AC 2010-1014: REFLECTIVE PRACTICES OF ENGINEERING CAPSTONE DESIGN TEAMS

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ABSTRACT

Reflection is widely understood as a critical component of learning, especially learning from experience. Effective professionals learn from experiences and use this knowledge when encountering similar or more complex problems. The engineering capstone design course provides an excellent opportunity for students to gain experience in design, but experience alone does not guarantee learning of skills and knowledge, or the ability to transfer this knowledge to new situations. Researchers and theorists have long trumpeted the value of reflective practice as a differentiating factor in the effectiveness of practitioners. As shown by the growing number of publications on the topic in engineering education literature, teaching students the process and value of reflection is increasingly recognized as an essential component of engineering design education.

To support teaching and learning of reflection in engineering capstone design courses, this study seeks to understand how students reflect—individually and as a team—as they are engaged in a design project, specifically in relation to teamwork. This study is part of a larger NSF supported project engaged in the development of capstone design course assessment instruments. Therefore, a second aim is to examine the effectiveness of the instruments in facilitating student and team reflective practice. The research questions for this study include: (1) What are the teamwork-related reflective practices of engineering capstone design teams and individuals? (i.e., what teamwork issues do they reflect on; for what purposes; how; what factors affect reflection; and what are the outcomes?), and (2) What impacts do "prompted" (instructor assigned) reflective assessments have on a team's overall reflective practice?

This qualitative study uses an analytic induction approach to analyzing data and for developing a model of student reflective practices, based on initial conceptual reflection models. Participants include members from two multidisciplinary design teams. Data collection methods include: (1) team meeting observations, (2) interviews (individual and team focus groups), and (3) review of student reflective assignments prompted by instructors. Data is being collected throughout the 2009-2010 academic year, spanning the complete project of each participating team. Results will be based on team reflective practices within the context of each of the three major design phases—problem scoping, concept development, and solution development. Additionally, the longitudinal aspects of the study allow for individual and team growth, regarding teamwork-reflection, to be analyzed and presented. Currently, data collection has begun for the first design phase, problem scoping, and this paper will present initial findings spanning this phase.

INTRODUCTION

Reflection is often stated as an important element in learning, especially learning from experience. The concept of reflection, though, is not clearly defined, and approaches to teaching, learning, and assessing it are reported as significant challenges in education. Part of this challenge, at least, results from the context-specific operationalization of reflection as well as the

varied purposes and outcomes set in educational curriculum. That is, an approach to discussing and teaching nursing students, for example, to reflect on their practice may be much different than that of student-teachers; although the actual mental processes involved may be similar. Differences in purposes and terminology between fields have often been stated as reasons for this confusion in meaning. Nevertheless, reflection for learning is increasingly being purported as an important learning outcome and educators are seeking ways to best address this in the classroom. This paper addresses this need by focusing on the reflective practice of students in engineering capstone design courses. This paper presents preliminary results from a study seeking to analyze and describe the reflective practices of student designers. The rationale for this work is that in order to teach and assess reflective thinking, it must be well understood; and, to understand it, we must first be able to analyze and describe it.

The study reported in this paper is part of a larger NSF-funded project aimed at developing assessment instruments for engineering capstone design course outcomes. The project is coordinated by the Transferable Integrated Design Engineering Education (TIDEE) consortium—an interdisciplinary community of educators. Currently, TIDEE has developed a set of fifteen assessment instruments for capstone courses, focusing on four major areas of performance: teamwork, professional development, design processes, and solution assets. Table 1 gives a list of these assessments with a sample of the performance factors explored by each (for more detail, see Davis et al., (2009), or visit the TIDEE website at www.tidee.org). A sample implementation sequence for the TIDEE instruments is shown in Figure 1 (see McCormack et al. (2009) for more information). The assessments address both design and professional outcomes and support formative and summative use. The role of this current study is to delve deeper into the reflective aspects of design, from which insights gained will be used to address reflective practices of students and teams more specifically in teaching and assessment.

Table 1. Summary of TIDEE's Capstone Design Course Assessment Instruments

Performance Area	**Assessment Instruments**	**Performance Factors (sample)**
Teamwork	1. Team Contract 2. Team Member Citizenship 3. Team Processes 4. Teamwork Achieved	• Inclusive climate • Goal establishment • Work allocation • Internal communication
Professional Development	5. Growth Planning 6. Growth Progress 7. Professional Practices 8. Growth Achieved	• Analyzing information • Collaborating • Adapting to change
Design Processes	9. Problem Scoping Processes 10. Concept Generation Processes 11. Solution Realization Processes 12. Design Reflection	• Process mechanics • Reflection on design processes • Informing design
Solution Assets	13. Defined Problem 14. Selected Concept 15. Proposed Solution	• Functionality • Profitability • Feasibility • Social impact

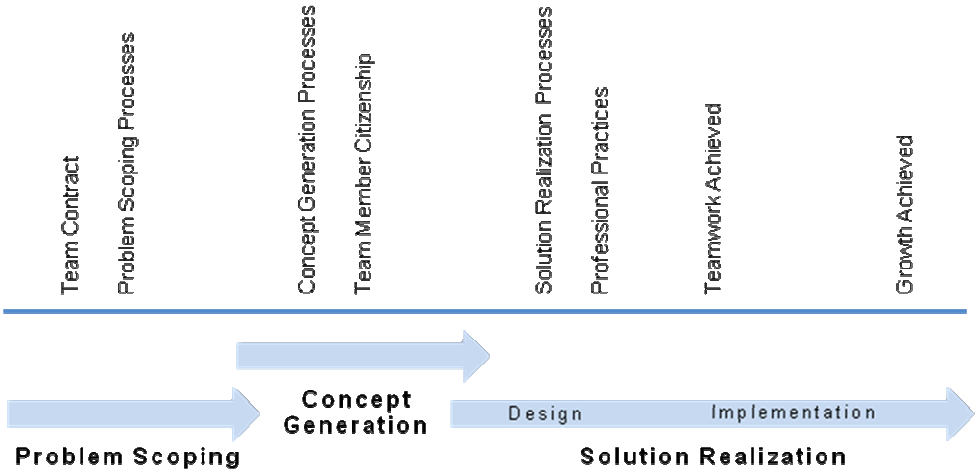

Figure 1. Sample implementation sequence for TIDEE assessments within a capstone course

A brief review of reflection is given in the following section, showing the various conceptual models developed and used to describe reflection and on which teaching and assessment approaches have been based. Following this, an overview of the current study is given along with results from preliminary data collection.

BACKGROUND

Definition of Reflection

Reflection is often represented as an element of models of learning from experience (e.g., Kolb's cycle of experiential learning). The reflective aspect of these models is not completely described, though, resulting in lack of clarity (Moon, 1999). In the past couple decades, there has been an increase in effort by researchers to better clarify and operationalize the concept of reflection. This section will briefly review the literature on this subject.

There are many definitions of reflection; some of those often cited include:

> an active, persistent and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it and the further conclusion to which it tends. (Dewey, 1933, p. 9)

> those intellectual and affective activities in which individuals engage to explore their experiences in order to lead to new understandings and appreciations. (Boud, Keogh, & Walker, 1985, p. 19)

> the process of internally examining and exploring an issue of concern, triggered by an experience, which creates and clarifies meaning in terms of self, and which results in a changed conceptual perspective. (Boyd & Fales, 1983, p. 100)

> a basic mental process with either a purpose or an outcome or both, that is applied in situations where material is ill-structured or uncertain and where there is no obvious solution. (Moon, 1999, p. 10)

A concise definition of reflection for learning may be stated as a process of making new meaning and understandings from critical analysis of uncertain situations.

Conceptual Models of Reflection

Several conceptual models of reflection have been developed. These models tend to describe either *levels* of reflection or the *processes* involved. Levels of reflection, in general, differentiate depths of reflection; processes of reflection describe activities/steps involved as one reflects. Table 2 gives a brief overview of the various models of reflection in terms of levels and processes.

Table 2. Conceptual Models of Reflection

Author	**Levels of Reflection**
Mezirow (1991)[a]	1. Habitual action, 2. Thoughtful action/Understanding, 3. Reflection, 4. Critical reflection
Thorpe (2004)[b]	1. Non-Reflectors (i.e., habitual action, thoughtful action, and introspection) 2. Reflectors (i.e., content reflection, process reflection) 3. Critical reflection (i.e., premise reflection)
King and Kitchener (1994)[c]	1. Pre-reflective reasoning, 2. Quasi-reflective reasoning, 3. Reflective reasoning
van Manen (1991)	1. 'Everyday' thinking and acting 2. Reflection focused on events or incidents 3. Reflection on personal experiences (a more systematic reflection with the objective of reaching understanding; the development of understanding through interpretation) 4. Reflection on the manner of reflection (self-reflection on the nature of knowing or metacognition on the way in which knowledge works)
Boud et al. (1985)[a]	1. Association (i.e., relate new ideas to what's known) 2. Integration (i.e., seek relationships among data) 3. Validation (i.e., determine authenticity of resulting ideas and feelings) 4. Appropriation (i.e., make knowledge one's own)
Author	**Processes of Reflection**
Dewey (1933)	1. [Problem] a felt difficulty (a problem, perplexity, hesitation, doubt, possibly as a shock) 2. [Definition] its location and definition (clear understanding of the problem) 3. [Hypothesis] suggestion of possible solution (supposition, conjecture, guess, hypothesis, theory, cultivation of a variety of alternative suggestions) 4. [Reasoning] development by reasoning of the bearings of the suggestion (reasoning about the implications of the suggestions; this is sometimes taken as the entire reflective process) 5. [Testing] further observation and experiment leading to its acceptance or rejection; that

	is, the conclusion of belief or disbelief (corroboration, or verification, of the conjectural idea).
Schön (1987)	1. Realizing a surprise during a task 2. Reflection on both the surprised event and the "knowing-in-action" which led up to the surprise… questioning, for example, "What is this?" and "How have I been thinking about it?"… iterating between the surprise and the thinking leading up to the surprise 3. Thinking critically about the thinking that resulted in the current "fix"… and restructuring strategies of action, understandings of phenomena, or ways of framing problems 4. On-the-spot experimentation… in order to think up and trying out new actions intended to explore the newly observed phenomena, testing tentative understandings of them, or affirm the moves invented to change things for the better
Moon (1999)	1. Development of a need 2. Clarification of issue 3. Review and recollection of additional information/knowledge pertaining to the issue 4. Review of emotional state 5. Processing of knowledge and ideas 6. Eventual resolution and possible action and transformation
Thorpe (2004)[b]	1. Awareness, 2. Critical analysis, 3. New perspective

[a]Adapted from "Reflection and Reflective Practice in Health Professions Education: A Systematic Review," by K. Mann, J. Gordon, and A. MacLeod, 2009, *Advances in Health Science Education, 14*, p. 598.
[b]Adapted from "Reflective Learning Journals: From Concept to Practice," by K. Thorpe, 2004, *Reflective Practice, 5*, p. 329.
[c]The complete model is given in Appendix A.

Models representing levels tend to describe a range of depth of reflection: from no reflection (as in everyday thinking), to some reflection (e.g., understanding), and then to very deep reflection (e.g., questioning assumptions). Process-related models describe the types of activities one would cycle through while reflecting on an experience, possibly iterating multiple times. The cycle may start with an awareness of some issue (as a result of a problem, perplexity, etc.), then progress to analyzing the issue, and finally, to some outcome (e.g., new understanding, resolution). A similarity between the two model types is that each culminates in a new perspective or transformational learning.

Another way of conceptualizing reflection may be with respect to the timing and purpose. Reflection-*on*-action, for example, is generally thought of as "looking back," in order to learn from an experience. This is the more common view of reflection: that it is conducted after the experience, such as a retrospective. Reflecting while in the midst of an experience is termed reflection-*in*-action (Schön, 1983) and has the purpose of affecting the pending action to be taken. The goal of reflection-in-action seems to be focused more on guiding practice than learning from experience, but as suggested by Moon (1999), the mental processes may indeed be the same.

The conceptual models of reflection presented above have been developed within specific contexts and for specific purposes. King and Kitchener's Reflective Judgment Model (RJM), for example, was developed to distinguish the depth of one's reflective thinking, in which a lengthy interview was conducted and participants responded to specific scenarios. A level of reflection

was then assigned based on criteria such as evaluation of evidence and understanding of the certainty of knowledge. This approach was undoubtedly useful for the author's purposes, but it is unclear whether the model would be applicable to other purposes and contexts, such as the capstone course, where part of the goal is to teach, assess against specific course criteria, and provide constructive feedback on reflection itself.

For the purposes of assessment, each view of reflection appears to have merit. For instance, assessing processes of reflection may allow for more instructive feedback on how to reflect, while assessing the level may be more useful for summative purposes. Both reflection-in-action and reflection-on-action are reported to be important for professional practice (Schön, 1987) and for lifelong learning (Jiusto & DiBiasio, 2006; Roselli & Brophy, 2006). Construction or adaptation of a model appears, then, to be dependent on the intended outcomes. For this study, the models presented above serve as initial lenses for interpreting students' reflective practices.

The remainder of this section presents examples from the engineering education literature of approaches others have taken to conceptualize reflection in an engineering academic context.

Nature of Design Team Reflections

Valkenburg and Dorst (1998) used Schön's model of reflection-in-action (see Table 2) to analyze and describe the nature of team designing. To do so they first operationalized the elements of reflection-in-action as the following four processes: "naming the relevant factors in the situation, framing a problem in a certain way, making moves toward a solution, and evaluating those moves" (p. 251); or, simply, "naming, framing, moving, and reflecting" (p. 254).

In their study, two teams participated in a week-long design project. Throughout the experiment, observations were made of the team activities and each team was audio recorded. Data were analyzed to characterize team processes through the lens of reflection-in-action. This was done by categorizing team activity according to the four steps above.

The four steps are seen as a hierarchy in which reflecting is the highest level and naming the lowest. Results of the study are presented as amount of time spent within each step. The two teams in the study were part of a larger competition of many teams, and as it turned out, one of the teams participating won the competition and the other team had a design that did not work. Results of time spent per step indicated that the winning team spent significantly more time in the reflecting stage while the losing team spent a large portion of the time in the naming stage. Valkenburg and Dorst state that the amount of time in the upper stages is not the only contributing factor, but that the quality of effort in each phase is also important. Based on correlations of results with the two teams' performance, there appears to be credibility in the suggestion that reflection is an important aspect of quality design.

Using a very similar approach as Valkenburg and Dorst, Adams, Turns, and Atman (2003) conducted a study to describe and compare the reflective practices of freshmen and senior design teams. Like Valkenburg and Dorst, Adams et al. also used Schön's reflection-in-action theory as a conceptual lens. Reflection was operationalized by (1) problem setting and (2) "listening to a situation's back-talk." Problem setting was analyzed by the number of design factors teams

identified, the amount of information they gathered on the problem, and the amount of time they spent in problem setting activities during the design process. Listening to a situation's back-talk is analyzed by looking at various elements of team iterations between the problem and solution space.

The results showed that seniors exhibited greater reflective practice than freshmen. In problem setting, the seniors identified more design factors for the problem, gathered more information, and spent more time iterating between the problem and solution, in order to better understand the problem. In contrast, freshmen tended to stay in one design phase for longer periods of time without returning to the problem space. In other words, the seniors engaged in a "conversation" with the problem: iterating as needed between the problem and solution in order to better understand the problem while advancing the solution.

These two studies suggest that Schön's model can be used to characterize student and team reflection. It is interesting to note that the authors approached the task of operationalizing the concepts differently. This highlights the variability in applying any particular model. Further, this approach addresses reflection-in-action, but not necessarily reflection-on-action; an important outcome for lifelong learning. Also, observation of the elements of this model involves observable external factors (e.g., design process activities, iterations), not the mental process students use in reflecting. For the purpose of teaching and providing feedback from assessment on reflective practices (i.e., on how to reflect), assessment of how students think while reflecting appears to be important. In that case, descriptions of the elements of reflection in terms of thinking processes should also be provided.

Studying the Impact of Reflective Thinking on Project Work

Huyck, Bryant, and Ferguson (2009) have presented a method for quantifying reflective judgment of students who are working on service learning projects. Ultimately, their goal was to determine if working on service learning teams promoted higher reflective thinking. To measure reflective thinking, prompted reflective questions were given and responses were analyzed using King and Kitchener's RJM (Appendix A). Results of the study indicated that students' reflective thinking was, on average, between stages 3 and 4 on the RJM; between pre-reflection (no reflection) and quasi-reflection (some reflection). This is on the lower side of the scale and indicates little reflective thinking by students. The authors concluded that engaging in reflective exercises did not increase students' self-perceived competence for the intended service learning outcomes. Acceptance and full participation from students was noted by the authors as problematic and one of the limitation of the study.

A similar study by Slivovsky et al. (2004) was conducted to study reflective thinking of students working in the Engineering Projects in Community Service (EPICS) program at Purdue University. Topics of reflection included teamwork, ethics, and community. Students were administered assessments focused on these topics and reflective thinking was then analyzed using King and Kitchener's RJM. Similar to the results reported by Huyck et al. (2009), students' reflective thinking levels were found to be between pre-reflective and quasi-reflective thinking. Results were used to inform instructors on changes that needed to be made to the course methods and topics.

Tsang (2002), also working with service learning projects, presented a course plan for assessing and evaluating reflective thinking. His goal was to document the development of reflective thinking in students as a result of participation on the project. In a slight shift from the method presented by the previous sets of researchers, Tsang applied the Reflective Judgment Rubric (developed by B. Olds) to evaluate reflective thinking. This model uses King and Kitchener's RJM scale together with criteria from Blosser's taxonomy. In essence, items from Blosser's taxonomy—evaluative thinking, divergent thinking, convergent thinking, and cognitive memory—were mapped into the RJM framework.

These three studies were based on similar methods. Their purposes were predominantly to judge the effectiveness of course material and/or programs. None of the authors indicated whether the results were reported back to the students. The goal was ultimately formative for each, as the authors made changes to improve learning of reflection practices.

Reviewing the models of reflection given in Table 2 and the suggested levels of reflective thinking, it appears that criteria such as these could be valuable for formative purposes. Boud's model, for example, which addresses association, integration, validation, and appropriation of information, may be useful for instructional purposes as well as for grading and course evaluation.

Assessment of Reflective Thinking Through TIDEE Instruments

Several approaches to characterizing the reflective practices of students have been presented in the literature. For the TIDEE assessments, the goal is to assess students' reflective practices for both formative and summative purposes, in order to improve their ability to reflect and to document their final state of development. This current study addresses this need by providing a description of the reflective practices of students engaged in engineering capstone design projects. Results will be used in developing subsequent assessment instruments and interpretation methods.

STUDY METHODOLOGY

The guiding question for this study is: What are the reflective practices of students in capstone design projects? Specifically, this study seeks to understand how students and teams reflect "on their own" (i.e., self-directed reflection), and to discuss this through the lenses of existing models of reflection. This will allow evaluation of the degree of congruence of how students reflect and existing models of reflection, thereby aiding in model adoption or adaptation. Additionally, as educators currently use various approaches intended to facilitate student reflection (e.g., assessments, journals, portfolios), a second goal is to describe the reflections of students when responding to prompted reflective assignments in a capstone course; in order to determine how well these align with course objectives.

This study uses a qualitative approach in which interviews, observations, and document reviews are used to study student reflections. Throughout the 2009-2010 academic year, members from

two engineering teams in a capstone design course are participating in the study. Each team is multidisciplinary (ME, CE, and Bio-engineering, as well as Finance and Entrepreneurial Studies) and their projects involve multiple engineering aspects. For team A, eight of the nine members elected to participate, and for team B, all five members are participating. Participation is voluntary and does not affect course grades.

For data collection, each participant will be interviewed four times (three individual interviews and one team focus group) throughout the study. Interviews will address self-directed reflective practices (the first interview protocol is given in Appendix B), while focus groups will address prompted reflections. Observations will be made during team meetings, and will focus on how students reflect as a team. Lastly, responses from TIDEE assessment assignments will focus on prompted reflections. This data collection approach allows for individual and team reflections to be studied at the various stages of design (i.e., at the problem scoping, conceptual development, and final solution development phases). Because the capstone project involves all aspects of design (from conception to prototyping) and tasks vary considerably between teams and members, for this study, in order to provide consistency in topics and adequate depth of coverage, the focus of analysis will be on teamwork. That is, data collected will pertain to how individuals and teams reflect on teamwork issues.

An analytic induction approach will be used for data analysis. In general, this entails comparing individual case studies with existing definitions and hypotheses of a phenomenon (Taylor and Bogdan, 1998). Each case is used to either confirm the existing model(s) or serve to reformulate them.

Currently, the first stage of data collection has been conducted. The next section presents results from this stage, which includes analysis of the first set of individual interviews with team members.

RESULTS

For the first stage of the study, interviews were conducted with twelve members from the two participating teams. These interviews were analyzed for congruence with the models listed in Table 2. Three representative interviews are presented and discussed below.

Interview #1

Teaming issue:
Lack of participation by team members

Scenario:
Participant described a teaming problem in which several of his team members (five of the nine) were not showing up to regular team meetings (a common issue with student teams). It was bothersome to him as he and three others were doing most of the work. In dealing with the situation, he and another member discussed the problem and came to the resolution that the team leader should “crack down on the slackers” and make

them more accountable to the team in participating. The idea was that any member not showing up to a meeting should discuss this in advance and should have a compelling reason.

From Dewey's model, the stages of awareness, definition, and suggestion can be identified in this situation. Namely, this participant became aware of an issue and realized that it needed to be addressed. After some thought and discussion (albeit brief) he/they later arrived at a solution and then implemented it. Missing is any reasoning about any implications of the proposed action and testing (mentally) to verify the appropriateness of the action.

Schön's model is somewhat similar to Dewey's: a surprise causes reflection on the situation which prompts development of a solution and mental testing of the implications. The reflection from this scenario describes (vaguely) the steps of naming the problem and determining a strategy of action (or moving). In Moon's model, the reflection addresses the development of a need, clarification of the issue, and action. Not included are review and recollection, review of the emotional state, processing of knowledge, and transformation (or new perspective). Lastly, from Thorpe's model, only the awareness stage is evinced by the student's reflection; critical analysis and new perspective are not demonstrated.

In terms of the conceptual models from Table 2 related to levels of reflection (as opposed to processes), it is difficult to characterize the student's reflection with any of the descriptions given in the models. For example, from King and Kitchener's Reflective Judgment Model (see Appendix A), the first level of reflective thinking is defined as "knowing is limited to single concrete observations: what a person observes is true;" higher levels indicate greater realization of the uncertainty of knowledge. These distinctions are difficult to apply to reflections such as described in this scenario. Likewise, other models from Table 2, with descriptions of various levels of reflective thinking, do not appear to be useful, as presented, in distinguishing this type of student reflection; nor do they appear to be useful as a method of facilitating effective feedback to students on their reflective practices.

In summary, this case scenario highlights a common teaming issue—lack of participation. The student described their process of thinking through and resolving the problem, which could generally be evaluated at a minimal degree of reflective thought. For the purpose of characterizing this student's reflective thinking, the stages, or process-type model appears to be more applicable than the levels-type. The process models would likely prove more meaningful in assessing and providing constructive feedback for formative purposes as well, supporting the goals of the capstone course assessments related to this study. A limitation here is that the student's description of his reflection on this situation is likely not an accurate representation of his true reflective process; as describing one's thinking is quite challenging. But, this type of self-assessment of reflection is typical of many assessment frameworks facilitating reflective thinking.

Interview #2

Teaming issue:

Coordination of meetings

Scenario:
Participant described a teaming problem in which team meetings were not productive. In response, the group discussed the problem and brainstormed possible solutions. In defining the problem, the group addressed questions such as: "Did we accomplish what was needed at the meeting? Why not? What showed some friction at the meeting? How can we filter the important things? How can we improve on it? How can we build on what we know?" Drawing on past experiences from internships, the team agreed to develop agendas for each meeting, prioritize and set time limits for agenda items, assign tasks to individuals to present at meetings and make everyone accountable for the tasks getting done. As a result, subsequent team meetings were more productive and team member attitudes were much better.

The reflection described in this scenario can be characterized in terms of several of the process-related models of reflection from Table 2. The participant realized a problem, brainstormed to understand the reasons underlying the problem, discussed possible solutions, drew on existing knowledge and experiences, and implemented changes. This was done individually and as a team. Not all of the elements from the process models were addressed, though, in this scenario; as similar to case 1 above. The participant, for instance, did not describe having a new perspective based on this experience. That is, as shown in the models (Moon and Thorpe) the final stage of reflecting is the development of a new perspective on the situation, or learning that is transformative. A deeper level of learning from reflection would, as purported in the models, lead to learning that is more abstract from the current situation; relating what is learned from the current situation to other, overarching situations. Neither of the two cases above evince this. As with case 1 above, the models from Table 2 based on levels of reflection would be difficult to relate to this reflection.

Interview #3

Teaming issue:
Poor attitude by another team member

Scenario:
Participant described a teaming problem in which one team member had a very negative attitude toward others. During team meetings, for example, that 'negative' team member would criticize the activities being done by the team, was not open to others' ideas (or quick to dismiss them), talked to others with abrasive tone, etc. Many of the other team members found it difficult to work with this teammate as he was often "bringing the team down." A specific instance was during a meeting in which concepts were being discussed and evaluated. The negative member thought the process was meaningless and wanted to move on while most of the team wanted to continue. The meeting turned disruptive and the overall team dynamics were affected.

The participant (interviewee here) was quite bothered by the incident and discussed

how she later reflected considerably on the situation and possible solutions. She described reflecting on all events leading up to the disruptive meeting and on why the meeting turned out the way it did. She questioned herself—her thoughts regarding the other member and her actions during the meeting. As an intern the previous summer, she drew on teamwork and management training she'd been given. She did not know the other individual personally, but knew that he may have been having personal problems which could likely be factoring in. Part of the problem, she concluded, was that the team was "not all on the same page." That is, the reasons and processes involved in conducting the concept evaluation in the meeting were not apparent to everyone, which caused the negative member to not value the activity. Her insights were that team processes, such as this, need to be clearly understood by all, including the purpose, process, and logistics (such as timing, participation, etc.). Also, she realized that she needed to separate her personal feelings toward the individual, not letting them affect the goals of the team.

The participant exhibited many of the process steps listed in the process reflection models from Table 2. She reflected considerably on understanding the problems and on the activities and thinking leading up to poor team attitudes. She considered multiple points of view and questioned her own emotions and logic. Drawing on discussions with others and on past experiences and training, she worked though possible actions to take to address the issue, considering implications of all possibilities. The reflection process led her to new understandings of team dynamics. The degree of reflection, in terms of processes listed in Table 2, appear to be much greater in case 3 than in cases 1 and 2 above. It was obvious from the interview that this participant in case 3 was very open-minded, whole-hearted, and was diligent in considering the consequences of proposed actions; all of which are dispositions for effective reflection, as outlined by Dewey (1933). In terms of the models pertaining to levels of reflective thinking, again, it's difficult to relate this participant's reflection with the descriptions given.

CONCLUSIONS

The overall goal of this study is to describe the reflective practices of engineering capstone students as they participate in a design project. The purpose for this is to develop teaching and assessment tools which will facilitate student learning of reflection; an outcome reported as important for effective professional practice and lifelong learning.

The three interviews presented are representative of the responses from the twelve participants during this set of interviews. In general, the reflections were mixed, with some appearing shallow and others considerably deeper. The process-type conceptual models from the literature were found to be more congruent with the data, with the level-type appearing difficult to apply meaningfully (for facilitating teaching and learning).

Using these existing models as initial conceptual lenses for analyzing the data, the following process steps have tentatively been found to represent the scope of student reflections; although no student indicated that they engaged in each step.

1. Clarify the problem, including review of emotional states and questioning of assumptions
2. Integrate previous knowledge and experience
3. Make meaning of the situation
4. Develop alternative solutions
5. Reason about the implications of proposed solutions (iterate between solution and implications, testing appropriateness of solution)
6. Decide on final resolution
7. Review what has been learned, generalize to other areas

As stated, these steps represent the full range of student practices, where each student may have indicated only a subset of those listed. These initial results have established a preliminary framework for describing and modeling student reflections, based on a coarse evaluation and comparison with existing models. The next phase of this study will involve testing each listed step with additional data for either further confirmation or revision. Subsequent data collected will also focus on fleshing out meaning and developing accurate descriptions and relationships in order to develop a representative model of student reflections.

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Appendix A.
King and Kitchener's Reflective Judgment Model (King & Kitchener, 1994)

Phase I. **Pre-Reflective Reasoning** (Stages 1-3): Belief that knowledge is gained through the word of an authority figure or through firsthand observation, rather than, for example, through the evaluation of evidence.

1. Knowing is limited to single concrete observations: what a person observes is true.

2. Two categories for knowing: right answers and wrong answers. Good authorities have knowledge; bad authorities lack knowledge.

3. In some areas, knowledge is certain and authorities have that knowledge. In other areas, knowledge is temporarily uncertain. Only personal beliefs can be known.

Phase II. **Quasi-Reflective Reasoning** (Stages 4 and 5): Recognition that knowledge-or more accurately, knowledge claims-contain elements of uncertainty, which [people who hold these assumptions] attribute to missing information or to methods of obtaining the evidence.

4. Concept that knowledge is unknown in several specific cases leads to the abstract generalization that knowledge is uncertain.

5. Knowledge is uncertain and must be understood within a context; thus justification is context specific.

Phase III. **Reflective Reasoning** (Stages 6 and 7): People who hold these assumptions accept that knowledge claims cannot be made with certainty, but [they] are not immobilized by it; rather, [they] make judgments that are "most reasonable" and about which they are "relatively certain," based on their evaluation of available data.

6. Knowledge is uncertain but constructed by comparing evidence and opinion on different sides of an issues or across contexts.

7. Knowledge is the outcome of a process of reasonable inquiry. This view is equivalent to a general principle that is consistent across domains.

Appendix B
Interview Protocol (first of three individual interviews)

I. Project and past experiences

1. Briefly describe your team's project and your specific role on the team.
2. Just prior to the start of the capstone class, what were your thoughts on working on a team with others? (prompts: anticipations and reservations regarding teamwork)

II. Current teamwork situation

3. Briefly describe your current team dynamics.
4. I will give a brief overview of some common aspects of teamwork. Discuss how your team is performing for each:
    - *Communication*: actively listening and appropriately sharing information with others
    - *Participation*: doing "fair share" of work, supporting others, collaborating
    - *Coordination*: decision making, problem solving, planning
    - *Monitoring*: actively looking out for others and the project, giving/receiving feedback
    - *Values*: having shared goals and expectations for the project
    - *Attitude*: having a positive and supportive attitude toward others and the project

III. Reflection on Teamwork – Approach 1

5. Based on these or any other element of teamwork, what's a teamwork issue that you have given a lot of thought to so far regarding your team? (prompts: situation, initiator, thinking process, role of emotions, factors affecting, resolution, current situation)

IV. Reflection on Teamwork – Approach 2

6. What's the most important thing you've learned so far about working as a team; that is, what have you taken away from this project about teamwork?
7. Describe the experience that caused this learning, from initiation to resolution.
8. Walk me through your thought processes in dealing with this issue.
9. How was this issue dealt with collectively as a team?
10. How did you think of this issue before starting the capstone class?
11. How will this affect you on your next team project and why do you think this?

V. Reflection on Teamwork – Approach 3

12. What was something that really surprised you while working on this team?
13. How did it affect you and/or your team?

VII. Conclusion

14. Have I missed anything that would help me understand how you've thought about teamwork issues so far on your project, or, is there anything you've thought of throughout this interview that you want to discuss more or clarify?