turn the Word document into HTML. By the end of class, Ann and the other students have created an initial web page. Again, the homework is an essay.

The basic structure of the third meeting, occurring two weeks later, is the same as the structure of the first two meetings. The students identify new concept map terms through discussion. They then spend time incorporating the new terms into the concept map and working on their personal CEE web pages. At the end of the third session, however, the facilitator orchestrates a viewing of the developing concept maps and asks for discussion.

These two-hour, bi-weekly meetings continue throughout the term with little significant change in structure except for one additional requirement. The students are told that the personal CEE web pages and concept maps will be printed and graded at the end of the term. The students, therefore, spend time cleaning up their concept maps and their web site.

This general process of (1) identifying concepts, (2) extending the concept map, (3) extending the personal CEE web page, and (4) writing reflective essays continues throughout the junior year and up to the end of the senior year. Over the two-year period, Ann's concept map and web page evolve a great deal. Her concept map tends to increase incrementally as additional concepts are added. Twice, however, Ann felt the need to completely restructure her concept map in order to bring the organization of the map in line with her current thoughts about the discipline of Civil and Environmental Engineering. Similarly, Ann's web page grows and shrinks as she evolves in her ideas about how to present it. Ann documents many of these changes in her reflective essays. At other times, she chooses to focus on one of the essay topics suggested by the instructor. The suggested reflective essay topics change through the junior and senior years in order to draw upon prominent student activities such as searching for a job and completing the senior design activity.

The Final Term

During the final term, the students work on an activity designed to provide closure for the entire program. The students in the course are given the challenge of using their maps and web pages to develop a Civil and Environmental Engineering recruitment web site. Specifically, the recruitment web site will be used to provide information to freshman engineering students, and even high school students, interested in pursuing studies in Civil and Environmental Engineering. With the many different views of Civil and Environmental Engineering that the students have created and their body of indexed materials suggestive of what Civil and Environmental Engineering work entails, the students in the KIAC program are in a unique position to develop such recruitment materials. The students discover, though, that the process of creating such materials is educational for them too. In the end, there is an open house where the KIAC students display the final product of their efforts and discuss the process.

At the end of the final term, the students complete a battery of evaluation activities that will be used to compare them to other graduating seniors who did not participate in the KIAC program. The purpose of this evaluation is to identify the effect of the program. At this point, Ann finds herself writing an essay about what Civil and Environmental Engineering is and sorting a series of Civil and Environmental Engineering problems as she feels appropriate. She is also reads a Civil and Environmental Engineering case study and later tries to recall from memory as many case details as possible.

Post Mortem

In an exit interview, Ann communicates her thoughts about the experience. She describes how she has used her online materials to prepare for and supplement her resume and job interviews. She describes how the experience helped her during her senior design activities. When asked about the time she spent on the course, she admits that she probably spent more than the average two hours per week, but that this did not bother her. She enthusiastically agrees to be a spokesperson for the program and agrees to help recruit students for the following year.

Uncovering the Structure in the Class

As should be apparent in the previous description, the structure underlying the proposed course is very regular. This structure, shown in Figure 3, involves students cycling through the following activities:

- Identifying concepts, via the discussions,
- Integrating these concepts into their externalized understanding, through the process of adding the concepts to a concept map,

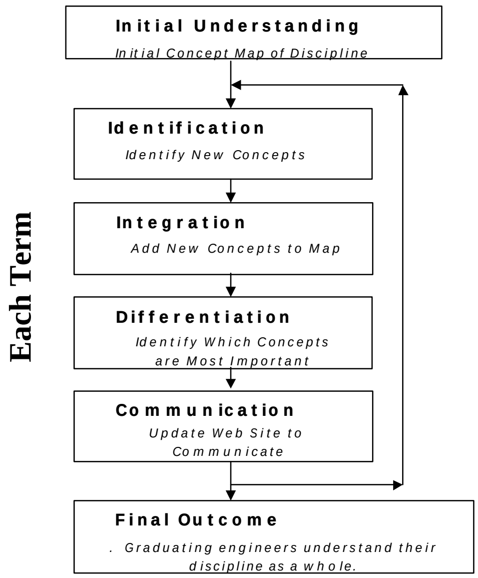

Figure 3. The Intervention Process

- Differentiating the central from the peripheral concepts, through the process of themes to pursue in the personal discipline web site, and
- Communicating the structure of their concepts, via the web site.

In the remainder of this section, each design principle is revisited, specifically pointing out how the features of the course description address each principle.

Concept maps are an externalization of integrated understanding. Concept maps (also known as knowledge maps, semantic networks, and cognitive maps) are frequently used tools in educational research [16]. Many researchers have observed an important property of concept maps – that they externalize the structure and relatedness of knowledge, and these researchers have built upon this property in designing instructional interventions [16]. Researchers have investigated student use of existing concept maps [17], student construction of concept maps [18], the effects of different display characteristics of concept maps [19], and the processes by which students are suggested to use concept maps [20]. By incorporating concept maps into our intervention, we will be building on a large body of previous research and can learn from the ideas and experiences of others.

Concept Maps and Personal Discipline Web Sites Permit Individual Differences. The use of concept maps and the development of discipline web pages are both open-ended activities. This ensures that there is wide latitude for students to express individual perspectives. Students will be free to choose concepts and web page designs, in order to represent their personal perspective.

Individual and Collaborative Activity are both Represented. In the scenario, students work jointly to identify new concepts for the concept maps, to observe the concepts maps of their peers, and to develop final projects involving the concept maps and web pages. Students work individually to create their personal concept maps, to select and create personal CEE web pages, and to write reflective essays about their experience.

The Proposed Program Takes into Account Practical Constraints – The designed course involves a limited commitment of time and a consistent structure for over two years. The naturally occurring products of the course provide a basis for assessment of students.

Current and Next Steps

The course we have described is in the planning stages. It has not been taught yet. The first offering of the program will occur in the Fall of 1999, with the support of the department of Civil and Environmental Engineering. In order to get this program into place by then, there are several issues still to be resolved.

Evaluation of the program. We are currently developing an evaluation approach for determining the impact of the program. We will be evaluating the program based on student performance on exit tasks. In developing these tasks, we will be guided by the work on expertise. In addition, we will be taking a developmental perspective throughout the duration of the program. For example, we will be looking at indicators such as the rate of growth of the concept maps and how often their structure is changed.

Identification and Development of Support Software. Software will be used to support many of the envisioned program activities including the development of the concept maps, the development of personal web sites, and the reflective essay writing. We are currently exploring the functionality of various concept map tools. We will probably be using the Reflective Learner system to support the reflective essay writing [21]. General-purpose html development tools may be used to support the creation of both the web pages and the case library / portfolio.

Enrollment of Undergraduates. One challenge in the development of such exploratory supplemental programs is the enrollment of students in these programs. In our case, we are proposing that students are enrolled for a two year period, receiving three credits when they have completed the course requirements and activities. We will need to refine our arguments in order to convince students that this experience will be worth while.

Gain Familiarity with Component Activities in the Curriculum. The proposed course includes several component activities such as concept map generation, reflective essay writing, and web page construction. In order to implement our envisioned course, we need to develop expertise in using each of these tools with students. We have begun to do this, by collecting concept maps from students in several environments and attempting to provide feedback on these maps. We will continue to develop this expertise, as we search the literature for guidance.

In addressing these issues, and in continuing to develop our envisioned program, we recognize that there are many lessons to learn from others who have created similar supplemental programs. We believe, however, that the program we are envisioning is fundamentally different from the programs others have documented. We look forward to presenting results from the initial efforts to pilot this course.

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References

1. NSPE, Engineering Education Issues: Report on Surveys of Opinions by Engineering Deans and Employers of Engineering Graduates on the First Professional Degree, 1992, National Society of Professional Engineers.
2. McMasters, J.H. and S.D. Ford, *An Industry View of Enhancing Design Education.* Engineering Education, 1990. **July/August**: p. 526-529.
3. NSF, *Restructuring Engineering Education: A Focus on Change*, 1995, Division of Undergraduate Education, Directorate for Education and Human Resources, National Science Foundation: Washington, D.C.
4. NRC, *Engineering Eduation: Designing an Adaptive System*. 1995, Washington, D.C.: National Academy Press.
5. ASEE, Engineering Education for a Changing World: Project Report, . 1994, ASEE: Washington, D.C.
6. Barrows, H.S., *A taxonomy of problem-based learning methods.* Medical Education, 1986. **20**: p. 481-486.
7. Wood, D.R., *et al.*, *Developing Problem Solving Skills: The McMaster Problem Solving Program.* Journal of Engineering Education, 1997. **86**(2): p. 75-91.
8. Sheppard, S. and R. Jenison, *Examples of Freshman Design Education.* International Journal of Engineering Education, 1997. **13**(4): p. 248-61.
9. Chi, M.T.H., R. Glaser, and M.J. Farr, eds. *The Nature of expertise*. . 1988, L. Erlbaum Associates: Hillsdale, N.J. 434.
10. Chi, M.T.H., P.J. Feltovich, and R. Glaser, *Categorization and Representation of Physics Problems by Experts and Novices.* Cognitive Science, 1981. **5**: p. 121-152.
11. Jonassen, D.H., K. Beissner, and M. Yacci, *Structural knowledge : techniques for representing, conveying, and acquiring structural knowledge*. 1993, Hillsdale, NJ: Lawrence Erlbaum Associates.
12. Schvaneveldt, R.W., *et al.*, *Measuring the structure of expertise.* International Journal of Man-Machine Studies, 1985. **23**: p. 699-728.
13. Gillan, D.J., S.D. Breedin, and N.J. Cooke, *Network and multidimensional representations of declarative knowledge of human-computer interface design experts.* International Journal of Man-Machine Studies, 1992. **36**: p. 587-615.
14. Cooke, N.J. and R.W. Schvaneveldt, *Effects of computer programming experience on network representations of abstract programming concepts.* International Journal of Man-Machine Studies, 1988. **29**: p. 407-427.
15. Papert, S., *Situating Constructionism*, in *Constructionism*, I.a.P. Harel, S., Editor. 1991, Ablex: Norwood, NJ. p. 1-11.
16. Novak, J.D., and Gowin, D.N., *Learning How to Learn*. 1984, Cambridge: Cambridge University Pres.
17. Lambiotte, J.G. and D.F. Dansereau, *Effects of Knowledge Maps and Prior Knowledge on Recall of Science Lecture Content.* Journal of Experimental Education, 1992. **60**(3): p. 189-201.
18. Jonassen, D.H., *Changes in Knowledge Structures from Building Semantic Net versus Production Rule Representations of Subject Content.* Journal of Computer Based Instruction, 1993. **20**(4): p. 99-106.
19. Wiegmann, D.A., *Effects of Knowledge Map Characteristics in Information Processing.* Comtemporary Educational Psychology, 1992. **17**(2): p. 136-155.
20. Patterson, M.E., *Effects of Communication Aids and Strategies on Cooperative Teaching.* Journal of Educational Psychology, 1992. **84**(4): p. 453-461.
21. Turns, J., *et al. The Reflective Learner: Supporting the Writing of Learning Essays that Support the Learning of Engineering Design through Experience*. in *ASEE*. 1997. Milwalkee, WI.