AC 2008-717: SCAFFOLDING COLLABORATIVE DESIGN ONLINE

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Scaffolding Collaborative Design Online

Among engineers, design is a ubiquitous professional activity. Most engineers engage in some form of design: writing software programs; designing a building; designing a new car or any of its 10,000 components, writing a manual, designing a data collection system, and so on. Design problems are among the most complex and ill-structured of all problem[1]. Despite the apparent goal of finding an optimal solution within pre-determined constraints, design problems usually have vaguely defined or unclear goals with unstated constraints. Multiple solutions from various different solution paths are possible. Perhaps the most vexing aspect of design problems is that they possess multiple criteria for evaluating solutions, and these criteria are often unclear. Ultimately, the designer must please the client, however the criteria for an acceptable design are often unstated. Design problems generally require the designer to make judgments about the problem and defend them or express personal opinions or beliefs about the problem, so solving an ill-structured problem is a uniquely human interpersonal activity [2].

The goal of most design activities is to construct an artifact (model, specifications list, drawing. etc.) that:

- Satisfies functional requirements
- Conforms to limitations of target
- Meets implicit and explicit performance requirements
- Satisfies implicit and explicit design criteria (style, simplicity, testability, maintainability, reusability, modularity, etc.), and
- Satisfies restrictions on design process itself (e.g. time, cost, tools available) [3].

Research Context

A professional goal of many engineering programs is to teach their students to think like engineers, which for most engineering disciplines means to think like designers. To that end, many engineering programs include design courses in their curricula. In these courses, students collaborate in teams to design a product. At Virginia Tech, students in the second semester of their freshman year enroll in ENGE 1114 where they work in teams of three to five students to solve a design problem, producing a formal design report including a set of working drawings, materials lists, and justification of their solution. During the semester, student groups are required to submit two progress reports. The first report details the problem definition, articulating the problem to be solved, the objectives (desirable attributes) of the solution, and the constraints limiting the design space. The second progress report moves through conceptual and preliminary design phases, articulating the required functions for the solution, documented by appropriate charts and figures (e.g., Black box analysis, Function Means Trees), and presenting alternative design ideas. The second report culminates in the evaluation of these alternative design ideas leading to the design decision. The preliminary designs must be evaluated based on the objectives, metrics, functions, and specifications derived for the problem. These progress reports are based on the design model articulated in the course text [4]. In that model, the design process includes problem definition based on client statement, conceptual design, preliminary design, detailed design, and design communication.

In our research, we are attempting to scaffold meaningful conversations among design teams in order to improve the quality of their designs. While the construction of shared knowledge occurs naturally in authentic work groups (project teams, scientific communities, etc.), the structure and methods employed in most university courses do not support these processes. Most instructional activities, such as laboratories and writing assignments, are individualistic. However, trends toward the integration of active and collaborative learning methods in large universities are changing the nature of design activities in many courses. Unfortunately, many of these efforts only are marginally effective because the students do not construct shared knowledge through a discourse process about the activities. They might learn how to cooperate adequately through division of labor, but socially constructing shared meaning about their activities requires that they know how to discuss their activities in meaningful ways. More often than not, students do not possess these skills, largely because they have seldom been encouraged or required to discuss meaningfully what they are doing. So, our goal was to structure their design conversations.

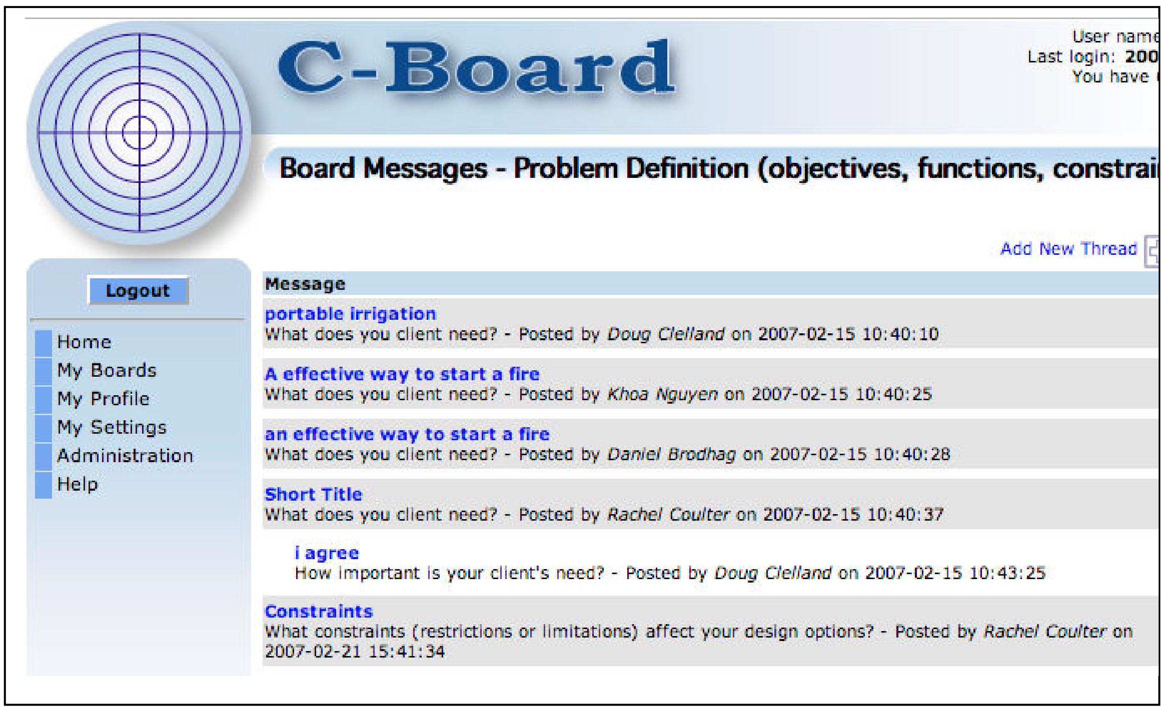

Figure 1. New threads on discussion board.

In order to help students to think like collaborative designers, we are investigating the use of conversation constraints to scaffold design thinking. The concept of constraints has been used in a variety of ways in the psychology literature. Reading researchers have explored syntactic and lexical constraints on meaning generation while parsing sentences. In problem-solving research, constraints are the set of possible combinations of values between variables in the problem to be progressively restricted (satisfied) during problem solving [5]. Chi, Slotta, and de Leeuw [6] describe constraint-based interaction in defined systems that behave according to principled interactions or two or more values in the systems. These interactions can be defined canonically. It is important to note that these constraints are implicit in the problem. Any conceptual system (from a simple sentence to a complex conceptual domain) consists of attributes with values that interact. Those interactions impose constraints on the psychological processes required to function in that system. Those constraints must be satisfied or eliminated in order for the processes to be completed.

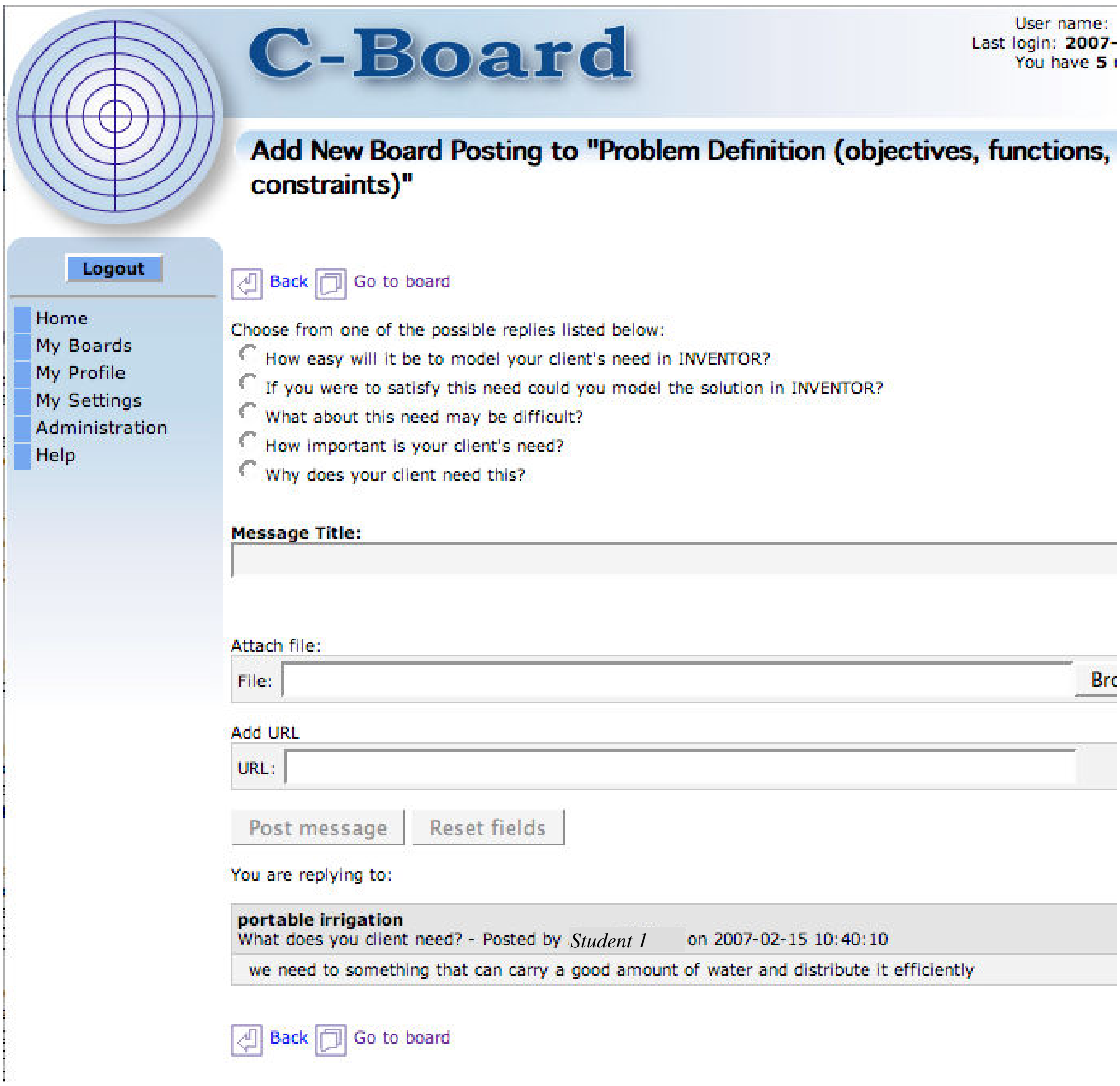

Figure 2. Student response options.

In our research, we use constraint-based discussion boards to model design thinking for students. We have developed a special threaded discussion board (electronic conferencing system) in which we overlay pre-structured forms of conversation, so that when students post a comment to the discussion board, they must first decide what kind of comment to post (see Figure 1). After logging onto the system and accessing preassigned discussion boards, students may begin a new discussion thread by only stating a client need (see example of board in Figure 1). Likewise, when responding to another post, the kinds of comments that students can make are pre-determined (What about this need may be difficult?, How important is your clients' need?, Why does your client need this?) (see Figure 2). Pre-classifying conversational attributes to fit these sets of canonical relations constrains the nature of verbal interactions among conversants.

- Why does your client need this?
  - Why does your client need this?
    - How do you know? What evidence supports this message?
  - How important is your client's need?
    - How do you know? What evidence supports this message?
  - What about this need may be difficult?
    - How do you know? What evidence supports this message?
  - If you were to satisfy this need could you model the solution in INVENTOR?
- What features or attributes must your design have to address the needs you have stated?
  - Why do you want this attribute in your design?
  - How important is this attribute to your design
    - How do you know? What evidence supports this message?
  - How is this attribute related to other attributes in your design?
  - How will you know if the attribute is effective in your design?
    - How will you measure this?
  - How feasible is it to include this attribute in your design?
- What constraints (restrictions or limitations) affect your design options?
  - Define this constraint; what does this mean?
    - How do you know? What evidence supports this message?
  - How important is this constraint or limitation to your design?
    - How do you know? What evidence supports this message?
  - What attribute in your design does this constraint affect?
    - How do you know? What evidence supports this message?
  - How will you measure this constraint or limitation?
    - How feasible is this measurement?
- What is a function for your design (what must your design do)?
  - Describe this function. What does it mean?
    - How do you know? What evidence supports this message?
  - Why do you want your design to do this?
  - How important is it that your design does this?
    - How do you know? What evidence supports this message?
  - How is this function related to other functions in your design?
  - How is this function related to other attributes in your design?
  - How will you know if your design does this function?
    - How will you measure how well your design does this function?
  - How feasible is it to include this function in your design?

Table 1. Constraints for first discussion.

Two separate discussion boards were used in this study. The first discussion board lasted for two weeks beginning in the fifth week of the semester and involved 2 teams of 3, 28 teams of 4, and 1 team of 5 students. The first board helped students to negotiate the needs, objectives, and functions of their design. The goal for this discussion was the first progress report that requires each design team to develop a problem statement and a project description, including objectives, attributes, and functions. The structure for the first discussion is listed in Table 1.

Students could begin a new thread to answer one of the four questions that are left-most indented. For example, they could start a new thread by justifying client's needs (Why does your client need this?) or articulating the attributes, constraints, or functions that must be met by the design. When students were reading a new thread and wished to respond to the message, they were constrained in their options. For example, when responding to a posting about an attribute or feature that must be met by the design, students could only post a response that answered why do we want this attribute, how important is it, how the attribute is related to others, how will you know it's effective, or how feasible is it to include this attribute. Students had the opportunity to respond to some of these second level discussion threads. For example, if a student were to respond to a comment about "How will you measure this constraint?" they could only respond by describing how feasible that measurement is. Again, the purpose of this constraint-based discussion board is to model for students the kinds of issues they need to be collaboratively resolving. Prior research showed that such constraints affect the quality of students problem solving, especially for ill-structured problems [7].

The second discussion board also lasted for two weeks, beginning in the eighth week of classes. That board focused on the students' generation of alternative design concepts and the negotiation of their preliminary design. The structure of that board is shown in Table 2.

Data Analysis

The data collected in this study includes:

- All postings from the discussion boards
- Group project reports
- Design exam where students are given a client need state and asked to describe how they would design a solution
- Epistemic Beliefs Inventory developed by Schommer. The instrument included 52 likert scale questions that were organized into the following factors: Seek single answers; avoid integration; avoid ambiguity; knowledge is certain; depend on authority; don't criticize authority; ability to learn is innate; learn the first time; and learning is quick.

Each of the postings was first analyzed for their accuracy (is each posting a legitimate example of the kind of statement being posted.) Second, the number of different levels and kinds of postings will be calculated for each team. Third, the quality of the team reports will be assessed using a rubric that assesses the quality of the attributes, constraints, and functions described in the report. Fourth, the exams will also be assessed using the combined rubrics from the first two project reports. The exam is designed to be an individual assessment of design. Finally, student scores on the EBI will be calculated.

What is a function your design solution must perform?
- Describe this function. What does it mean?
- How important is it that your design do this?
  - How do you know? What evidence supports your evaluation of the importance?
- How will you measure how well your design does this function?
- How is this function related to other functions?
- What is an existing means for implementing this function?
  - How do you know?
  - Is this means feasible?
  - Is this means incompatible with identified means for other functions? Which one(s)?
- What other means might you use to implement this function in your design?
  - Is this means feasible?
  - Is this means incompatible with other identified means? Which one(s)?

What is a top level objective for your solution?
- Why is this objective important?
  - How do you know? What evidence supports your evaluation of the importance?
- Is this objective defined well enough that you can use it to evaluate your design concepts or do you need to break this objective in to sub-objectives to be able to use it?
  - What is a sub-objective of this objective?
    - Why is this sub-objective important?
    - How important is this sub-objective compared to other sub-objectives?
- What percentage of your evaluation will be based on this objective?
  - Why?
- How will you know how well a design alternative meets this objective? What are the metrics for this objective?

Table 2. Structure for second discussion board.

Results

A totals of 31 teams made some use of the discussion board while 24 teams in the control grup did not use it. In the first discussion, teams made average 10.23 responses (SD = 6.96) and average 8.84 correct responses (SD = 6.78) representing an average 2.58 responses (SD = 2.26) and average 2.23 correct responses (SD = 2.17). In the second discussion, teams made average 10.48 responses (SD = 5.51) and average 9.81 correct responses (SD = 5.22) representing an average 2.64 responses (SD = 2.05) and average 2.47 correct responses (SD = 2).

For the first report, the average report score of C-Board teams was 18.32 and that of control teams was 18.21. There was no significant difference between two groups in report scores, $t = .17$, $df = 53$, $p = .86$. In the second discussion, the average report score of C-Board teams was 17.48 and that of control teams was 17.58. There was no significant difference between two groups in report scores, $t = -.18$, $df = 53$, $p = .86$.

We performed a correlation analysis between the report scores and usage scores for the discussion board. For the initial discussion and report, report scores were not significantly correlated with discussion board responses ($r = -.08$). For the second discussion and report, report scores were not significantly correlated with response ($r = .18$) and correct response ($r = .2$) numbers. In a follow-up regression analysis, response numbers did not significantly predict report scores on either the first ($\beta = -.08$, $p = .66$) or second discussion ($\beta = .18$, $p = .32$).

Finally, we regressed factor scores on the epistemological beliefs survey onto usage patterns. Two factors (avoid ambiguity and ability to learn is innate) marginally predicted their number of discussion responses ($p < 0.10$). Students who agreed with avoidance of ambiguity and disagreed with innate learning ability were likely to make more responses in the discussion board.

Discussion

This study did not yield significant effects from the discussion board. There are a variety of reasons for this result. First, design is a uniquely human activity. Design teams tend to work effectively in face-to-face interactions. A question that emerges from this study is how virtual can a design process be. It is likely that virtual design will be effective only for design teams with extensive experience working together. Additionally, research needs to focus on the kinds of computer-supported collaborative work technologies may most effectively support design processes.

Second, this study took students out of their zone of comfort. In this study, we were implementing an online discussion board into a large, freshman face-to-face class. These students were inured to working with each other in class in face-to-face work sessions. We did not realize how little interaction there would be and now must conclude that a discussion board is not an effective strategy for this type of class, at least not without more extensive training and encouragement. It may be more effective if discussion boards were used more consistently in the course or were counted as part of the course grade. It may well be that online discussion boards are if limited use in face-to-face courses and can be effectively implemented only in online courses. Additional experience is needed to assess that hypothesis.

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