DEVELOPMENT AND TESTING OF ASSESSMENT INSTRUMENTS FOR MULTIDISCIPLINARY ENGINEERING CAPSTONE DESIGN COURSES

By

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Abstract

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Chair: Denny Davis

The research presented in this manuscript was focused on the development of assessments for engineering design outcomes. The primary goal was to support efforts by the Transferrable Integrated Design Engineering Education (TIDEE) consortium in developing assessment instruments for multidisciplinary engineering capstone courses. Research conducted in this study included (1) the development of an assessment structure and methodology for assessing engineering design processes and products, (2) exploring the reflective practices of students participating in a capstone design project, and (3) testing multiple TIDEE assessment instruments for inter-rater agreement.

The assessment structure developed includes a comprehensive plan for assessing students’ design process activities and products within the context of three design phases: the problem scoping, concept generation, and solution realization phases. For each phase, one formative assessment is implemented mid-phase and one summative assessment is implemented end-of-phase. The rationale for this structure is to provide students and instructors an optimally timed and sequenced plan for facilitating student reflections and for documenting achievement of student learning outcomes.
Student reflective practices were studied and compared with existing conceptualizations of reflection. A modified analytic induction approach was used to review and reformulate existing reflection concepts based on student data. Six general categories were found to represent student reflective practice: realization of a problem or contrasting idea, clarification of the problem or idea, analysis of one’s thinking leading to the problem or challenging belief, synthesis of existing knowledge and theories to make interpretation and meaning of the problem or belief, validation of one’s existing or revised belief through corroboration, and gaining of a new perspective through critical thinking on foundational premises of the belief.

Finally, seven TIDEE assessments were tested for inter-rater agreement, including Team Member Citizenship, Team Processes, Team Contract, Growth Planning, Growth Progress, Growth Achieved, and Professional Practices. Multiple faculty and teaching assistant raters scored subsets of student work after being given a brief training session on the assessments and scoring procedures. Results indicated acceptable inter-rater agreement for each of the assessments intended for formative use, and suggested one summative assessment, Growth Achieved, may need revisions to the assessment, performance criteria, or rater-training protocol.
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Dedication

For Piper, Ethan, Kai, and DeAnn
Chapter 1

Introduction

INTRODUCTION

The focus of this research is on the development of assessments for multidisciplinary engineering capstone design outcomes. Multiple aspects of the assessment development process are engaged through this work, including building a foundation for a cognitive model of student reflective practices, developing a structure and methodology for assessments related to design processes and products, and testing the technical qualities of assessments based on inter-rater agreement. The goal of this research is to support efforts of the Transferable Integrated Design Engineering Education (TIDEE) consortium, whose overall focus is developing and assessing students’ engineering design capabilities related to teamwork, professional development, design processes, and solution assets (Davis et al., 2010). This manuscript is presented as a compilation of four independent articles relating to the research goals indicated above, with the addition of this introductory chapter and a concluding chapter. The remainder of this chapter introduces concepts involved in the assessment development process. An overview of each chapter is then given which presents the major objectives, general approach to the study, deliverables, and significance to the development of assessment instruments for engineering capstone courses.
BACKGROUND

What is Assessment?

Assessment is the collection of information for the purpose of informing decisions. In the context of capstone design courses, this may involve the observation of students and teams as they perform a task, traditional pen-and-paper exams, individual or team oral presentations, reports, informal discussions, and so on for any form of information gathering. Assessment data is evaluated and then used to inform stakeholders, which, for the capstone course, includes students, faculty, and program administrators. Faculty, for example, may use assessment data to gauge students’ conceptual understanding, leading to decisions on next steps of instruction. Faculty may also use assessment results as a basis for constructive feedback or even to inform themselves of their own performance. Grading is perhaps the most common purpose of assessment use, which, as stated, may also involve a variety of methods for collecting and evaluating student performance data.

Similar to faculty, students use assessment results for multiple purposes: to track their success, to identify their needs, to suggest a new or revised direction of study, etc. (Stiggins, 1997). For academic programs, continuous improvement and documentation are based almost exclusively on assessment data. As stated in Criterion 3 of ABET’s Criteria for Accrediting Engineering Programs: 2010-2011, “There must be an assessment and evaluation process that periodically documents and demonstrates the degree to which the program outcomes are attained.” and from Criterion 4, “Each program must show evidence of actions to improve the program. These actions should be based on available information, such as results from Criteria 2 and 3 processes.” (ABET, 2009, p. 3). Assessment can, therefore, be a critically important aspect of teaching and learning.
The overall purposes for which an assessment is conducted can be described as summative, formative, or both. Summative assessment is generally used to measure achievement of a stated outcome whereas formative assessment may be used to promote improvements in student learning. Black and Wiliam (1998) describe formative assessment as a means of providing feedback in order to adapt teaching to the needs of the learners. Sadler (1989) states that formative feedback is necessary to help learners understand deficiencies in their current understandings and will guide them in improvements. Some implications of these distinctions in assessment purposes relate to variations in design, content, administration, use of results, and testing of an assessment (Stiggins, 2008).

TIDEE’s capstone design assessments include both formative and summative purposes, with certain assessments intended to serve as both. Specifically, assessments have been developed with the goal of understanding students’ performance throughout their capstone course so that constructive feedback and guidance can be given to teams and individuals at optimal phases of their design process. Additional summative assessments have been developed to measure defined performance outcomes, which are also administered at appropriate milestones throughout a design project. As stated, this study engages multiple areas of the assessment development process for several of TIDEE’s capstone assessments.

Assessment Development

As stressed above, several factors influence the development of assessment instruments. Stiggins (2008) suggests four keys, or principles, for producing valid and reliable assessments (adapted from p. 20):
• Have a clear purpose for assessment. As assessment can be used to both promote and verify student learning, guiding questions for this principle may include: Why assess? What’s the purpose? Who will use the results? How?

• Have clear and appropriate achievement targets. Guiding questions may include: What are the learning targets? Are they clear? Are they appropriate?

• Have appropriate methods for assessment. Guiding questions may include: Is the method capable of reflecting the targets? Are the test items of high-quality? Does the assessment adequately sample the target to provide sufficient evidence? Is the assessment bias-free?

• Have an effective plan for communicating the results. Guiding questions may include: Who are the results for? What form is needed? How will the results be communicated?

Stiggins’ (2008) four principles are represented in graphical form below, Figure 1. The four principles are seen as a “map” for developing valid and reliable assessments, although, as suggested by Stiggins, the order is immaterial as each element is interrelated and equally important.

The National Research Council ([NRC], 2001) has described a similar approach to assessment development. In Knowing What Students Know: The Science and Design of Educational Assessment, the NRC advocates the development and alignment of three elements for assessment design: a cognitive model of learning, observation tasks, and an interpretation model. The cognitive model serves as the foundation and describes how knowledge is represented and how competence is then developed in the content domain of interest. That is, the
model suggests what learners know and how they progress over time. Observation tasks represent the method for data collection: exam questions, observation protocols, performance protocols, etc. The NRC defines the observation element as the tasks or situations that allow observation of student performance. Lastly, the interpretation model describes the method for drawing conclusions from the student performance. This may be, among other methods, a scoring rubric used to evaluate student performance with the resulting score suggestive of a student’s achievement level regarding a particular outcome. The NRC’s three elements are depicted in Figure 2 below, known as the assessment triangle.

The cognitive model in NRC’s assessment triangle forms the foundation of assessment development. Each element, though, is developed in parallel: the interpretation model influences the types of observations needed, etc. Therefore, in developing assessments, iteration is needed to ensure each element is designed to meet the assessment needs.
Performance, or scoring, criteria provide a basis for making interpretations regarding student performance. Scoring criteria define the dimensions or traits needed to evaluate the performance, provide a rating system or scale depicting performance quality for each trait, and describe standards of performance for each trait (Trevisan, Davis, Calkins, & Gentili, 1999). Trevisan et al. suggest the following steps in defining scoring criteria: (1) define quality performance for a particular set of competencies, (2) define poor and mid-range performance, (3) determine the length of the scale, (4) pilot test the scoring criteria, and (5) revise the scoring criteria (p. 2-3).

A similar process for developing performance criteria is given by Arter and McTighe (2001): (1) gather samples of student work, (2) sort student work into groups and write down reasons, (3) cluster the reasons into “traits” or important dimensions of performance, (4) write a value-neutral definition of each trait, (5) find samples of student performance that illustrate each score point on each trait to provide anchors for needed levels of performance, and (6) test and refine (p. 37-44). Scores or ranges indicating the level of a student’s performance on defined traits allow interpretations to be made concerning the students’ overall ability. Coupled with assessment tasks, the performance traits and descriptions of high to low performance behaviors
represent the elements of the NRC’s assessment triangle and, therefore, give a holistic view of the assessment development process.

**Assessment Testing**

Performance criteria serve as a lens for interpreting the performance elicited by an assessment. As mentioned above, the performance criteria must be tested to ensure that the purpose of the assessment is met; that is, testing to gather evidence that the interpretations reflect actual performance. Likewise, the quality of the assessment itself—what is done by the student and observed by the instructor—affects the accuracy of the interpretations. Assessment methods, such as oral presentation, pen-and-paper exams, and visual observations, may be appropriate for certain assessment purposes, but not for others; an oral presentation, for example, may not elicit mastery of content knowledge, and similarly, an essay exam may not elicit the level of one’s inter-personal communication abilities. Proper selection of an assessment method(s) is needed to make adequate interpretations. Assessment content is also important for similar reasons. With given choices of assessment method, content, implementation process, etc., testing is then used to verify the appropriateness and adequacy of the choices—for both the assessment instrument and performance scoring and interpretation model.

Testing may involve gathering evidence on the degree of accuracy in measuring what is intended, called construct validity, as well as gathering evidence on the degree of precision in measurement, called reliability. Testing may also be conducted to determine the value of the assessment to students and instructors in the classroom, referred to as value or consequential validity by Brookhart (2003). For TIDEE’s capstone design course assessments, with purposes including both formative and summative, several aspects of validity and reliability are important
to provide credibility that the assessments will serve the intended purposes. This study addresses one aspect of testing—inter-rater reliability—which is an indication of the degree of consistency in scoring between multiple scorers on a performance. Brief descriptions of the assessment development processes included in this study follow.

DESCRIPTION OF RESEARCH

Chapters two through five are composed of articles written and submitted for publication regarding the research included in this study. This section will give a brief overview of each of the remaining chapters, including objectives for the individual research studies, methodologies used, study deliverables, and significance of each to the overall goals of the research.

Chapter two presents a study on the development of a structure and methodology for assessing a range of capstone design course outcomes related to design processes and assets. TIDEE’s overall framework incorporates outcomes related to learner development and solution development. Learner development outcomes pertain to professional knowledge, skills, and affective qualities, and are differentiated into two performance areas: teamwork and professional development. Solution development pertains to outcomes related to engineering design, represented by two additional performance areas: design processes and solution assets. The goal for this study is to develop a structure for assessing students’ design processes and design solution assets throughout their capstone project in which the purposes for the assessment are both formative and summative. The research approach consists of a review of the literature on design processes and assets to develop an overall assessment plan and identifying the major dimensions for assessment. An assessment development methodology is also provided, which incorporates the concepts of a cognitive model, observation tasks, and interpretation model to the
specific outcomes relating to design processes and assets for capstone design courses. The significance of this work is that it provides a comprehensive assessment plan tailored specifically to students in the context of capstones; that is, areas for assessment are aligned with natural design phases as well as to the content applicable to multidisciplinary capstone courses.

Chapters three and five present a study on the reflective practices of students in a capstone course citation for chapter five. The intention of this study is to develop an understanding of students’ reflective practices which will, in turn, provide a foundation for tailoring assessments to this topic. A qualitative approach is used to capture and describe students’ reflective practice, as viewed through existing conceptualizations of reflection from the literature. Reflection is closely linked to self-directed learning (Brookfield, 1985; Jiusto & DiBiasio, 2006; Mezirow, 1985; National Research Council, 2005) and, as expressed by the National Academy of Engineering (2004), SDL is an important ability for future engineers. The significance of this study is that it provides the foundation for incorporating reflective practice into the capstone course by describing reflection in the context of design outcomes of students. Chapters three and five of this manuscript correspond to a single study; chapter three provides results based on initial findings while chapter five includes final results from the entire study.

Chapter four presents results from an inter-rater agreement study with TIDEE’s teamwork and professional development assessments. Seven assessments were tested for rater consistency in scoring (i.e., inter-rater reliability). Results are used to indicate the quality of the performance scoring criteria (rubrics developed for each assessment) as well as the rater training protocol developed for the assessments. The study is significant as the results provide evidence of credibility to users that the assessment and rubrics can be used reliably across diverse raters.
Chapter six provides a summary of the overall research conducted and presented in this manuscript.

SUMMARY

Assessment of learning and assessment for learning are crucial aspects of the learning process. Instructors and students both need to look back and gauge their progress in order to make decisions on effective next steps. Similarly, programs need to assess their overall effectiveness and evidence this to accrediting bodies and to academic program reviewers, and also use this data as a basis for continuous improvements. With the importance of assessment to all stakeholders in education, appropriate assessment development is needed. This manuscript presents three individual research studies involved in assessment development within the context of engineering capstone design courses. The three studies are used to support the goals of TIDEE, a multidisciplinary consortium seeking to advance the capabilities of engineering graduates through the development of effective instruction tools for design education.
REFERENCES


Chapter 2

Assessment Structure and Methodology for Design Processes

and Products in Engineering Capstone Courses

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Citation:

ABSTRACT

To enhance learning as well as satisfy requirements mandated by ABET, engineering programs and faculty are increasingly investigating ways to teach and assess the technical and non-technical outcomes set for students. Capstone courses provide an ideal place to assess these outcomes, as they typically address all or most of those listed in Criterion 3. With ongoing NSF support, the Transferable Integrated Design Engineering Education consortium (TIDEE) has been developing transferable assessment tools specifically for engineering capstone design courses. This work has produced a framework and cognitive model which outline the primary performance areas associated with capstones and provide an overarching structure of the assessment implementation strategy. The model represents the structure of a complete package of instruments that are valid for varied capstone courses, institutions, and faculty. Over the past few years, with this framework and model, TIDEE has designed, tested, and implemented several assessment instruments as part of this package. The work presented in this chapter is a continuation of TIDEE’s effort, and describes the structure of the remaining assessment instruments to be developed—for design processes and resulting design products—along with a methodology for creation of these instruments.

BACKGROUND

The quality of engineering education in the US has received considerable attention recently, largely motivated by increased global competition (The National Academies, 2006; Wormley, 2006). The National Research Council’s congressional report, Rising Above the Gathering Storm (The National Academies, 2006), underscores the need for education and policy leaders to embrace these changing dynamics and strive to better prepare future engineers for both
known and unknown challenges. In the recently published book, *The Engineer of 2020: Visions of Engineering of the New Century* (National Academy of Engineering, 2004), along with its companion, *Educating the Engineer of 2020: Adapting Engineering Education to the New Century* (National Academy of Engineering, 2005), the National Academy of Engineering gives a vision of these challenges, including social, political, cultural, and economic, as well as addresses many of the professional attributes needed for future graduates, such as strong analytical skills, creativity, ingenuity, professionalism, and leadership. Additionally, and in support of this common vision, the engineering community has developed an extensive research agenda directed specifically at the transformation of engineering education to address these needs (Anonymous, 2006; Fortenberry, 2006).

Engineering capstone design courses play an integral role in this effort. As a culminating experience for graduates, students apply their newly acquired knowledge and abilities to practical engineering problems. This experience allows them to make valuable connections between theory and practice, and serves as an excellent opportunity to develop critical professional skills (Howe & Wilbarger, 2006; Shuman, Besterfield-Sacre, & McGourty, 2005). The value and significance of this course is highlighted by the inclusion of Criterion 4, the professional component in ABET’s accreditation requirements, which states that “students must be prepared for engineering practice through the curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier courses” (Accreditation Board for Engineering and Technology, 2006).

A vital component to the success of capstone courses, and education in general, is the incorporation of a quality assessment program, at both the program and student level. At the program level, it provides the basis for institutional changes and improvements. At the student
level, assessment allows faculty to gauge the quality of the student’s work and provides the communication link between faculty and students, leading to improved instruction and enhanced learning. The literature is rich with research highlighting the benefits of both formative and summative assessment as the key to effective teaching and learning (P. Black & Wiliam, 1998; Paul Black & Wiliam, 2003; McKenzie, Trevisan, Davis, Beyerlein, & Huang, 2004). ABET also stresses the use of assessment in Criterion 1, requiring institutions to “evaluate, advise, and monitor students’ progress to foster their success in achieving program outcomes” (Accreditation Board for Engineering and Technology, 2006). In addition, ABET’s criteria now place the ‘burden of proof’ on programs to demonstrate that outcomes are being met by students, which is largely accomplished through adequate assessment methods.

The engineering capstone course provides an ideal place for assessing these student learning outcomes. Many, if not all, of ABET’s eleven outcomes of Criterion 3 are encountered by students at some point throughout their design project (McKenzie et al., 2004). With the design nature of the course, several of these outcomes serve as the course’s primary focus; for example, Criterion 3c, “design of a system, component” (Accreditation Board for Engineering and Technology, 2006). In a national study by McKenzie (2004), he reports that 90% of capstone faculty participating in the survey indicated that they engage in some form of assessment in their course. This percentage is likely to rise even further with the increased exposure and development of valid and reliable assessment instruments.

Research into the development of quality assessment instruments for capstones, as well as engineering in general, has been gaining momentum since ABET’s mandate of assessment in its 2000 Criteria. The literature now offers a considerable database of assessments for various aspects of engineering, and for capstones in particular. Many researchers report on the
development, implementation, and tested results of instruments they have developed specifically for their course application (Cooney & Reid, 2004; Plumb & Scott, 2002; Rice, Boysen, & Stetler, 2004; J. E. Sims-Knight, Upchurch, & Fortier, 2005; Sobek & Jain, 2004). Although this rich repository of information is valuable and effective for individual uses and situations, missing is an organized system of assessments that are generalizable and yet focused enough to be valid for multiple programs, disciplines, and faculty needs. This need led participants of TIDEE to embark on an NSF supported project to develop a package of transferable assessments for capstone design courses.

TIDEE was formed for the purpose of developing, testing, and disseminating effective educational materials for engineering design education, and consists of participating institutions across the US. In 2004 it began development of assessment instruments specifically for capstone courses (Beyerlein, Davis, Thompson, Trevisan, & Harrison, 2006). Results from this work include a developmental framework and model based on current assessment foundations and principles, and a partial set of assessment instruments for capstone use. The framework provides an overall philosophy for the design of assessment instruments. This is based on the assessment triangle presented by the National Research Council (2001), which advocates the alignment of three elements for quality assessment design: a cognitive model of learning, observation tasks, and interpretation. For the first of these elements, TIDEE has developed a model based on the outcomes addressed in typical capstone courses. The model organizes the outcomes by differentiating between those related to Learner Development and Solution Development. These have each been further divided into specific performance areas. The performance areas for Learner Development include Teamwork and Personal Capacity, and for Solution Development the areas are Design Process and Solution Assets. Assessments have been designed and validated
for the Learner Development outcomes. Current and future efforts, as presented in this paper, will focus on developing the remaining Solution Development instruments, which will complete TIDEE’s assessment package for capstone courses.

RESEARCH GOALS AND APPROACH

The long term goals of this research are:

- To develop assessment instruments for assessing students’ knowledge of design processes (Design Process performance area assessments) used in engineering capstone projects.

- To develop assessment instruments for assessing the quality of students’ design products (Solution Assets performance area assessments) in capstones.

- To package these, together with those developed for Teamwork and Personal Capacity, into a complete set of assessments, scoring and interpretation rationale, and implementation guidance.

- To develop a web-based system, allowing for easy adoption and dissemination among capstone design course faculty.

The objectives of this paper are:

- To present a course structure for assessing design processes and products in engineering capstone design courses.

- To present a methodology for designing assessment instruments for design processes and products in capstones.
The research plan for this paper is to review literature on design processes, products, and current assessment practices in capstone design courses, and then use this as the basis for assessment development. A description and synthesis of common design processes and resulting products will be presented to identify those particular to capstone courses. Following, a brief review of current assessment practices for design processes and products in capstone courses will suggest appropriate assessments for capstones that will be valid and applicable for multiple uses and users.

LITERATURE REVIEW

Design Processes and Products

A first task in developing assessment instruments for design processes and products associated with student projects is to clearly define those which are commonly used or produced by students. Several design texts were consulted to survey design processes and products of importance, with some texts considered general purpose and others specific to one type of capstone design course. Nine sources were reviewed before new information gains from the last source suggested that a comprehensive listing of the design processes had been achieved (Bystrom & Eisenstein, 2005; Cross, 1994; Dominick et al., 2001; Dym & Little, 2000; Otto & Wood, 2001; Pahl & Beitz, 1996; Ullman, 1992; Ulrich & Eppinger, 2004; Yang & El-Haik, 2003).

For design processes, each text reviewed lists similar but slightly varied versions of the typical progression of activities of a design project. Each gives similar discussions of the major phases and process activities, but with no clear boundaries between phases. Functional
decomposition, for example, is presented in some texts as an activity performed during the problem definition phase to aid in defining customer requirements and engineering specification, while in other texts it is part of the concept generation phase. In reality, elements from this activity are required at multiple times throughout the project, highlighting the iterative nature of the design process.

It is therefore important to realize that the value of these design process philosophies is in the general sense, providing a semi-hierarchical snapshot of typical design activities, but not necessarily a prescriptive approach to all engineering projects. For the purposes of assessment development, a quite general categorization of the design process will be adequate, as the primary purpose of the assessment will be to broadly assess students’ approaches and uses of these activities, allowing for feedback and instruction to be given.

Table 1 gives a listing of the design phases with associated processes and products from the reviewed texts. Since each text divides the design process into different phases, a common basis for review is provided by synthesizing these into seven common phases. Common activities and products reported from the texts have been allocated to one of these seven phases.

**Assessment in Capstone Design Courses**

*Approaches used to assess design processes in capstones*

The following review highlights some of the different approaches taken to assess students’ application of design processes in engineering design. The review is not particular to capstone courses, but covers engineering design in general. The aim of this section is to show different methods of process-related practices in terms of both assessment and implementation.
The next section will address assessment approaches taken for the products resulting from engineering design projects.

Table 1. Summary of common phases, processes, and products of design

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<th>Common Design Phases</th>
<th>Common Phase Processes/Activities</th>
<th>Common Phase Products</th>
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<td><strong>Product Opportunity Analysis</strong>&lt;br&gt;The process of determining a product to develop.</td>
<td>- Develop a vision&lt;br&gt;- Analyze market opportunity and company situation&lt;br&gt;- Evaluate and select product opportunity(ies)&lt;br&gt;- Formulate product proposal&lt;br&gt;- Plan design project (identify and coordinate tasks and resources: schedule, budget, team)</td>
<td>- Mission statement&lt;br&gt;- Design proposal or business plan&lt;br&gt;- Project plan (task list, team roles, schedule, budget)</td>
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<tr>
<td><strong>Problem Definition</strong>&lt;br&gt;The process of defining primary functions of the product to be developed and setting target design specifications.</td>
<td>- Clarify objectives&lt;br&gt;- Identify customers&lt;br&gt;- Determine and evaluate needs and requirements&lt;br&gt;- Identify constraints&lt;br&gt;- Identify essential functions/problems&lt;br&gt;- Evaluate competition&lt;br&gt;- Establish design specifications (metrics/parameters)&lt;br&gt;- Set target specifications</td>
<td>- Problem statement&lt;br&gt;- Objective trees&lt;br&gt;- House of quality matrix</td>
</tr>
<tr>
<td><strong>Concept Generation</strong>&lt;br&gt;The process of defining the means to satisfy the required functions.</td>
<td>- Perform functional modeling/decomposition&lt;br&gt;- Define major subsystems and interfaces&lt;br&gt;- Search for working principles&lt;br&gt;- Generate alternatives&lt;br&gt;- Model concepts&lt;br&gt;- Test concepts&lt;br&gt;- Perform economic analysis&lt;br&gt;- Evaluate alternatives&lt;br&gt;- Select concept&lt;br&gt;- Set final specifications</td>
<td>- Function model structure/tree&lt;br&gt;- Morphological chart&lt;br&gt;- Concept (presented as a model: graphically, physically, and/or analytically; as a textual description; or other form that gives indication of the manner in which functions are achieved)&lt;br&gt;- Justification for concept selection: Pugh chart, evaluation matrix&lt;br&gt;- Final specifications</td>
</tr>
<tr>
<td><strong>Preliminary Design</strong>&lt;br&gt;The process of establishing form to the concept functions while meeting defined specifications.</td>
<td>- Generate alternative product architectures&lt;br&gt;- Select materials, components, etc.&lt;br&gt;- Perform preliminary design calculations&lt;br&gt;- Select best preliminary layouts&lt;br&gt;- Select modeling/simulation process&lt;br&gt;- Model/simulate/analyze design&lt;br&gt;- Test, evaluate, refine, optimize design</td>
<td>- Layout drawing&lt;br&gt;- Preliminary detail drawing&lt;br&gt;- Model (graphical, physical, and/or analytical)</td>
</tr>
<tr>
<td><strong>Detail Design</strong>&lt;br&gt;The process of optimizing the final product form.</td>
<td>- Perform detailed modeling: physical and analytical&lt;br&gt;- Design for X (performance, robustness, etc.)&lt;br&gt;- Test and evaluate design&lt;br&gt;- Refine, optimize, and validate design&lt;br&gt;- Develop prototype</td>
<td>- Final model analysis&lt;br&gt;- Detailed design&lt;br&gt;- Test and validation results&lt;br&gt;- Prototype</td>
</tr>
<tr>
<td><strong>Documentation and Communication</strong>&lt;br&gt;The process of developing and finalizing final project documentation and communications.</td>
<td>- Develop required design documentation&lt;br&gt;- Communicate design</td>
<td>- Final design communications (reports, presentations, drawings, support documentation, etc.)</td>
</tr>
<tr>
<td><strong>Implementation</strong>&lt;br&gt;The process of producing/realizing the design product.</td>
<td>- Implement production&lt;br&gt;- Market and distribute&lt;br&gt;- Follow up</td>
<td>- Final product</td>
</tr>
</tbody>
</table>
Atman and Bursic (1998) suggest the use of verbal protocol analysis (VPA) to assess the design process abilities of students (in freshmen and senior engineering courses). With this method, students think aloud as they solve engineering problems or perform tasks. Their thought processes are recorded using audio, video, or both, and are then analyzed based on given criteria. Results indicate that the use of VPA is a powerful tool for understanding students’ knowledge of the design process. They report that comparison of the process knowledge with the quality of the final product allows for inferences to be made between good and poor processes and indicates which problems should be addressed by student teams.

Sims-Knight et al. (2003) have reported on a suite of assessments used to assess students’ declarative, procedural, and metacognitive knowledge of the design process in both capstone and general engineering courses. For declarative knowledge, they have developed a multiple-choice test, called the Design Process Knowledge Test, which “assesses the extent to which students understand the rules of best practices in design process.” For assessing design procedural knowledge, they discuss an assessment in which students engage in a design task (2-3 hours long task), followed by a postmortem questionnaire regarding the process activities used. Students are evaluated based on how well they address the processes used in the task. Other methods stated for collecting data on design procedural knowledge include: 1) verbal protocol analysis of students’ design notes from the task, 2) verbal protocol analysis of videotaped recordings of students performing the task (where the amount of time spent on each design activity was the criteria for assessment), and 3) the use of pre- and intermittent-tests throughout a design activity, in which students give an ordered list of the design process activities used. Evaluation is based on the quality of the processes used.
As a further method for assessing procedural knowledge of the design process, Sims-Knight (2005) has discussed the use of a computer-based simulation task, in which students watch a team engaged in design. At intermittent times throughout the task they are prompted to make recommendations on how the design team should proceed. Assessment questions probe, for example, what the team should do next and allow students to choose between alternative responses.

Additionally, Sims-Knight et al. (2004) have reported on the use of concept maps to assess students’ design process knowledge. The target is to assess understanding of how various aspects of the design process go together; a measure of structural knowledge of the design process, versus declarative knowledge. The purpose stated for the above mentioned assessments is continuous improvement of students in meeting the ABET criteria (formative use).

Bailey and Szabo (2006) have reported on an assessment tool to assess design process knowledge in first year and senior capstone courses in which students analyze and critique a proposed process. After the process is presented to the students outlining the various steps, they are asked to identify the strengths and weaknesses of the proposed process. Students are given pre- and post-tests and an analytic rubric is used to evaluate the design knowledge evident in their responses. This process can be used to measure the amount of design process knowledge gained over time.

Newstetter and Khan (1997) have reported on the use of portfolios and cognitive maps as effective tools for assessing student design process skills and knowledge. For the portfolios, targets for assessment include: 1) design of the portfolio as an artifact of communication and persuasion 2) evidence of problem-structuring, 3) evidence of problem decomposition 4) evidence of incremental development of the design solution 5) evidence of constraint setting, and
6) evidence of different levels of abstraction and various types of modeling/representation of the problem space. The cognitive maps are used to assess knowledge of the structure and relationships of design. Targets for assessment include propositions, hierarchy, cross-links, and examples.

As a method for course planning and assessment, Safoutin et al. (2000) have developed a design attribute framework of the design process activities based on Bloom’s taxonomy. ABET outcome 3c, “design of a component…” for example, is broken into various components (need recognition, problem definition, planning, etc.), and each component is defined for the seven cognitive levels – Bloom’s six cognitive levels and one additional level of “valuation.” This framework is a means of refining the broadly defined ABET outcome, and provides a way of organizing these outcomes based on an established and accepted cognitive hierarchy. For assessment purposes this framework can be used by selecting an appropriate combination of the design component and desired cognitive level for assessment. Based on this framework, Safoutin et al. have developed an assessment instrument for a general engineering design course. The instrument is a student survey which includes multiple components of the design process, each at various cognitive levels. For each survey item, students rate their confidence level on a five point scale. The emphasis of the assessment is on how students approach design problem solving, verses simply recall of information.

The examples above highlight some common methods for assessing student design process knowledge. In addition to this, faculty have used design products as opportunities to assess process activities. For instance, common capstone products include design reviews (peer, client, and faculty), oral presentations, and written reports. In the assessment and evaluation of these products, performance criteria may also be included to address various elements of the
design process. This is commonly done by addressing a particular activity – identification of customer needs, for example – through a single scoring metric in a rubric. In this case, the nature of the assessment is more holistic with little depth, mainly used as a checklist for activity completion verses assessment of deep understanding (Brackin & Gibson, 2001; K. C. Davis, 2004; Estell & Hurtig, 2006; Kampf, Stefan, & Labuz, 2004; Miskimins, Graves, & Van Kirk, 2006; Shaeiwitz, 2002).

Approaches used to assess design products in capstones

Products, as mentioned, are the results of tasks, phase activities, and overall project efforts. The purpose for product assessment is typically to provide evaluation data, where scores are based on the quality of the product as defined by selected performance criteria. Table 1 gave a list of the products associated with engineering design courses. A few of the most common products used for assessment, as seen in the literature, include progress reports, design reviews, final oral presentations, and final written reports. The following provides an overview of typical product assessments.

Brackin and Gibson (2001) demonstrate the use of multiple methods for assessing student performance in typical capstone courses. These include: company evaluations, status reports, student self-assessments, peer reviews, oral reports, and design reports. Performance criteria are given for the assessments as well as discussions of how the results can be used to improve student performance. Purposes include both formative and summative uses.

Sobek and Jain (2004) present two instruments for assessing and measuring the quality of design outcomes of capstone projects: the Client Satisfaction Questionnaire and the Design Quality Rubric. For the Client Satisfaction Questionnaire, clients or sponsors assess the quality
of the final design project based on six metrics: quality, cost-benefit, involvement (between client and student team), complexity, deliverables (final report, final presentation, drawings, prototype), and an ‘overall’ metric (feasibility, satisfaction, thoroughness). To weight the metrics, they used the analytic hierarchy process, which is a systematic method for evaluating alternatives along multiple criteria. The Design Quality Rubric was developed to more objectively measure design quality. Metrics include: requirements (functionality), feasibility (manufacturability, marketability, application), creativity (originality, novelty, innovation), simplicity (reliability, serviceability, practicality, ergonomics, safety), and overall (aesthetics, professionalism). These instruments are given as a final assessment and evaluation of the students’ project. Therefore, emphasis is on summative use.

Estell and Hurtig (2006) discuss the use of rubrics for assessing capstone design projects. Included are detailed rubrics for written reports, design reviews, constraints analyses, oral presentations, poster evaluations, and project web sites. Assessment targets and corresponding performance criteria are given for each instrument. Targets of assessment for four of these instruments are as follows:

- For the technical written report, targets include: format and organization, mechanics, illustrations, references, use of appendices.

- For the technical design review, targets include: identification of the problem, information gathering, definition of the problem, development plan, execution plan, design verification, scheduling, and technical level.

- For constraints analysis, targets include the consideration of the following constraints: economic, environmental, sustainability, manufacturability, ethical, health and safety, social, and political.
For the oral presentation, targets include: content, visuals, presentation skills, organization, and handling of questions.

Cooney and Reid (2004) present similar rubrics for assessing student outcomes. Rubrics are given for written reports, oral presentations, design project (design review), and teamwork. For oral presentations, two sources which give detailed discussions of developing sound assessments are that of Rice et al. (2004) and Sharp (1996). Assessment elements and performance criteria are discussed as well as evaluation and feedback methods.

The types of products assessed along with the performance targets and criteria stated above are typical of most engineering design projects, as seen in the literature. Most common are the end-of-term products, such as written reports and design presentations. Design reviews provide a means for checking the progress of the team at various milestones throughout the project, where the content for review and assessment could include any aspect of the design, from the initial planning phase to the final development phase. For instance, the House of Quality or similar matrix tool could be assessed to determine how well technical specifications meet the user needs (Sobek & Jain, 2004). The brief literature review above provides an understanding of the methods used and types of targets faculty are interested in assessing. This will help to define targets, performance criteria, and methods for assessment and interpretation for the current set of instruments presented in this paper.

CURRENT CAPSTONE COURSE ASSESSMENT FRAMEWORK AND MODEL

TIDEE’s general framework for developing valid assessment instruments, as previously mentioned, is based on the assessment triangle presented by the National Research Council
(2001), adapted and detailed further for specific engineering capstone courses by Beyerlein et al. (2006). The goal of this framework is the alignment of the elements of development model, observation tasks in the assessment instrument, and interpretation of assessment responses. Diagrams of this framework and the development model are given in Appendix A and B, respectively.

The model represents the first leg of the assessment triangle and has been broadly defined based on typical capstone course outcomes (Denny Davis, Beyerlein, Thompson, Harrison, & Trevisan, 2006b). Outcomes are divided into two distinguishable areas of student learning objectives: Learner Development and Solution Development. Learner Development includes outcomes relating to the professional attributes important to students in a design project, such as ethics, reflection, personal growth, professional development, and teaming skill. These are broadly classified into two student performance areas: Personal Capacity and Teamwork. Solution Development includes outcomes associated with the technical aspects of a project, including the processes students utilize throughout a project and their corresponding products (the assets). Solution Development is therefore classified into two student performance areas: Design Process and Solution Assets.

Figure 3 gives an outline of TIDEE’s model, showing the breakdown of learning outcomes into the four performance areas for assessment. These are briefly defined in Table 2 and discussed further below. Table 3, identifying the ABET outcomes relating to each performance area, illustrates that all ABET Engineering Criterion 3 outcomes can be encompassed in the four performance areas for capstone engineering design courses. Together, the framework and model discussed provide a solid foundation for building assessment instruments for ABET outcomes demonstrated in a capstone design course.
Figure 3. Outline of engineering capstone design course assessment performance areas

Table 2. Description of capstone course performance areas (adapted from Davis et al. (2006b))

<table>
<thead>
<tr>
<th>Performance Area</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personal Capacity</td>
<td>Individuals performing and improving individual skills essential to engineering design</td>
</tr>
<tr>
<td>Teamwork</td>
<td>Teams developing and implementing collective processes that support team productivity in design</td>
</tr>
<tr>
<td>Design Process</td>
<td>Teams selecting and implementing design processes that effectively and efficiently facilitate the production of valuable project assets</td>
</tr>
<tr>
<td>Solution Assets</td>
<td>Results produced throughout a design project that meet needs and deliver satisfaction and value to key project stakeholders</td>
</tr>
</tbody>
</table>

Design Process Performance Area

The term process refers to a set of actions employed to accomplish a particular goal. More specifically, the engineering design process is the transformation of customer needs into valuable products (assets) through a planned sequence of activities, or sub-processes. A myriad of standard processes and formal tools for use in carrying out particular processes are taught throughout the engineering curriculum.
Table 3. Alignment of TIDEE’s assessment model with ABET criteria (from Davis et al. (2006a))

<table>
<thead>
<tr>
<th>Performance Areas</th>
<th>ABET Criteria 3 Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3a. Apply math, science, and engineering knowledge</td>
</tr>
<tr>
<td>Personal Capacity</td>
<td>X</td>
</tr>
<tr>
<td>Teamwork</td>
<td></td>
</tr>
<tr>
<td>Design Process</td>
<td>X</td>
</tr>
<tr>
<td>Solution Assets</td>
<td>X</td>
</tr>
</tbody>
</table>

A critical aspect of the capstone course is its ability to solidify students’ technical and procedural knowledge of these processes with hands-on opportunities. Unlike most technical content of engineering education, which has solid mathematical roots, design methodology encompasses creativity, ingenuity, and subjectivity, and therefore skill is most readily gained through experience. The authentic nature of a capstone project, with real constraints such as time and resources, forces students to analyze potential methods and select those which will best serve their purposes under the given conditions.

**Solution Assets Performance Area**

Typical results from a design project include a physical product, a final design communicated in some form (drawings, models, software, oral or written reports, etc.), or other required deliverables. Solution Assets refer to results from intermediate processes and phases, in addition to those of the overall project. The Solution Assets performance area focuses on
assessing the quality of these resulting assets. This provides an opportunity to give feedback to students at various times prior to the project’s completion.

CAPSTONE COURSE ASSESSMENT STRUCTURE FOR SOLUTION DEVELOPMENT

The four performance areas provide an overarching structure from which to base assessment development. For Learner Development, previous work has encompassed the development, testing, and validation of four assessment instruments: two for Personal Capacity and two for Teamwork (D. Davis, Beyerlein, Harrison, Thompson, & Trevisan, 2007). This section will present the structure of assessments for the Solution Development performance areas. A general methodology for designing these assessments will be given in the next section.

The approach taken for defining assessments for the two Solution Development performance areas includes:

- First, identifying design activities and products most commonly associated with a wide variety of capstone design projects.
- Second, organizing these processes and resulting products into an appropriate assessment structure and defining assessments for the Design Process and Solution Assets performance areas.
- Third, defining an implementation sequence for each assessment.

Design Process

Table 1 listed and described important activities and products of the design process, as reported in various student design textbooks. Table 4 presents a synthesis of these processes and products most common to capstone design projects. This synthesis of the seven phases from
Table 1 produces three generalized design phases – Problem Scoping, Concept Generation, and Solution Realization.

The processes and products listed in Table 4 are applicable for many engineering fields, but do not necessarily constitute a comprehensive or exclusive list. As mentioned, the table is a synthesis of several texts common to engineering design courses. The discipline specific expertise of each author will undoubtedly contribute some bias. Accordingly, while generating Table 4, effort was made to maintain generality across disciplines while still providing sufficient detail.

**Assessment Structure**

The three design phases from Table 4 are central to the development of assessments for capstone design. They give an appropriate level of depth and breadth for the purpose of providing a general and transferable assessment system for engineering capstone courses based on the commonality among various disciplines. That is, most engineering projects, regardless of field, entail a period of scoping, where information gathering and refinement processes are the focus, followed by a phase of transforming this information into a useful solution concept, and then an implementation phase where the information is used to construct a product to satisfy a need.

The common nature of these phases among disciplines provides justification for framing assessment opportunities around these three project phases. Therefore, Design Process assessments will look at common processes associated with each phase, assessing the appropriateness and effectiveness of the processes selected and implemented by students. For Solution Assets, assessments will look at the quality of the resulting products for each design
phase. Table 5 describes the assessments for the Design Process and Solution Assets performance areas.

Table 4. Common design phases, processes, and products for capstone projects

<table>
<thead>
<tr>
<th>Design Phases</th>
<th>Design Processes/Activities</th>
<th>Design Products</th>
</tr>
</thead>
</table>
| **Problem Scoping** | Analyze product opportunity:  
- Analyze, evaluate, and select product opportunity(ies)  
- Formulate product proposal  
- Plan design project (identify and plan tasks and resources: schedule, budget, team)  
- Clearly define the problem:  
  - Identify customers  
  - Identify and evaluate requirements and constraints  
  - Identify essential functions  
  - Evaluate competition/similar products  
  - Establish specifications (metrics/parameters)  
  - Set target specifications | Product opportunity proposal:  
- Mission statement  
- Design proposal and/or business plan  
- Project plan (task list, schedule, budget, responsibilities)  
- Problem definition:  
  - Preliminary design specifications or similar |
| **Concept Generation** | Generate alternative concepts:  
- Perform functional decomposition  
- Define major subsystems and interfaces  
- Search for working principles and working structures  
- Generate concepts  
- Select concept:  
  - Evaluate concepts  
  - Select concept  
  - Set final specifications | Concept variants:  
- Functional analysis communication  
- Morphological chart  
- Concept variants  
- Concept selection:  
  - Justification of selected concept  
  - Concept communication (sketch, model, artifact, report, etc.)  
  - Final solution specifications |
| **Solution Realization** | Design product:  
- Generate product embodiment (architecture/layout)  
- Model/simulate/analyze design  
- Design for X (performance, robustness, reliability, etc.)  
- Test, evaluate, refine, optimize, validate design  
- Communicate design:  
  - Develop detail drawings and support documentation  
  - Document and communicate design  
  - Implement production | Final design:  
- Layout drawings, models, etc.  
- Detailed design  
- Test and validation results  
- Final design communications:  
  - Final design communications (reports, presentations, drawings, support documentation, etc.)  
  - Final product |

The Design Process area comprises three assessments: Problem Scoping Processes, Concept Generation Processes, and Solution Realization Processes. The focus of each is stated in Table 5, which closely follows the major design process categories given in Table 4.

Three companion Solution Assets assessments include Problem Definition, Selected Concept, and Proposed Solution. This set of assessments provides generality and transferability.
for multiple users. The focus for assessment includes the quality of the asset as well as the quality of the communication itself. The communication is the form of the presentation, which can be written, oral, physical, etc. For a final design solution of a project, for example, the asset is the design, which is assessed based on appropriate engineering design criteria, while the communication could be a written report, which is assessed based on a different set of criteria.

Table 5. Design process and solution assets assessment instruments

<table>
<thead>
<tr>
<th>Design Phases</th>
<th>Design Process Assessments</th>
<th>Solution Assets Assessments</th>
</tr>
</thead>
</table>
| **Problem Scoping**| Problem Scoping Processes assessment addresses the selection and use of processes/activities related to:  
- analyzing product opportunity(ies)  
- defining the design problem | Problem Definition assessment addresses:  
- communication of the problem definition  
- quality of the problem definition |
| **Concept Generation** | Concept Generation Processes assessment addresses the selection and use of processes/activities related to:  
- generating alternative concepts  
- selecting a concept | Selected Concept assessment addresses:  
- communication of the selected concept  
- quality of the concept |
| **Solution Realization** | Solution Realization Processes assessment addresses the selection and use of processes/activities related to:  
- designing the product solution  
- validating the product solution | Proposed Solution assessment addresses:  
- communication of the design solution  
- quality of the solution |

**Assessment Implementation**

The implementation sequence and timing for Solution Development assessments is given in Figure 4. The three general phases are shown, illustrating typical progression in capstone courses. Design Process assessments are administered midway throughout each phase while the resulting Solution Assets assessments are administered toward the end of each phase. The mid-phase administration of the process assessments allows for critical feedback to be given to students with sufficient time to make corrections or improvements (formative use). End-of-phase
product assessments provide an opportunity to evaluate the quality of solution assets resulting from each phase, verses a single end-of-project assessment and evaluation (summative use).

The underlying organization of this structure is the use of formative assessments for phase processes and summative assessments to evaluate phase products. This formative/summative sequence requires students to engage in self reflection at critical project milestones, and allows adequate time for them to readdress any problematic aspects. The motivation for this assessment philosophy is to instill in students the value of reflective practice and iteration in design.

Figure 4. Capstone course assessment implementation sequence

METHODOLOGY FOR CREATING ASSESSMENT INSTRUMENTS FOR SOLUTION DEVELOPMENT

The following sections will present the methodology and principles for assessment design as they pertain to both design processes and products. One of the Solution Development
assessments – the Problem Scoping Processes assessment – is referenced throughout this section to illustrate each principle.

**Purposes for Assessment**

Assessment is simply the process of gathering data that is indicative of the desired qualities or performances (Drummond & Jones, 2006). Use of this data depends upon the assessment’s purpose. The evaluation and interpretation of valid assessment data form the basis for which subsequent decisions are made and corresponding actions taken. Therefore, accurate assessment is a prerequisite for well-informed decisions.

Clearly defining the purpose for assessment represents one of the most important aspects of the assessment design process. There are multiple purposes for assessment, all of which can be categorized into either assessment of learning or assessment for learning. Examples of these, relevant to capstones, are indicated in the following list (adapted from Stiggins (1997)):

- Purposes for students: to track own success, to identify own needs, to plan educational needs (study plan).
- Purposes for faculty: to identify needs of individual, to identify needs of groups or class, for grading, to evaluate instruction, to evaluate self.
- Purposes for policy makers: to document, evaluate, and base program-level improvement decisions on.

These purposes can similarly be stated as: 1) to assist learning (formative), 2) to assess individual achievement (summative), and 3) to evaluate programs (National Research Council,
The purpose for an assessment has implications for its construction, use, and interpretation.

**Purpose of the Problem Scoping Processes assessment:**

The purpose of this assessment is primarily for formative use; to assist students by helping them to identify areas for improvement. Assessment data will allow faculty to address issues at the individual, team, and class level. The data can also be used for assigning scores and documenting achievement for ABET requirements. Mid-phase implementation allows adequate time for feedback and improvements to be made prior to moving on to the next phase.

**Targets for Assessment**

Targets represent the specific achievement students strive towards in a learning experience. That is, targets are defined by first specifying *what* is to be assessed, followed by defining the quality level expected. Examples could include: mastery of content knowledge, achieving a certain level of proficiency in giving oral presentations, or acquiring a certain level of understanding on a topic. Therefore, targets are defined in terms of specifically stated performance criteria (Stiggins, 1997).

Stiggins (1997) defines five kinds of achievement targets – knowledge, reasoning, skill, product, and disposition – and suggests the following guidance for determining these for assessment design:

- Define the important knowledge students should understand: declarative and procedural.
- Reflect on the patterns of reasoning you might expect they will need to acquire. For example, analytic, synthesis, comparative, classification, inferential, evaluation.

- Identify any skill or product development targets: skills they are to master, things they should be able to do, products you want them to create.

- Identify the disposition (attitudes, values, interests) you hope for them to acquire.

In developing performance criteria for targets, Stiggins (1997) gives the following six step method:

1. Develop a list of factors associated with the performance addressed (the five kinds of achievement targets would be a starting point from which to expand).

2. Condense the list into major categories.

3. Define each major category (considering elements from original list).

4. Contrast levels of proficiency for each major category by qualitatively describing a range of performances (establishing a continuum of performance in levels).

5. Add detail by assigning scoring values to each performance level.

6. Test and refine the set of performance criteria.

**Targets for the Problem Scoping Processes assessment:**

The broad targets for assessment include:

- Appropriate selection of design processes based on given project needs, resources, constraints, etc.

- Effective and efficient implementation of design processes
• Constructive self-assessment regarding the selection and use of design processes throughout project

Methods for Assessing

Assessment tasks for students can be designed when the targets for assessment and performance criteria have been clearly defined. Methods commonly used include: selected response questions, essays, authentic performance, as well as personal observation and communication (Stiggins, 1997). For effective assessment, the method selected must be appropriate for the types of inferences desired. For example, to assess analytical reasoning, an essay type of assessment would be preferred over selected response. The selection of a method is also influenced by other factors such as the level of detail desired, implementation constraints, and time considerations for reviewing and evaluation. A variety of methods are used for the multiple assessments included in TIDEE’s assessment system, including selected response, reflective essays, and authentic performance. Selected response requires less time for reviewing but is limited in the level of depth assessable, while essays give richer insights to the level of understanding students have, but require significantly more time investment. Methods for the current assessments are selected to minimize these limitations.

Methods for the Problem Scoping Processes assessment:

The assessment will consist of both selected response questions and short essays. Selected response will probe students’ declarative knowledge about appropriate design phase processes. Reflective essays will be used to query students’ procedural
knowledge, reasoning, and skill regarding the processes applied; for example, procedural knowledge of particular processes involved in gathering customer needs, reasoning regarding the analysis, synthesis, and evaluation of customer needs, and skill in manipulating needs data into usable engineering specifications.

**Interpreting Assessments**

Interpreting and reporting assessment results are keys to student improvement. Defined targets and performance criteria provide guidance for designing a scoring methodology for an assessment. Inferences can then be made based on these scores as to the quality of the student’s work. Scores can be reported to students and should be coupled with constructive feedback critiquing their performance. Therefore, for formative assessment purposes, assessments should be designed such that feedback can be provided easily for: (1) allowing the student to know how they are performing relative to expectations, (2) what are areas of strength to build upon, and (3) what can be done to improve. In the broad sense, this philosophy follows that of the common SII method (Strength, Improvement, and Insight) for assessing and providing useful feedback. For summative assessment use, descriptive feedback can also be given to provide guidance for productive iteration of necessary activities.

**Interpretation of the Problem Scoping Processes assessment:**

A scoring rubric, based on detailed performance criteria, will be developed and used to evaluate student responses to the assessment. The rubric will be analytic—a three to five point descriptive scale—providing greater detail for constructive feedback. Additionally,
CONCLUSIONS

1. A structure was presented showing a plan for assessment of both design processes and products in engineering capstone courses.

2. Building on TIDEE’s previous work on Learner Development assessments, a methodology was developed and presented for use in designing assessments for design processes and products in capstones.

3. The generic nature of the design processes selected for this study makes the methodology transferable across faculty, institutions, and disciplines.

4. Elements of one assessment were used in illustrating the key principles of the methodology – purposes, targets, performance criteria, methods, interpretation, and alignment – providing for easy adaptation to other instruments.

FUTURE WORK AND RECOMMENDATIONS

Future work includes:

1. Use this structure and methodology to design the remaining instruments for design processes and products.

2. Test and refine instruments, individually, for construct validity and reliability.

3. Test instruments, collectively, for validity and reliability.

4. Test in various contexts for transferability: different disciplines, capstone courses, project types, etc.

5. Incorporate assessments into a web-based implementation system.
6. With the validated capstone assessment package, this could open the path for additional research in effectiveness of instructional practices in achieving targeted student performance in capstone design courses.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the support of the National Science Foundation for funding to develop and test assessments for capstone engineering design under grants: DUE 0404924 and DUE 0717561.
REFERENCES


APPENDIX

Appendix A. Capstone course assessment framework diagram (from Beyerlein et al. (2006))

Appendix B. Capstone course assessment model diagram (from TIDEE, www.tidee.org)
Chapter 3

Reflective Practice of Engineering Capstone Design Teams

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Citation:

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 6 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 5 (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.

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.
Table 6. Summary of TIDEE’s capstone design course assessment instruments

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

Figure 5. Sample implementation sequence for TIDEE assessments within a capstone course
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 7 gives a brief overview of the various models of reflection in terms of levels and processes.

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.
Table 7. Conceptual models of reflection

<table>
<thead>
<tr>
<th>Author</th>
<th>Levels of Reflection</th>
</tr>
</thead>
</table>
| Mezirow (1991)<sup>a</sup> | 1. Habitual action,  
2. Thoughtful action/Understanding,  
3. Reflection,  
4. Critical reflection |
| Thorpe (2004)<sup>⁹</sup> | 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)<sup>c</sup> | 1. Pre-reflective reasoning,  
2. Quasi-reflective reasoning,  
3. Reflective reasoning |
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)<sup>a</sup> | 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) |

<table>
<thead>
<tr>
<th>Author</th>
<th>Processes of Reflection</th>
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</table>
| 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 |
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.  
\[c\] The complete model is given in Appendix A.

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 7) 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’ performances, 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 limitations 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 7 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 Bioengineering, 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 7. 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 7 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 7, 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 7. 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 7 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 7. 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 7, 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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REFERENCES


APPENDIX

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 issue 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

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?
Chapter 4

Establishing Inter-rater Agreement for TIDEE’s Teamwork and Professional Development Assessments

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Citation:

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ABSTRACT

Senior capstone design courses in engineering programs provide an opportunity to address important curricular objectives related to teamwork and professional development. In this course, students work within a team environment and are challenged with non-technical issues, such as communication, organization, self-directed learning, etc. By the end of their capstone experience it is hoped that students are prepared for the professional working environment. Capstone faculty, often with technical expertise in a specific branch of engineering, have expressed difficulty in teaching and assessing the types of knowledge, skills, and affective behaviors associated with these non-technical performance areas. When assessing teamwork, for example, the approach of “I know it when I see it” is not uncommon for an assessment process. Valid and reliable assessment instruments are needed for capstones which define expected performance criteria, and therefore offer guidance for teaching and learning. In addition to this formative use, summative assessments are also needed to document achievement of student growth with regards to these outcomes. To this end, collaborators from the Transferable Integrated Design Engineering Education consortium (TIDEE) have developed a suite of assessments for use in capstone courses, comprising four common performance areas: teamwork, professional development, design processes, and solution assets. For each of these areas of performance, multiple assessments have been developed and testing for validity and reliability has been ongoing. The purpose of this paper is to present results from a reliability study conducted with seven TIDEE assessments from the teamwork and professional development performance areas.

For each of the assessments tested, the degree of inter-rater reliability was determined, representing an estimate of the consistency of scoring between multiple raters. This type of
reliability is significant for the TIDEE assessments as essay-type responses are elicited from students and, therefore, requires professional judgments by faculty to assess achievement. Each assessment was tested by having two faculty raters and two teaching assistant raters score a subset of student work with corresponding scoring rubrics. Percent agreement calculations and correlations were used to interpret the level of rater agreement. Interpretations of the results were made in light of the intended uses of each assessment: formative and/or summative. In general, the assessments were found to have scoring agreement of 85% to 100% within a one-point variation. Exact agreement ranged from a high of 60% to a low of 20%. Overall, the results indicated sufficient agreement for use with formative assessment (for enhancing teaching and learning). For summative use, five of the assessments should prove adequate in documenting student growth, including the Team Contract, Team Member Citizenship, Growth Planning, Growth Progress, and Professional Practices assessments. The remaining two, Team Processes and Growth Achieved, may need to be revised to improve agreement. Suggestions for improvement include revisions to rubric descriptors for each level of performance, improved Frame-of-Reference rater training to decrease rater errors and increase accuracy, and, lastly, incorporation of Behavior-Observation-Training in the training protocol.

INTRODUCTION

Assessment is integral to effective teaching and learning as information gained through assessment allows instructors and students to gauge their progress and make necessary changes for continued improvement. In addition, assessment provides engineering programs information to gauge and document the achievement of stated learning outcomes, each of these being important components of ABET requirements (ABET, 2010). The particular assessment
instrument(s) developed and used for these purposes must therefore give users valid and reliable results on which decisions can be based.

To support these types of course-level and program assessment needs in engineering design, multiple assessment instruments related to design and lifelong learning outcomes have been developed by collaborators from the Transferable Integrated Design Engineering Education (TIDEE) consortium. Pilot testing has been conducted in recent years to study the validity and reliability related to TIDEE’s instruments. In particular, validity studies have addressed the value of the assessments to users (instructors and students) from varied engineering disciplines while reliability studies have focused specifically on the level of inter-rater agreement (IRA) of scoring between multiple and diverse raters. The purpose of this paper is to present results from the IRA study conducted with the TIDEE assessment instruments. A total of seven of the fifteen TIDEE instruments are reported in this paper, including three related to teamwork and four related to professional development. The next sections give a general overview of the assessments included in this study followed by a description of the approach to testing for IRA, the methods used, and finally the results and discussion.

Overview of TIDEE Assessments

The TIDEE assessments are primarily intended for engineering capstone design courses in order to aid in the teaching and learning of professional skills and knowledge required of engineering graduates. In addition to this formative use, certain assessments were designed for summative purposes, allowing the achievement of outcomes to be measured for program and ABET accreditation documentation. Fifteen TIDEE assessments have been developed to address four critical performance areas in engineering design: teamwork, professional development,
design processes, and solution assets. Table 8 presents a brief overview of these performance areas along with corresponding assessment instruments and the general performance criteria of each (adapted from Davis et al., 2009).

Table 8. Summary of TIDEE’s capstone design course assessment instruments

<table>
<thead>
<tr>
<th>Performance Area</th>
<th>Assessment Instruments*</th>
<th>General Performance Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Teamwork:</strong> Team member contributions and team processes employed to support team productivity in design</td>
<td>1. Team Contract (F)</td>
<td>Team member behaviors and team processes contribute to constructive relationships, joint achievements, individual contributions, and information management that synergistically yield high productivity.</td>
</tr>
<tr>
<td></td>
<td>2. Team Member Citizenship (F)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Team Processes (F)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4. Teamwork Achieved (S)</td>
<td></td>
</tr>
<tr>
<td><strong>Professional Development:</strong> Individual demonstration of improved knowledge, skills, and behaviors essential to engineering practice</td>
<td>5. Growth Planning (F)</td>
<td>Individuals document professional development in technical, interpersonal, and individual attributes important to their personal and project needs, professional behaviors, and ways of a reflective practitioner.</td>
</tr>
<tr>
<td></td>
<td>6. Growth Progress (F)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7. Professional Practices (F)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8. Growth Achieved (S)</td>
<td></td>
</tr>
<tr>
<td><strong>Design Processes:</strong> Practices implemented that effectively and efficiently facilitate the production of valuable design project assets</td>
<td>9. Problem Scoping Processes (F)</td>
<td>Designers reflectively use design tools and information throughout problem scoping, concept generation, and solution realization activities to co-develop problem understanding and a responsive design solution.</td>
</tr>
<tr>
<td></td>
<td>10. Concept Generation Processes (F)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>11. Solution Realization Processes (F)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>12. Design Reflection (S)</td>
<td></td>
</tr>
<tr>
<td><strong>Solution Assets:</strong> Design results that meet needs and deliver satisfaction and value to key project stakeholders</td>
<td>13. Defined Problem (F)</td>
<td>Designers deliver and effectively defend solutions that satisfy stakeholder needs for functionality, financial benefit, implementation feasibility, and impacts on society.</td>
</tr>
<tr>
<td></td>
<td>14. Selected Concept (F)</td>
<td></td>
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<tr>
<td></td>
<td>15. Proposed Solution (S)</td>
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</tbody>
</table>

* (F) indicates formative use; (S) indicates summative use

The TIDEE assessments typically incorporate multiple response methods including checklist, short answer, and essay. The Team Member Citizenship assessment, for example, asks students to assess themselves and their teammates with respect to important attributes of teamwork, as listed in Table 9. Students then assess the overall contributions of each member,
including themselves, by assigning a relative value (in terms of a percentage contribution) to each member of the team. Following this, students then write essays describing a current strength and area for improvement of each team member. A similar approach is used in assessments within the professional development performance area. For the Growth Planning assessment, students first rate the importance and their current level of performance of a set of attributes identified for professional development, listed in Table 10. Next they write a short essay on one of these attributes which they feel is important to their professional growth and which needs to be developed further. The remaining TIDEE assessments within these two performance areas follow a similar format. Additional information and details for all of the TIDEE assessments can be found in the following references (Davis et al., 2010a; Davis et al., 2010b) and can also be found at www.tidee.org.

Table 9. Attributes for team member citizenship assessment

<table>
<thead>
<tr>
<th>Category</th>
<th>Attribute/Ability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Team Relationships</td>
<td>1. Engages members with respect</td>
</tr>
<tr>
<td></td>
<td>2. Commits, encourages involvement</td>
</tr>
<tr>
<td></td>
<td>3. Resolves conflicts constructively</td>
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<tr>
<td>Joint Achievements</td>
<td>4. Helps establish shared goals</td>
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<td></td>
<td>5. Follows plans to achieve team goals</td>
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<tr>
<td></td>
<td>6. Works synergistically with others</td>
</tr>
<tr>
<td>Member Contributions</td>
<td>7. Delegates/completes tasks, as needed</td>
</tr>
<tr>
<td></td>
<td>8. Performs competently to team standards</td>
</tr>
<tr>
<td></td>
<td>9. Enables development in self and others</td>
</tr>
<tr>
<td>Team Information</td>
<td>10. Strives for fully-informed members</td>
</tr>
<tr>
<td></td>
<td>11. Communicates well with stakeholders</td>
</tr>
<tr>
<td></td>
<td>12. Documents achievements well</td>
</tr>
</tbody>
</table>
## Table 10. Attributes for professional development

<table>
<thead>
<tr>
<th>Category</th>
<th>Attribute/Ability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical</td>
<td>1. <strong>Analyzing information</strong>: Applying methods/tools of analysis to understand and predict conditions</td>
</tr>
<tr>
<td></td>
<td>2. <strong>Solving problems</strong>: Formulating, selecting, and implementing actions for optimal outcomes</td>
</tr>
<tr>
<td></td>
<td>3. <strong>Designing products</strong>: Producing creative, practical products that bring value to varied stakeholders</td>
</tr>
<tr>
<td></td>
<td>4. <strong>Researching questions</strong>: Investigating, processing and interpreting information to answer important questions</td>
</tr>
<tr>
<td>Interpersonal</td>
<td>5. <strong>Communicating</strong>: Receiving, processing, sharing information in many forms to achieve desired impact</td>
</tr>
<tr>
<td></td>
<td>6. <strong>Collaborating</strong>: Working with a team to achieve collective and individual goals</td>
</tr>
<tr>
<td></td>
<td>7. <strong>Relating inclusively</strong>: Valuing and sustaining a supportive environment for all knowledge and perspectives</td>
</tr>
<tr>
<td></td>
<td>8. <strong>Leading others</strong>: Developing shared vision &amp; plans; empowering to achieve individual &amp; collective goals</td>
</tr>
<tr>
<td>Individual</td>
<td>9. <strong>Practicing self-growth</strong>: Planning, self-assessing, and achieving goals for personal development</td>
</tr>
<tr>
<td></td>
<td>10. <strong>Being a high achiever</strong>: Delivering consistently high quality work and results on time</td>
</tr>
<tr>
<td></td>
<td>11. <strong>Adapting to change</strong>: Being aware and responding proactively to social, global, and technological change</td>
</tr>
<tr>
<td></td>
<td>12. <strong>Serving professionally</strong>: Serving with integrity, responsibility and sensitivity to individual and societal norms</td>
</tr>
</tbody>
</table>

The assessments are administered to students through a web interface where members complete the assignment—either individually or as a team—and responses are then available to the instructor for review. A scoring rubric is used by the instructor to evaluate the responses and a summative score, along with instructor feedback, is returned to the student/team. Any or all of the assessments can be used throughout the duration of the course and the sequence and timing is determined by the instructor.

**STUDY APPROACH**
Reliability refers to the consistency of repeated measurements (AERA, 1999). Operationally, this addresses to what extent test scores are consistent, dependable, and repeatable (Drummond & Jones, 2006). If an assessment is reliable, scores will be relatively stable over multiple administrations, given the trait measured doesn’t change. The three basic methods for determining reliability include test-retest reliability, equivalent forms reliability, and internal consistency (Kubiszyn & Borich, 2003), and relate to the properties of the test. That is, the causes of measurement error are due to the quality of the items on the test, construction of the test, implementation process, etc. A fourth type of reliability, inter-rater agreement (IRA), refers to the level of agreement between multiple raters in scoring and is the method used for this study.

In objective tests, such as those with multiple-choice responses, correct responses are set and any errors in the scoring process are unintended. In subjective tests, where responses include essays, scoring is often dependent on the interpretations and standards of the rater (different raters may score the same response differently). IRA is significant for the TIDEE assessments since essay-type responses comprise a large part of the responses scored in each assessment. Additionally, as one of the primary objectives of the TIDEE assessments is transferability across multiple disciplines and diverse users, adequate IRA is an important quality. Consequences for mismeasuring student performance can lead to ineffective feedback, or possibly feedback which is counterproductive for students. For summative use, mismeasurement of performance can lead to inappropriate grading and, when used for ABET and program documentation, an incorrect basis for decisions.

Several methods are available for calculating IRA: percent agreement, Pearson’s correlation, Cronbach’s alpha, Cohen’s Kappa, generalizability coefficient, intra-class correlation, and others. All of these methods have advantages and disadvantages and the choice
of method depends on variables such as the number of test items, number of students/tests, range of scale (e.g., 2- or 7-pts.), type of scale (e.g., nominal, ordinal, interval, ratio), variance in scores, number of raters, etc. (Abedi, Baker, & Herl, 1995). For this study two measures are used to report and interpret the degree of IRA: percentage agreement (PA) and Pearson’s product moment correlation coefficient (r). The choice of these two measures is based on the following factors, specific to this study and the TIDEE assessments:

- **Number of raters**: This study utilized two faculty raters and two teaching assistant (TA) raters.

- **Type of assessment scales**: Each associated scoring rubric utilized a 5-point Likert scales (for all TIDEE assessments).

- **Ease of interpretation**

- **Purpose**: The TIDEE assessments are primarily formative and, as such, higher-level statistical measures are not necessary as would be in large-scale, high-stakes assessment. That is, the measures chosen are sufficient as an indicator of the level of rater agreement which will be used to inform developers of the technical quality of the assessments and whether improvements are needed.

With the percent agreement method, the percentage of instances that multiple raters agree on a score, or within a score range, is given. This method is simple yet provides readers with results that are easily interpreted and meaningful, relative to more abstract coefficients of rater agreement. One problem with PA, though, is that the resulting value decreases with additional raters; three raters will likely have a lower agreement than two raters (Abedi et al., 1995). Also, the method does not consider chance agreement. That is, with a 5-point scale, two raters scoring
the same set of student work could have PA results based on chance alone of 20% exact agreement, 32% differing by one, and 48% differing by two; or, in terms of within a range of scores, 20% exact, 52% within 1 point of each other, and 100% chance that the two scores are within 2 points. To address the shortcomings of this method, this study will compare only two raters at a time and the results will be discussed in light of chance agreement statistics.

The Pearson correlation reflects the degree to which variables are related. Values for Pearson’s range from +1 to -1, with +1 representing a perfect relationship, 0 no relationship, and -1 a perfectly negative relationship. This correlation provides a way to interpret the results in light of PA. For example, given a set of ratings which have low agreement, if the ratings do show a very high correlation, r (e.g., the two raters are consistently off by the same amount relative to one another), this would shed light on the nature of the error involved.

DATA COLLECTION METHODS

Participants and Data Sets

Pilot testing of the TIDEE Teamwork and Professional Development assessments was conducted throughout the 2008-09 and 2009-10 academic years with collaborators from six universities. Participating institutions varied in size and background and included disciplines from mechanical, civil, bioengineering, general engineering, and others. The faculty from these institutions selected various TIDEE assessments to implement during their capstone course—typically consisting of two assessments from the Teamwork area and two from the Professional Development area—through the web-based TIDEE system. Student responses and resulting faculty scoring and feedback were then made available to TIDEE researchers. From this data, a sample of student work was collected and used to conduct the IRA study.
The IRA study was conducted during the Spring of 2009 with the three formative Teamwork assessments—Team Member Citizenship, Team Processes, and Team Contract—and all four of the Professional Development assessments (see Table 8). For each assessment, a set of student work was selected from the available data and scored by four raters—two faculty and two TAs. Criteria for faculty participation included being in an engineering discipline and having experience teaching capstone design courses. A total of fourteen faculty participants were recruited from nine different engineering colleges throughout the US. This allowed faculty raters to vary for each of the assessments. For the TA raters, two were used for all seven assessments tested. One student was an engineering doctoral candidate in Chemical Engineering while the other was a senior in Bioengineering who had previously taken the capstone design course and had experience with the TIDEE assessments.

Student work selected for use in the study was actual work submitted by students from the six collaborating schools. For each assessment, twenty pieces of student work were selected for testing with an additional two pieces selected for rater training. The selection process for student work included, first, reviewing all work available, discarding any work with no student responses submitted (only those with at least partial completion were considered), and then randomly choosing twenty pieces from those remaining.

**Study Procedure**

For each of the seven assessments, two faculty raters were randomly assigned to one assessment for scoring. Each rater was contacted by email and a convenient date and time coordinated for the study, on an individual basis. A packet was mailed to each rater prior to the study. Packets contained a brief overview of the purpose of the study, rater instructions, two
pieces of student work for rater training, twenty pieces of student work for the study, a scoring sheet (with rubric) for each of the twenty works, and a return envelope for mailing scoring sheets back. At the scheduled date and time, each rater was contacted by telephone and given training on the assessment and scoring process; all raters received individual training and conducted the scoring independent of other raters. Rater training consisted of two types of training: rater-error training (RET) and frame-of-reference (FOR) training.

In general, the goal of RET is to improve rater accuracy by reducing errors, or rater biases. Common types of errors include halo, leniency/severity, and central tendency, among others. RET focuses on familiarizing raters with these types of errors through exemplar works and then encouraging raters to avoid them (Woehr & Huffcutt, 1994). For this study, RET was accomplished by first giving a brief description of these typical errors and then instructing raters on appropriate scoring procedures (discussed below). RET represented a small portion of the total training protocol.

FOR training was used more extensively in this study. This type of training involves orienting raters with the norms and standards expected for the particular behavior being evaluated. That is, in addition to instructing raters on performance dimensions/behaviors being assessed, exemplars of critical incidents are also presented which give raters an understanding, or, frame-of-reference, of the performance in the specific context of the organization (in this case, capstone design courses). The FOR training process can be described as the following sequence of activities: defining the performance dimensions, providing multiple incidents of behavior for each dimension and descriptions of the levels of performance for each (through several vignettes; each at different levels of performance), rater practice in evaluating performance followed by discussions on the discrepancies between participant ratings and true
ratings (Bernardin & Buckley, 1981). Some other training approaches also used in performance appraisal include behavior observation training (BOT) and performance dimension training (PDT) (Woehr & Huffcutt, 1994). However, FOR training was selected for this study, as it has been reported to result in higher inter-rater agreement and accuracy (Lievens, 2001; Stamoulis & Hauenstein, 1993).

The rater training protocol used in this study consisted of the following activities for each rater participant:

1. Review the purpose and significance of the IR agreement study.
2. Closely review and discuss the assessment to be scored and its associated scoring rubric.
3. Give instructions and tips for scoring (addressing RET, listed below).
4. Rater reads through one piece of student work (a calibration work, which is in addition to the twenty pieces used for IRA calculations) and scores with rubric.
5. Review rater’s scores and justifications with those of trainer; discuss differences and reach consensus.
6. Repeat 4 and 5 with a second calibration work.

Instructions and tips for scoring, including those related to RET, were given in the training session and consisted of the following:

- Circle one, and only one, descriptor for each criterion in the rubric.
- Take 4 to 5 minutes to score each one of the twenty pieces of work—no more or less.
- Score all work in a single session.
- Score each criterion individually, each based on its own merit.
Rate absence of material according to criterion descriptors.

Do not rate students against each other.

Score work according to the rubric descriptor; don’t let other factors affect scores (e.g., writing quality, perception of student’s understanding, quantity of writing).

Following this rater training, each rater was instructed to score the work within the next two days. Raters then returned the twenty score sheets in the return envelope provided. The two TAs were given the same training as the faculty raters for each for the seven assessments and their scoring of work was completed in the same sequence as the faculty raters.

RESULTS AND DISCUSSION

For each of the seven assessments tested, a set of scores was obtained from each of the four raters. Each of these sets included twenty individual ratings: one per student for each of the twenty pieces. Calculations of PA were made between the two faculty scores and then between the two TA scores for both exact agreement as well as for agreement within one point. These results are presented in Figure 6 below in graphical and tabular form.

Results presented in Figure 6 beg several observations. To begin with, five of the seven assessments show faculty raters (labeled Instr in Figure 1), with exact agreement above 20%, the level of agreement based on chance alone. Interestingly, exact agreement levels by the TAs were well above 20% for all of the assessments. Additionally, for all but one assessment, Team Contract, the levels of exact agreement for the TAs were higher or equal to those of the instructors. In terms of agreement within one point, both instructors and TAs showed much higher agreement than what would be expected based on chance alone, which is found to be 52%
for a 5-point Likert scale. Lastly, no rater-pair scores differed by more than two points for any of the assessments.

One challenge to interpreting the results of this study is that no standard exists that signifies the acceptable range of percent agreement levels. This may be due, in part, to the various contexts in which assessments are used as well as the various purposes for assessment; for example, large-scale, high-stakes summative assessment versus classroom-level formative assessment. For the intended formative purposes of these TIDEE assessments, the 85 to 100% agreement found for the within one point range would likely be quite adequate. The intent of the assessments is to support the types of instruction/learning decisions and goals of instructors and students with regard to teamwork and professional development in the context of engineering design. Since it is highly likely (an 85 to 100% chance) that any given rater will score work within one point of another rater, students (irrespective of rater) are very likely to get similar and
consistent feedback on their performance. Based on this observation, the level of agreement found between raters should be considered acceptable for each of the seven assessments tested in this study.

In addition to this evaluation of the assessments, the results can also shed light on the degree of transferability of the assessments, an important goal of TIDEE collaborators. Faculty raters were from very diverse backgrounds and undoubtedly had many differences that could have influenced their ratings. For example, differences between any two raters throughout this study likely included many of the following: engineering discipline, levels of involvement in capstone design courses (and therefore different knowledge of the related outcomes), years of experience in industry and academia, perceived importance of the capstone design experience, pre-existing knowledge of teamwork/professional development, pre-existing standards of student performance, attitude toward assessment, attitude toward students, and probably many others. In light of these differences, the degree of rater agreement found shows transferability among different raters. This conclusion can be extended to TA raters also as their agreement was as high or often higher than those of instructors, an important finding as TAs are anticipated to be involved in the scoring of assessment work.

For continued improvements to the TIDEE assessments, sources of rater differences need to be identified. To aid in this analysis, values of Pearson’s correlation coefficient were found and are presented in Figure 7. In contrast to the higher levels of rater agreement of TAs over instructors mentioned above, the correlation of ratings between instructors was higher or equal to those of TAs for five of the six assessments. Therefore, while TAs more often agreed with one another on ratings, instructors were more consistent in relative rankings of performance. A possible explanation for this is that TAs, with little engineering experience to draw on or
experience in observing student teams in a capstone environment, may have referred to the scoring rubric more closely and more often. Conversely, instructors may not have applied the rubric as strictly as TAs. Given their greater experience with capstone teams and with grading in general, instructors may have understood and adequately applied the relative rubric graduations, but with their own performance standards factoring in as well. With Team Member Citizenship, for instance, TA raters scored exactly the same 60% of the time while instructors were the same 20% of the time. In terms of rankings, though, instructor’s scores were more highly correlated than TA’s by .57 to .45.

![Figure 7. Results of Pearson’s correlation between raters](image)

Of the seven assessments tested, the Team Processes was found to have the lowest correlations: 0.00 for instructors and 0.15 for TAs. In terms of PA, instructors agreed exactly 20% of the time and 85% of the time within one point while TA’s were 40% exact and 90% within one point. For the Growth Achieved assessment, the TAs also had a low correlation, -
0.06, but the assessment had sufficiently high agreement for both sets of raters. As mentioned above, for each of these assessments the higher percentages of agreement within one point should prove adequate for the purpose of achieving teaching and learning goals. The rubrics will guide various raters toward similar interpretations of student work and, subsequently, provide similar types of feedback to students as well as consistent feedback on teaching practices. The low correlations, though, may indicate that the assessment needs revisions or the rubric descriptors need further specificity, giving raters more detailed instructions on ratings. This approach, though, would decrease generalizability, representing a common tradeoff in assessment/rubric design.

CONCLUSIONS AND RECOMMENDATIONS

The IRA results presented in Figure 6 along with the corresponding correlations in Figure 7 indicate areas of strength and possibilities for improvements. In particular, all assessments show levels of rater agreement likely to be sufficient for the purposes of formative assessments in capstone design courses, as shown by the high percentages of agreement within one point. The Team Processes and Team Member Citizenship assessments show the lowest percentages of exact agreement between instructor raters, although, given the high agreement within one point and the formative use of the assessments, this result should be considered acceptable. The Growth Achieved assessment, on the other hand, which is intended for summative use, shows a correlation of -.06 for TA raters. And, as mentioned, since TAs are likely to be involved in the ratings of student work, decreasing this variability in ratings for this assessment would be beneficial.
To improve IRA, qualitative analysis of each rater’s actual scoring approach, obtained through post-scoring interviews, would certainly shed greater light on possible sources of errors. Errors may be related to the rubric design (e.g., exclusiveness of anchors), to the varied backgrounds of raters, or to rater training. Without any certain indication of the source of errors, and hence clear direction to take in improving agreement, addressing rater training in any case would undoubtedly lead to improvements in rater agreement, as reported by several researchers in this field (Bernardin & Buckley, 1981; Borman, 1979; Lievens, 2001; McIntyre, Smith, & Hassett, 1984; Stamoulis & Hauenstein, 1993; Woehr & Huffcutt, 1994). The training provided to raters during this study was a scaled down version of Bernardin and Buckley’s frame-of-reference (FOR) training. For example, Bernardin and Buckley suggest that three vignettes be used to provide a frame-of-reference for three distinct levels of performance: high, medium, and low. In this study, only two were used, drawn from actual student work and thus not necessarily the optimal exemplars for training purposes. It is also suggested by Bernardin and Buckley that, prior to reviewing the three vignettes during training, raters develop (through group discussion) a set of performance behaviors for the target as well as the corresponding levels of performance for each. This would require raters to reflect on the performance more deeply, which would presumably lead to greater awareness of the behaviors during scoring. During this study, raters did not go through this activity. After reviewing the assessment, the rubric was reviewed only briefly (not every detail was discussed). With the training process in this study typically lasting between twenty and thirty minutes, a practical balance must be reached between breadth and depth as this timeframe was probably on the longer side of what raters considered acceptable.

Therefore, one recommendation to improve rater agreement would be to design a training protocol which provides trainees with a very clear understanding of performance expectations,
shown through tailor-made critical incident vignettes. A second recommendation would be to include elements of behavior observation training (BOT) into the training protocol as well. This type of training gives raters skills and experience in observing behaviors effectively. This is suggested since, without knowledge of what to observe, raters are said to rely on their own experiences to decide what to observe (Lievens, 2001). This could allow deviation to occur in methods of observation, and, therefore, deviation in scores. Additionally, BOT may be particularly beneficial to formative assessment as raters are encouraged to notice particular behaviors, which could then lead to more pointed feedback.

Rubric anchors for the Growth Achieved assessment could also be revised so that the descriptions of each level of performance are more robust, leading to higher correlations among scores. Although this may result in less flexibility in scoring—a priority of instructors—greater consistency is needed as this particular assessment is intended for summative purposes. The low levels of exact agreement, coupled with relatively low correlations of the Team Processes assessment, warrant similar adjustments.

Lastly, a recommendation for further study relates to the variables affecting faculty scoring agreement. These potential variables may include (as listed above): engineering discipline, levels of involvement in capstone design courses, years of experience in industry and academia, perceived importance of the capstone design experience, knowledge of teamwork and professional development concepts, standards of student performance, attitude toward assessment, and attitude toward students. With transferability among diverse faculty and disciplines representing an important goal for the TIDEE assessments, a clearer understanding of the causal relationships associated with variables such as these may suggest areas for improvement in rater training, administration practices, and/or assessment content.
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Chapter 5

A Description of the Reflective Practices of Students Regarding Teamwork within a Capstone Design Course

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ABSTRACT

Engineering students often face new and challenging situations in their senior capstone design course, where the goal is to give students design experience prior to graduation. Issues arise as students typically have little or no experience collaborating with fellow students in a professional and productive manner. Team issues, resulting from poor planning, lack of communication, or unshared goals or values, often result in individuals or whole teams struggling to be productive. Without past experiences to serve as a guide, teamwork challenges are expected and are part of the learning experience.

An important goal of the capstone course is to teach students to be self-directed, life-long learners. That is, as students will surely face novel situations throughout their careers, an essential skill will be the ability to reflect and think critically on uncertain issues, questioning root causes and even foundational theories and assumptions, which will then lead to appropriate decisions and solutions. Reflective thinking, though, is not a well-defined process and theorists have often differed on the meaning of reflection and suggestive steps, confounded by differing contexts and purposes for reflection. In response, the study presented in this paper was aimed at developing an understanding of the reflective practices of students in the specific context of teamwork in capstone design courses. This paper includes a description of the teamwork issues common to multidisciplinary engineering student teams followed by a description of the reflective practices of these students and teams in light of existing conceptual models of reflection.

Participants for the study included twelve senior-level students who were enrolled in a multidisciplinary capstone design course at a moderate-to-large university. Participants comprised two teams and were from a variety of engineering and business-related backgrounds.
Qualitative data was collected through observations, interviews, and reflective course assessments. Descriptions of teamwork and student reflective practices were deduced from the data by traditional qualitative analysis techniques. Results from this study are intended to be used as a foundation for assessment and instruction on reflective practice for students in engineering capstone design courses.

INTRODUCTION

The capstone design course is a culmination of three years of engineering study, a course in which students work within a team to design and produce an engineering design product. The course is important to graduates as it may be their only opportunity to gain practical semi-authentic design experience. Students learn to apply theoretical knowledge as well as learn the “softer” skills of teamwork and professional development. These professional skills, while not emphasized substantially in the theoretically-oriented courses, are tremendously important to students’ success as professionals, and the capstone course provides the opportunity for students to develop their skills and knowledge in these areas.

Of great importance to engineering professionals is their ability to be self-directed and lifelong learners (National Academy of Engineering, 2004). Reflection is often referred to as making meaning from a situation and is reported to be a key element in learning—including self-directed learning (Jiusto & DiBiasio, 2006) and learning from experience (Kolb, 1984). The capstone course can play an important role in teaching students to be reflective learners because new situations arising will challenge their current knowledge and skills and force them into uncharted territory. Addressing problematic situations allows students the opportunity to create new meaning schemas and perspectives or to build on existing ones (Mezirow, 1991). The
The capstone course in particular is replete with opportunities to learn, especially knowledge and skills related to teamwork. But this opportunity alone does not guarantee that learning will occur. Therefore, teaching and encouraging students to reflect on experiences—as opposed to simply directing their action—is needed to develop this important skill for graduating engineers and one very fitting to the outcomes of the engineering capstone design course. The instructional challenge is operationalizing reflection in the specific context of interest, when there is no current consensus on the reflection process (Moon, 1999).

To address this need, the goal for the study presented in this paper was to develop an understanding of the reflective practices of multidisciplinary engineering capstone design students in the context of teamwork within their projects. This paper will first present a brief review of the concepts of reflection and teamwork. Next, teamwork practices of current student teams are illustrated, followed by a presentation and analysis of their teamwork-related reflective practices.

BACKGROUND

Elements of Teamwork

Teams can obtain an outcome that typically could not be achieved by a single individual and, ideally, the team’s output is much greater than the sum of the individual members’ outputs, in terms of quality, cost, and/or time effectiveness. Poor teamwork can negate these benefits and may even result in the opposite: higher cost and time with lower quality. The capstone course gives students the opportunity to learn effective teamwork skills and knowledge through their hands-on project experience, lower-risk learning than in the workplace.
Teamwork can have slightly different meanings depending on context. For example, teamwork for the Navy is likely different from teamwork for a student design team. The former may stress the importance of following well-defined plans and protocols where deviations from these would be discouraged (Morgan, Glickman, Woodard, Blaiwes, & Salas, 1986). The student design team, on the other hand, may give less importance to procedures and emphasize more the cohesiveness of the members and establishing shared commitments and goals.

Teamwork can be defined as the cohesive, or synergistic, collaboration between members who have inter-dependent roles to perform, each critical to the success of the team (Kohn & O’Connell, 2007; Katzenbach & Smith, 1993). Teamwork can be viewed in contrast to group work, where each member of the group performs a similar task, such that losing one member does not inhibit the completion of the project but may only slow the progress.

To discuss, teach, and assess teamwork, various components are usually defined and are intended to encompass what teamwork means in a particular context. Communication, for instance, is a typical component as some form is needed for two or more people to work together. For this study, a review of the literature on teamwork was conducted and, based on the context of capstone design courses, six components of teamwork were selected. The six components will be used to organize and discuss teamwork issues encountered by students in this study. The components selected and listed below were adapted largely from Dickinson and McIntyre’s (1997) Teamwork Model, which includes seven core components of teamwork, and the Advanced Team Decision Making (ATDM) model by Militello et al. (1999), which was a synthesis of several models of teamwork resulting from a meta-analysis of the literature on this subject.

Values: refers to having shared goals and expectations for the project.
Coordination: refers to executing activities in a timely and integrated manner; implies that the performance of some members influences the performance of others; includes decision making, planning.

Participation: refers to contributing as expected, including providing leadership in one’s role as necessary; includes supporting/backing up others as needed, collaborating.

Attitude: also called team orientation, refers to the attitudes that members have toward the project and one another; reflects acceptance of team norms, level of group cohesiveness, and importance of team membership.

Monitoring: refers to observing the activities and performance of others as well as the progress of the project; actively giving and receiving feedback.

Communication: involves actively listening and appropriately sharing information in a prescribed manner.

What is Reflection?

Engineering faculty are increasingly acknowledging the role of reflection in the capstone course, as seen by the increased works related to reflection in the engineering education literature. Several authors have illustrated their approach to operationalizing and assessing student reflective practices. Adams, Turns, and Atman (2003), for example, have defined reflection through the activities of problem setting and “listening to a situation’s back talk,” which was based on Donald Schön’s model of reflection-in-action (1983). From their study of student design teams, results illustrated that more effective designers tended to reflect more throughout the design process.
A similar study by Valkenburg and Dorst (1998) also used Schön’s model of reflection-in-action to define the design processes of engineering students engaged in a design project. Reflection steps were termed “naming, framing, moving, and reflecting” (p. 254). Results here also indicated that reflective designers produce higher quality solutions. Both of these studies operationalized reflection in terms of design process steps, or activities, and, therefore, highlighted the steps which were considered more reflective. The value of these studies to practitioners is that they provide guidance on how to utilize the design process steps most effectively: by reflectively iterating and reformulating the problem and solution.

Other authors have discussed approaches to facilitating and improving student reflections through service learning projects (Huyck, Bryant, & Ferguson, 2009; Slivovsky, DeRegio, Zoltowski, Jamieson, & Oakes, 2004; Tsang, 2002). To evaluate the effects of programs on student reflections, these authors have used some form of the Reflective Judgment Model developed by King and Kitchener (1994). Assessment results were reported to be used as a basis for improvements to the programs.

This current study deviates from the approaches above by, first, exploring the cognitive processes of student reflections and, second, by looking at reflection in the context of teamwork rather than the design process. To do so, existing conceptual models of reflection are reviewed and used as a basis for interpreting student reflective practices. The remainder of this section defines the process of reflection as it relates to learning and professional practice.

Dewey (1933) describes reflection as “assessing the grounds of one’s beliefs” (p. 9), indicating an attempt to validate ideas. Boud et al. (1985) define reflection as “those intellectual and affective activities in which individuals engage to explore their experiences in order to lead to new understandings and appreciation” (p. 19); in other words, reflection means learning from
looking back on experiences. Others also describe reflection as a central role in the learning process. Seibert and Daudelin (1999) describe the process of learning for managers as “learning from the meaning they give to experience, not from the experience itself, and they give meaning to experience through reflecting” (p. xvi). Similarly, Mezirow describes learning through reflection as “learning is to make meaning… to make sense of an experience… to make an interpretation of the experience” (1991, p. 5), which he states is done through reflection. Mezirow defines reflection as “an assessment of how or why we have perceived, thought, felt, or acted” (p. 12).

Schön’s model of reflection is the model most often cited in contemporary pedagogical literature. It can be seen as quite similar to the descriptions of reflection above and includes the following thought processes on an experience:

- Realizing a “surprise” event.
- Reflecting on the surprise event and the “knowing-in-action” which led up to the surprise. Questioning “What is this?” and “How have I been thinking about it?”
- Iterating between the surprise and the thinking leading up to the surprise.
- Thinking critically about the thinking that resulted in the current “fix” and restructuring strategies of action, understanding of phenomena, or ways of framing the problem.
- On-the-spot experimentation in order to think up and try out new actions intended to explore the newly observed phenomena, testing tentative understandings of them or affirming the moves invented to change things for the better.
Schön’s model, as a summary, involves recalling one’s thinking which led up to a problem and then critiquing that thinking to determine how or if it resulted in the problem. Following a tentative understanding of the thinking that caused the problem, and with a newly proposed thought process, the new theory is then tested virtually. Kolb’s model of learning from experience is similar to this and includes the following four elements: (1) a concrete experience, (2) reflective observation on the experience, (3) abstract conceptualization (learning from the experience), and (4) active experimentation (trying out what was learned) (Kolb, 1984).

The descriptions above put reflection in the context of an experience: reflecting on an experience in order to make meaning of the situation, and therefore, to learn from it. Mezirow identifies this as learning by doing, or, *instrumental learning*, such as in problem solving. Here, reflection is involved when we look back, such as on content or assumptions in the problem-solving process, to “reassess the efficacy of the strategies and tactics we used” (p. 9). Mezirow states that this is metacognition: reflecting on the thinking processes through which one has learned.

In addition to this instrumental learning, Mezirow states that not all learning has to be through doing and that *communicative learning* is learning by understanding the meaning of what others communicate. For example, communication may be concerning values, ideals, feelings, moral decisions, commitment, and so on. Here, we are trying to determine what is meant by someone else and that to do so involves determining the conditions under which the assertions are valid.

In addition to the definitions and conceptions of reflection above—by Schön, Mezirow, and Dewey—several other scholars have proposed and presented models of reflection. Many can be generalized as a series of mental activities intended to define the reflective process and
typically start from a state of awareness of an issue, progressing to some form of analysis and synthesis on the issue, and resulting in an outcome, such as an action, a resolution, or a new perspective. Still, other authors have presented reflection according to suggested levels, or depths, of thinking or understanding. King and Kitchener (1994), for example, propose seven stages of reflective judgment based on one’s view of the certainty of knowledge. A brief overview of the models utilized in this study is given in the Appendix.

In summary, reflection is a process of looking back on actions or thinking in light of an experience or communication in order to make meaning, and therefore to learn from it. Reflecting involves considering the how and why of our thoughts or actions, or those of others, questioning presuppositions and validating what is known. It can be used to correct distortions in beliefs or correct errors in problem solving. For this study, these definitions of reflection discussed will serve as the existing theoretical basis for interpreting and describing the reflective practices of students.

PROBLEM STATEMENT

As mentioned above, there are several perspectives on the meaning and operationalization of reflection. Some may be based on practice, such as with Schön’s model of reflection-in-action, where the intent is to provide practitioners direction on solving an immediate problem. Others are more related to learning from past experiences and therefore seem to be similar to a retrospective, as with Kolb’s learning cycle. Mezirow suggests that reflection is learning by making meaning from any experience or communicated philosophical idea. Several authors have also suggested that the purpose and process of reflection varies with the context of the situation. For example, nursing practitioners may reflect on their daily
assignments differently and for different reasons than a person in management/finance. The goal for this study was not to develop a new theory on student reflective practice, but to contextualize existing theories with respect to student designers in the engineering capstone course. In particular, this study addressed the following questions:

1. What are the reflective practices of engineering capstone design students with respect to teamwork?
2. How well do existing models of reflection represent the reflective practices of students?

METHODOLOGY

Study Design

This study used a qualitative approach to studying the teamwork and reflective practices of students in capstone design teams. A qualitative approach is appropriate as the goal is to gather an in-depth understanding of students’ behaviors, addressing how students reflected, in addition to what, where, when, etc. This section will discuss the participants of the study, the data collected, and the method of data analysis.

Participants

Participants for this study included thirteen students who were enrolled in a multidisciplinary capstone design course in a relatively large university. The participants represented two teams from the course, with eight members from Team A and five members from Team B. All participants were senior-level students who had completed at least three years of school prior to the course. The capstone course was multidisciplinary with an emphasis in
both engineering and business-related majors and, likewise, the projects chosen by the teams were diverse in terms of engineering and business. Backgrounds of participants included several different disciplines of engineering and also a variety of disciplines related to business.

Of the eight teams in the course, the two teams selected (on a volunteer basis) were most suited for this study due to the diverse team composition, including disciplines and gender, as well as the diverse nature of their projects. The rationale for this sampling effort was to maximize generalization of the results.

The project chosen by Team A involved the design of a sustainable irrigation system which would be used for subsistence farmers in a third-world country. The project included the design of a procedure and system which would extract oil (biofuel) from soybeans, collect and store the biofuel, and then use the biofuel to power an irrigation system for maize and other crops. For Team B, their project was to develop the architecture for a software system which would support more cost-effective communications between engineering, business, and manufacturing departments to handle change orders in a large design and manufacturing company.

**Data Collection**

Data for this study included first-hand accounts of teaming and reflective practices of participants collected through individual semi-structured interviews. Three interviews were conducted with each participant over the course of two academic semesters, spanning their entire design project. Questions posed related to initial and current perceptions of teamwork, teaming issues encountered, reflections on teaming issues, and lessons learned regarding teamwork.
Additional secondary data was collected through observations of team meetings and reviews of teamwork assessment responses from the course—both used to further clarify or add detail to individual student accounts. The teamwork assessments administered in the course consisted of four instruments developed by the Transferrable Integrated Design Engineering Education (TIDEE) consortium: Team Contract, Team Member Citizenship, Team Processes, and Teamwork Achieved. The first three represent formative assessments and are intended to develop students’ teamwork knowledge and skills while the Teamwork Achieved assessment gathers evidence for the documentation of teamwork knowledge and skills and is intended as a summative assessment (Davis et al., 2010). The Team Contract was implemented at the start of the course to orient students to the concepts of teamwork. Teams were required to discuss and reach a consensus on their expectations related to team relationships, individual and joint contributions, and team information. The Team Member Citizenship and Team Processes assessments were administered mid-project and required students to reflect on their teaming performance, with the goal of facilitating improvements and learning of critical teaming concepts. The Teamwork Achieved assessment documents students’ understanding of teamwork, their perception of performance, and their growth through the project, and was administered towards the end of the project (for more detailed information, see http://tidee.org). The methodology for selecting, timing, and sequencing of the TIDEE assessment is described further by McCormack et al. (2009).

**Data Analysis**

For this study a modified-analytic induction method of data analysis and interpretation is used where the intent is to either verify the congruence of existing concepts or reformulate them.
based on the data, or a combination of both (Taylor & Bogdan, 1998). The data were reviewed, transcribed, and then coded according to traditional qualitative techniques as discussed by Miles and Huberman (1994). Memoing of codes and concepts was performed as suggested by Glaser and Strauss (1967), which involves the theorizing write-up of ideas emerging from the data. Results of this study will be descriptions of the teamwork-related reflective practices presented in narrative form and discussions of the major elements of reflection related to capstone students.

DESCRIPTONS OF TEAMWORK ISSUES IN A CAPSTONE DESIGN COURSE

As a precursor to the discussion on reflective practices of students regarding teamwork, this section will present teamwork problems that surfaced within the two teams participating in this study. Problems are defined in the context of the six components of teamwork described above: values, participation, coordination, monitoring, attitudes, and communication. Identifiers to students have been removed and references to gender through the use of she/he have been applied randomly in order to maintain anonymity. To provide further anonymity, the term engineer will be used without reference to a specific discipline and the various business-related majors will simply be referenced to as business students. Lastly, for the comments below, student comments are given the identifier Student. For a single topic (i.e., for a given string of continuous student and interviewer comments/questions), Student represents one student from the set of participants. For the next topic, the next reference to Student has no relation to the previous unless noted in the discussion. If a string of comments within a single topic includes multiple students, a number value is given to Student (i.e., Student #) to differentiate between students; and again, no relation is kept from one topic to the next.
**Values**

The values category represents the general values and goals shared by team members. In this study many, if not most, teamwork-related problems could be traced to misunderstandings of the goals or scope of the project or to differences in member expectations for the project. Examples for both Team A and Team B are discussed next.

Team A had initially defined project goals that were not completely explicit and left room for varied interpretations. The different disciplines on the team, including multiple engineering disciplines as well as various business-related majors, generally differed in their perspectives of the project’s ultimate goal and also with respect to their personal interests for the project. For example, some of the engineering students viewed the project as more open-ended and with the intent to start a non-profit organization from the project, which was to build a complete system to irrigate crops during the dry season of the host country. One student described their team goal as follows:

*Student: The problem is that they don’t have enough water to irrigate the land year-round when the rain season is over; it’s a dry place. They don’t have a way to bring the water from the irrigation source, which is a large lake miles away, up to the farmlands. We want to start a non-profit which will help them grow maize [the farmers subsistence crop] over the whole year. Right now it only grows for six months; the other six months, nothing grows. We’re investigating growing soybeans during the six months [of dry season] and then taking the soybeans and making... extracting oil. From the oil we’ll create biofuels and from the biofuels we’ll create an irrigation system that will be able to run year-round so that they can grow the maize*
year-round. [The oil is intended to be used to power an irrigation system during the dry season; also to be designed by the team.]

Other engineers on the team were less interested in the non-profit aspects and wanted a small, more defined set of deliverables. When asked about the goal of the project, one student responded by detailing the exact scope of work she was in charge of and the engineering principles involved. This student was interested in the design aspects of the project and did not express much enthusiasm for the business-related goals. She also was skeptical of the large scope of work which was embraced by others on the team, thinking that it was more than the team could handle with their experience and time constraints. This difference in goals resulted in problems as the team wrestled with the scope during the Problem Scoping design phase.

Student: Some members want to save the world. Others say ‘let’s do a really good job on this one market part and just develop there’. And so half are for-profit and wants to aim for a single market niche and grow from there and half are for not-for-profit. They [the not-for-profit students] try to take a much broader view without being very specific... biting off a lot at once.

Interview Question: Is this frustrating to you?

Student: It’s not frustrating, but it seems like we’re getting off track. It’s like ‘let’s get this done now, and later, if we got time, we’ll see what else we can put in’. That’s why they say I’m the one who always keeps them grounded. I say ‘hey, let’s get back to the
task at hand. We’ve got one year to get this and we’re all college students and not professionals and we don’t have fifteen years of experience. So let’s get this first part done and then see about doing others; so that we don’t have like fifteen tasks half-completed’.

The business students on the team, while also enthusiastic and supportive of the project, seemed to be slightly more invested in the business prospects of the project, which involved developing a quality business plan to submit to the school’s annual business plan competition. They tended to go along with the wishes of the engineers on the team, but felt that the goals were not clear:

*Student: They are trying to water a field. Everything else is good, but the main focus is to water a field. They don’t know how much water a 5hp engine will pump or how long it will run on a liter of fuel. They’re still scrambling to understand the problem definition and to define a clear and bounded space. They need a focused goal.*

The lack of clarity in goals resulted in the team arguing about the scope of the project, with some of the engineers and the business students having different expectations for the project than the rest of the team, in general. While the debates on the goals are not necessarily bad, and actually needed to some degree to further define the project, the trouble with the team, in this case, is the damage done to the team climate, or sense of cohesiveness. Members described a sense of combativeness and ill-feelings due to the heated debates, which significantly degraded their team communications between some for the remainder of the project. Most importantly,
though, was the loss of commitment to the project by some members as they felt their voice and beliefs were not valued. This caused them to lose interest and participate less, which contributed to further team problems later in the project.

Unshared goals and values also contributed to team problems within Team B as well. The business students on Team B, as with Team A, were very interested in developing a competitive business plan for the school’s business plan competition. Success at this competition was beneficial to the business students for future job prospects, and this success hinged on a solid product idea. Poor communications between the team and project sponsor resulted in the team floundering for much of the first semester, with no clear problem definition. This caused all members to lose considerable motivation and commitment in the project, with some students participating hardly at all, further affecting team productivity and dynamics. One student expressed this as follows:

*Student: I’ve been demoralized, or not motivated, because why should I put out the effort if it’s not reciprocated by [the sponsor]. It’s tough to find the motivation. There was never any good direction. We never had any clear goal, like ‘Okay, this is want we want to see’. And I don’t do well with that. I’m not a really creative person, so I just have trouble making sense of it. I just don’t know what to do. If there’s a goal, it’s much easier to work.*

Following this issue throughout their project, it seemed the sponsor did communicate their expectations to the team, but the team was not experienced enough to really understand the directions, and so they were somewhat lost. My conjecture is that the sponsor also lost
motivation with the team on account of a few mishaps with team members: some missed a few
meetings with the sponsor, some failed to respond to the sponsor’s requests on certain issues, etc.
In any case, the lack of shared goals and values resulted in significant teaming problems, for both
teams. Most obvious was the decreased motivation of members and lowered or no participation
by some.

After some time Team B began to narrow their options and scope out a problem. Toward
the end of the first semester, they settled on a project involving the design of a communication
software system for their client. But a similar debate on the new project goals developed between
members due to differing personal values and interests, as indicated by the following:

*Student:* Software is something that you can’t put out in a year. It’s a big project that’ll
take two or three years.... When you see the immense challenges and you don’t see a
way through them or around them or above them, then why are you going to spend
your time doing that.

This student did not want to undertake the project suggested by other team members but
was overruled, which caused him to lose motivation and essentially quit participating.

Each of these instances above speaks to the affects of unshared goals and values on team
dynamics. The students struggled with this as they did not know how to engage each other and
communicate their thoughts professionally and productively, resulting in long-lasting teaming
effects regarding motivation and commitment. Instructing individuals and teams on reflective
practice is a means to get students to become aware of issues such as these and to address and
communicate the underlying causes.
Coordination

Lack of coordination was another major source of contention for the teams, as would be expected since students are often inexperienced in working on teams, especially on a design project spanning all phases of the design process. Two issues most often found with the two teams were ill-defined roles and responsibilities and lack of coordination in group work (e.g., team meeting organization).

Nearly all participants from both teams reported frustration at first with team meetings as little or no work was accomplished during them. Meetings were often not planned with agendas and timelines. Members showed up and discussed random ideas and work that they were doing, going off on tangents a lot of the time. The following are comments by students expressing discontent about the team meetings; they felt there were no real goals for the meetings and that they were generally a waste of time.

Student 1: ...[at group meetings] nobody really knew what to talk about and then we just talk about other things. It was just coming together as a group and talking about random things and then leaving. Nothing got done.... [One member] would talk a lot, he’d just talk and talk and talk, about random things that I didn’t even know what he was talking about, and so I just quit listening. It was probably something important; it’s about business stuff... all the nitty-gritty details. But we don’t have to know everything.
Student 2: [During meetings] some members are finicky about the little things; they pay attention to every little detail. Little things that I just find are trivial, unimportant. Sometimes it’s like ‘okay, you need this by tomorrow… strict deadlines’…. Just different perspectives, opinions. I find it’s not focusing on the big picture…. Sometimes I just feel like some members are focusing on the wrong things. [he mentioned that he gets frustrated at this and that it de-motivates him]. It’s a waste of time. Busy work. And I spend my time on things that aren’t moving us towards our goals.

During the initial problem scoping design phase, both teams described problems with roles and responsibilities of team members, even though they had articulated these at the start of the course. That is, while they did assign titles and general responsibilities, their problems were likely due to these being too general as a result of not knowing what exactly was entailed in design and project management. The following comments illustrate this issue.

Student 1: [He] wouldn’t tell people what to do specifically, and so no one would do anything.

Student 2: At first we weren’t on the same page about what the overall goal was technically or about people having roles. Some people were doing more than others, either by design or the way it happened to fall out…. I felt that I wasn’t contributing anything to the group because I didn’t know what I was supposed to be researching
or what I was supposed to be doing. I was just going in there and kind of feeling like a 9th wheel.

**Student 3:** [Regarding everyone doing their fair share of work] I think everyone is doing as much as they can competently, I’ll say that... given that some people aren’t sure what they are supposed to do. Like... ‘well, I’m not really sure what I’m supposed to do’.

**Participation**

Equal and active participation is a very common problem with student teams in general and the motivations students have for participating and contributing effectively vary considerably. Shared or unshared goals and values can cause changes in the level of participation of a member, as described. Some students have significant buy-in to the project while others give it low priority.

Each of the two teams in this study had problems with participation. For Team A members could generally be found to lie within one of the following three categories of participation: high, average, and low participation. The **high** participators were found to be emotionally attached to the cause of the project or had a personal stake in its success. The **average** participators were those who were treating the project as any other class and were found to do what they were told, but without taking much initiative—they just wanted to get out of the course and graduate. The **low** participators were often those criticized by their teammates as not doing, or wanting to do, much; they had very little emotional attachment to the project. Two comments by students highlight this.
Student 1: I’d say three of us do the majority of the work, out of nine…. Like, we’re treating this as a job, right; that’s what we’ve decided to do. And you can tell who’s really passionate about the project and who’s not, just based on who shows up to the meetings and how much work they put in and how adamant they are about the idea.

Student 2: One or two are just treating it as a class… this brings down the mentality of the group.

Attitude

Attitudes, or inter-personal relations, are also contributing factors to student-team dynamics. This represents a significant factor—positive and negative—affecting team cohesiveness and, ultimately, participation and success. The personalities of some students from this study were such that they often expressed their thoughts and ideas quickly and powerfully, and were quick to critique others, usually without discussions or any attempt at delicacy. In one situation, while Team A was conducting a concept review of alternatives, one member declared the process being used (a matrix of alternatives with weights given to selected criteria) “useless” as there was not enough information to accurately evaluate alternatives. One member described the situation as follows:

Student: There’s one pessimistic person and she brings down the project.... She was pessimistic when we were doing the concept matrix and I was getting on edge
For the most part, though, students were found to work together respectfully and collegially. For Team A, seven of the members considered themselves friends prior to the course and they indicated this to be one reason for being respectful and cooperative to one another. They also indicated, on the other hand, that this initial friendship caused some internal resentment because they did not feel they could express their opinions as openly to their friends (to critique them) as they would with others. It was clear, though, after hearing about issues from multiple perspectives, that the friendships between members prevented some disagreements from propagating and, at times, also preventing positive discourse which would have moved the project forward. For both teams it was found that most personal conflicts were between students from different backgrounds—engineers versus business students. Several students mentioned that the two groups “just think different” and that this was the source of contention.

**Monitoring**

Monitoring refers to team members paying attention to the progress of the project, with the objectives in mind, as well as paying attention to other members. Included in monitoring is the active feedback to the team or individual on problems and improvements. In essence, it’s the role of all members to monitor the team and project to ensure that everyone is participating and progressing as expected. In general, most members expressed instances of monitoring in some form, often through critiquing others’ work and participation as well as the state of their project, as illustrated with the following student’s comments:
Student: Right now they’re at a general feeling of frustration. At meetings now, we’re talking about things that we’ve already talked about before, and so no progress is happening and no one really knows what to do. These kind of things kind of give the felling of spinning in circles.

Student: A lot of this stuff has been like ‘find out about this, and find out about this’... it’s information gathering. And some of the information is good and some is a waste of time. I mean, we have people who are researching soybean plants right now, and while that’s important to the success of the product, that’s not the deliverable we have [for the team’s scope of work].... So it’s kind of wasted energy.

This last student was aware of the team’s problems but mentioned that he didn’t address it with the team at the time. It appeared that he wasn’t quite sure how to address the situation and he did not want to confront others or add additional stress to the team.

Communication

Communication is central to all aspects of teamwork as students must communicate their goals and values, their positive and negative attitudes, their feedback from monitoring, etc. They also must communicate information from their design project: calculations, schedules, budgets, information from stakeholders, and so on, through appropriate and effective methods.
As discussed above, Team A had issues with communication between their sponsor which caused them setbacks to their project, and ultimately, lowered enthusiasm and commitment. Team B had inter-personal communication issues which caused poor team dynamics as well. Therefore, issues with communication in this study were found to result from problems with active listening, professionalism, and the sharing and documentation of information. The next section will discuss communication and the other teamwork categories in light of the reflective practices found from the participating teams and individuals.

DESCRIPTIONS OF THE REFLECTIVE PRACTICES OF STUDENTS AND TEAMS

This section presents a variety of accounts of student reflections showing the relationships of each to existing definitions and models of reflection. While each example is presented in the context of one of the six major elements of teamwork, multiple aspects of reflection can be found within each example.

Example #1: Shared Values and Goals

The teamwork issue above on values and goals involved a situation where students from three different backgrounds had somewhat different motivations for the course. During the initial phase of the project, objectives for the teams were not clear, nor were the exact roles and responsibilities of members. Inexperience and enthusiasm resulted in the team moving forward without a clear scope of work. Problems arose when some members felt their interests/needs were not included or would not be met. This continued throughout much of their first semester. As the team matured from the initial “norming” stage of development—with respect to the
norming-forming-storming-performing model of group development (Tuckman, 1965)—members began voicing their concerns and frustration.

In terms of reflection, members did become aware of the problem and did learn from it. Speaking about what they had learned from the situation, one student replied:

*Interview Question: What did you learn? What will you take with you to your next team project?*

*Student: Teamwork requires an open mind. I wasn’t... I wanted it my way. You have to be open to change and others’ ideas.*

The student was speaking of the necessity of addressing the needs of all members in order to keep everyone motivated and “on the same page,” as he put it. Talking with all members regarding this issue, it was seen that each of them was frustrated at the lack of clarity and direction. One student described this issue as “a boiling problem... swept under the rug.” The prompt for bringing the issue up finally, as a team, was a course administered reflective assessment. All teams were required to complete a Team Contract at the beginning of the course. Teams generally completed these with very general statements regarding their goals, planning, roles, etc. They were also encouraged to update the Team Contract throughout the course as they gained experience and a firmer understanding of their project. For this team, this review of their Team Contract helped them to see what their problems were and exactly where they needed to concentrate to solve the issue. As mentioned above, the following statement highlights this insight:
Student: We were so overwhelmed we needed some kind of track to follow, and then we
kind of regrouped and realized that we need to stop and make specifications and start
thinking about the criteria that we need to meet.

This realization was prompted by the course assessment, as stated by several of the team
members during their interviews. The statements above indicate a couple elements from the
reflective concepts. First, the members did realize a problem, albeit through an external prompt,
which is a first element in many models of reflection. Second, this student (as well as several
others) did report that they had learned from the situation, which is a primary goal of reflection.
The process of this learning was not described in this case, though. Based on the several different
perspectives gathered on this issue and the fact that none of the students discussed any internal
reflections of how they were thinking or why they were thinking as they were, it may likely be
that they did not seek to determine how or why they were in the state of confusion during the
initial design phase. According to the concepts and models of reflection, the sense of frustration
that most members felt should have raised the following types of reflective questions: What are
we doing; this doesn’t seem right? What are we supposed to be doing? How did we get here?
How were we thinking? Should I have done something different? These are general clarification
types of questions as suggested by Schön, Moon, Dewey, and others, which represent a first step
in reflecting.

Example #2: Communication
A second case, which was found to represent a deeper level of reflection, was that of one student’s personal growth in team communication. During the first semester this student indicated that she did not speak at team meetings, although she had relevant information for the team and also needed information from others to support her tasks. She indicated that she was normally a social person but was still reluctant to contribute in meetings. The following passages describe the situation and her reflective activities.

Student: I learned that I need to communicate more. I tend to just let conversations go on around me and then I don’t always contribute. But then... but then, I guess the TIDEE assignments might be beneficial because one of them [one addressing team communications] was talking about what you should do to improve and I said communication [she chose this as a personal growth area to improve on]. So that’s what I’ve been working on recently... actually communicating my opinions and the things that I need; stuff like that with the group... which is helping my motivation also because if I feel like I’m part of the group, then I’m more motivated to contribute and do stuff for the group.

Interview Question: So how did the assignment make you think about it?

Student: Reflection is always hard to do on yourself. I guess it made me say ‘Am I really doing that?’ Why am I not doing that?’ and it pointed toward communication more. Because it was like ‘I’m not participating really well with the team,’ like at team meetings and stuff, and not necessarily voicing my opinions, and I’m not telling other
people what I’m thinking. And that’s causing me to... but I feel like if I just started communicating my opinions more, these other things would just start falling into place as a result of communicating.... I realized that, first, that I wasn’t... like I, at the time, I needed to figure out how to buy the stuff for making bio-diesel. But I hadn’t really told anybody that that was the stage I was at and that I needed to do that. And so I wasn’t really moving forward in my project. So I was like ‘Why am I not moving forward?’ It’s not because I’m lazy. It’s more because I just don’t know how to do this stuff. I need to communicate this with my team members what it is that I need.

Interview Question: So what was the effect of this for you?

Student: I was grumpy at the team. Because, obviously, if I’m not communicating what I think, they’re not gonna be listening to my ideas. So I was frustrated. I didn’t feel like I was really part of the team. But it wasn’t really the team’s fault. It was my fault for not really communicating. I started communicating more now. I’ve started speaking up and team meetings are now kind of more enjoyable because people listen to me; they listen to my opinions. Sometimes I have good opinions, sometimes I have bad opinions. But it’s more like I’m part of the team; and I wasn’t before. I was more like a bystander watching everyone else. And it made me feel grumpy towards the team; almost like having a grudge on them for not including me. And also it made me not want to do the project.
Interview Question: So what did the assignment do?

Student: Reflecting on it made me realize that I could take control of that. Like, I shouldn’t be saying ‘Oh, it’s all the team’s fault.’ It could be my fault too. And so I should do everything I can to make sure it’s not my fault. And then, like, if I start doing everything that I say I’m not doing right now and I still feel that way, then I should… ‘Okay, now I can definitely blame you guys.’

Interview Question: Any changes so far?

Student: [before] no one was assigning me projects and I was like ‘people should assign me projects to do; I don’t feel like I’m doing anything.’ But now I’m like, ‘Okay, I can do that’ [in a proactive way with the team]. And I feel more included in the team. I’m volunteering to things as opposed to people telling me ‘you should do that.’

This case includes several conceptual aspects of reflection from the models described above. First, this student noticed a problem: she was not part of the team and was getting frustrated because of it. The course reflective assessment prompted her to address it more deeply and caused her to narrow down the root of the problem, which was her lack of communicating: “…and it pointed toward communication more. Because it was like ‘I’m not participating really well with the team,’ like at team meetings and stuff, and not necessarily voicing my opinions, and I’m not telling other people what I’m thinking...”
Second, as she addressed it, she whole-heartedly tried to determine why she was not communicating by asking herself “Am I really doing that?... Why am I not doing that?... Why am I not moving forward?” This represents a significant aspect of learning, according to Mezirow, as she was trying to find meaning in her actions and thoughts through this analysis. This also corresponds to step two of Schön’s model of reflection-in-action: “Reflecting on the surprise event and the knowing-in-action which led up to the surprise. Questioning ‘What is this?’ and ‘How have I been thinking about it?’ Iterating between the surprise and the thinking leading up to the surprise.”

This student’s reflection also appears to include the aspect of validating one’s beliefs, as described in Dewey’s and Mezirow’s definition of reflection, as well as step four of Schön’s reflection-in-action model regarding “on-the-spot experimentation in order to think up and try out new actions intended to explore the newly observed phenomena, testing tentative understandings of them or affirming the moves invented to change things for the better.” The following passage illustrates these concepts (restated from above):

Student: Reflecting on it made me realize that I could take control of that. Like, I shouldn’t be saying ‘Oh, it’s all the team’s fault.’ It could be my fault too. And so I should do everything I can to make sure it’s not my fault. And then, like, if I start doing everything that I say I’m not doing right now and I still feel that way, then I should... ‘Okay, now I can definitely blame you guys.’
Here, the student acknowledges her fault and has made a plan of action for improvement. She believes that her changes will improve the situation and had noted that she is testing her idea and plan.

Overall, this student was found to be the most reflective of the participants. In terms of the conceptual models of reflection, she diligently tried to determine the why of her actions, thought through a plan of action (i.e., through virtual pre-testing of alternative plans), set a course of action with plans to reevaluate, or validate, this thinking later on. She stressed the success of her actions at that point and had obviously learned a great deal as a result of her reflections on the experience.

Example #3: Participation

Participation was a dominant topic in both teams. Interviewees often discussed problems with participation, but usually did not indicate that they had reflected on the issue to any great degree. An exception was a student on Team A who was very much committed to the project and team, but felt only he and two or three others were contributing. His comment from above is restated below with follow-up questions and responses related to his reflections on the issue.

Student: I’d say three of us do the majority of the work, out of nine.... Like, we’re treating this as a job, right; that’s what we’ve decided to do. And you can tell who’s really passionate about the project and who’s not, just based on who shows up to the meetings and how much work they put in and how adamant they are about the idea.

Interview Question: So what do you think of these types of teamwork issues?
Student: I get mad at them, frustrated. If it were an actual company, and we were running it, they’d just receive less shares, or something like that...

Interview Question: So how do you think through these things?

Student: Spur of the moment. I talk to my roommate about it… and we just talk about our groups, and we compare them. We just complain. He complains about [his group], how crappy they’re doing, and I just complain about what group members are slacking, or, you know... I just convey... like... ‘Is it sensible to be thinking this way?’ and then just get another person’s input on it.

Interview Question: Just to make sure you’re not overreacting?

Student: Yea, yea... good to have a talking board.

In this passage, and particularly in his comment “Is it sensible to be thinking this way?” the student indicated great reflective thinking. He obviously had an opinion of his teammates and wanted to validate those beliefs by member checking with his roommate. This also indicates that the student was trying to interpret his teammates’ actions and, therefore, to make some meaning from the situation. This reflection was not a result of a prompted assessment and so indicates a self-reflective disposition on the student’s part. One reason for this may be due to the student’s whole-hearted commitment to the project’s goals; he was very enthusiastic in helping others...
through a successful project. The student also went on to mention his plan of action, which was addressing the issue with the team and demanding greater participation. He mentioned that in coming up with his planned actions that they were “spur of the moment,” representing little reflection: no deliberation regarding potential impacts or repercussions (e.g., resentment from teammates, decreased commitment, etc.). Therefore, while the student could be thought of as motivated to reflect, he did not reflect as thoroughly as suggested by the models of reflection. Schön’s model, for example, includes virtual hypothesizing and testing alternative ideas, which this student did not do.

*Example #4: Coordination*

Ill-planned team meetings were a major cause of team problems during the first semester. This could be expected since students are not experienced in planning or conducting meetings. Toward the end of the first semester, both teams began organizing meetings much better by defining detailed agendas with timeframes and member roles. Students all expressed frustration at the initial meetings, often citing that they were a waste of time, but few discussed any significant reflection on the issue. One student did mention that, when discussing the situation with the team, he drew on past experiences with internships to recommend a new approach, which he said was helpful to the team. This *looking back* is one step in reflection and the student obviously was clarifying the problem and making associations between the current situation and what he knew was a better approach.

The second issue concerning coordination was the lack of clarity of member roles and responsibilities. This again can be expected with students who are inexperienced and have only limited practical knowledge in design. In gaining a better understanding of their team’s goals and
the specifics of each subsystem of the design, the teams eventually came to a better understanding of the roles and tasks for each member, similar to the situation with team meetings. Leading up to this, though, students became very frustrated with their lack of productivity and organization. One student’s comment on this was (from above) “…I felt that I wasn’t contributing anything to the group because I didn’t know what I was supposed to be researching or what I was supposed to be doing. I was just going in there and kind of feeling like a 9th wheel”. Most students echoed a similar type of frustration regarding this issue. Both teams seemed to flounder for part of the first semester, which, as stated, may not be unusual for inexperienced students. Without any past experiences which would draw attention to their current errors in management, students often did not know what the problems were. For this issue of unclear roles and responsibilities, the prompt for reflection and eventual solution for both teams was a course administered reflective assessment which specifically related to this issue.

Example #5: Attitude

Following up on the Attitude team issue discussed in the previous section, regarding differences in opinion of the value of a concept evaluation matrix, the inter-personal problems between team members resulted in reflections from several individuals. Soon after the situation, the team completed a prompted reflective assessment in the course. The assessment asked each member to write about a strength and weakness of each team member. For the student who opposed the matrix idea, the consensus from her teammates was that, although correct in her views, her tone was abrasive and that she doesn’t listen to the ideas of others. Discussing this in the interview, this student responded to their claims as follows:
**Student:** They were kind of right. After I read that [feedback from the TIDEE assessment] I started thinking ‘Have I really done that?’ and *I started thinking* about ideas that other people have come up with and I’d be like ‘that won’t work because of …’ and so *I realized* I really have been doing that.

The student questioning herself with “*Have I really done that?*” and the comments “*I started thinking...*” and “*I realized...*” show that she was attempting to clarify the situation and that she was trying to validate their beliefs, both elements in the reflection models of Dewey, Schön, Mezirow, Moon, and others. The student did indicate that she learned from this experience, which was that she should “*use more tact*” when dealing with others. In describing this reflection, the student did not mention that she was trying to find meaning in the experience—for example, meaning with respect to personality, background, etc. She simply stated that she realized she could have done a better job in her communications.

*Example 6: Monitoring*

Most of the instances of monitoring which led to team improvements resulted from the prompted assessments in the course (i.e., the four TIDEE teamwork assessments). These assessments guided the teams in becoming aware of their problems by requiring the students to reflect on their current teaming performance. In doing so, the students were asked to review a list of twelve common performance factors related to teamwork and to then write short essays about two—one related to an area of strength and another related to an area in which they felt their performance could be improved. Prior to the assessments, students described particular instances
of problems but did not appear to know or think about the overall nature of the issue or its
genral relation to teamwork (as found through the series of individual interviews with each
student). That is, they may have noticed low participation or little progress, but typically did not
understand that the underlying reasons were due to unshared values or lack of clarity in roles or
responsibilities. The assessments caused students to identify and label their problems more
abstractly into the general performance factors given and then to think critically about potential
causes and solutions. The following cases illustrate this.

Student: When we did the TIDEE work [the Team Member Citizenship assessment], when
we had to say an improvement, we all said the same thing, which was defining roles
and communicating that more effectively.... At the next meeting we all sat down and
we’re like ‘yea, we need to do something about that.’

The team then brainstormed as a group and defined exactly what each member would do
and how they would distribute the work for the remainder of the project. In another case, after
completing one of the course assessments, Team A realized that they needed to better clarify the
problem and stakeholders before continuing on to generating concepts.

Student: We kind of jumped the gun and started designing before we even defined our
problem and knew what the stakeholders wanted and what the needs are. And so we
kind of backtracked a little and then created that. So then we thought ‘Oh, we should
talk to [their sponsor]’. We were so overwhelmed we needed some kind of track to
follow, and then we kind of regrouped and realized that we need to stop and make specifications and start thinking about the criteria that we need to meet.

Students indicated that the TIDEE assessments helped lead them in this direction. Several other members from both teams also described similar instances where “they were up against a wall” until prompted with the guided reflective assessments.

DISCUSSION AND ANALYSIS

The previous section presented examples of student reflections with their relations to existing conceptualizations of reflection. This section will discuss the applicability of the existing concepts of reflection to the reflective practices of capstone students from this study. To do so, the reflective models from the literature have first been compiled and synthesized into a loose set of six processes: realization, clarification, analysis, synthesis, validation, and new perspective. This compilation and synthesis is given in Table 11; greater description for each item is given in the Appendix. This synthesis (based on interpretations of the given authors’ work) provides a concise way to compare and contrast the different models with respect to student reflections. The remainder of this section is a discussion of these six process steps and how they are represented in the data collected over the course of this study.

Realization

Realization refers to noticing or becoming aware of troubling or contrasting issues or ideas and is the first step in the reflective process. Dewey describes this as a “felt difficulty.”
Schön states that reflection is prompted by a surprise event; something that contrasts with our expectations. The following issues relate to the concept of realization for students in this study.

Table 11. Compilation and synthesis of existing conceptions/models of reflection

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<td>Hypothesizing possible solutions</td>
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<td>Validation of conjectural idea through testing of hypotheses</td>
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<td><strong>New Perspective</strong> (non-specific; foundational)</td>
<td>Appropriation to make knowledge one’s own</td>
<td>Transformative learning</td>
<td>Critical reflection by challenging validity of premises; paradigm shift</td>
<td>Self-reflection on nature of knowing or metacognition on the way knowledge works</td>
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a Adapted from Mann, Gordon, & MacLeod (2009, p. 598)
b Adapted from Thorpe (2004, p. 329)
Prompts for Reflection. While there was ample opportunity for reflection, based on stated felt difficulties or surprises concerning experiences and/or ideas, students were found to not reflect on the issues much until prompted by course assignments (as best as can be interpreted from interview discussions). Students certainly thought back on teaming and other issues throughout their project, but for major teamwork challenges reported by them, the prompt to reflect on the issue, as well as the guidance for working towards a solution, was due to course assessments.

Motivation and Dispositions. Most students did not appear to be motivated to reflect on their experiences. Those who were motivated could generally be described as having above average enthusiasm for their project and/or the course. Students who showed no indication of reflection, or who saw no value in reflecting, most often were those who were very discouraged by their project or were motivated by other factors, such as job opportunities. Overall, the most reflective students were those who had whole-hearted dispositions regarding personal growth, though only a couple students out of the thirteen could potentially be classified as such. As a group, the engineering students viewed reflection as a “soft” skill only marginally needed for engineers. That is, it appeared that mastery of engineering content was thought to be the highest priority of students, whereas professional skills such as teamwork and reflection were given little value. This notion seemed to be based on their interpretation of industry needs. Conversely, business students all seemed to place more importance on the practice of teamwork for their future careers; although, this difference between the two groups (engineers and business students) did not appear to result in different reflective practices. In terms of instructor prompted reflective assessments, most students described a benefit from their use, although, on the other hand, most still were opposed to the additional coursework.
Purpose for Reflecting. As mentioned, reflections were often a result of instructor prompts, and so the purposes for reflecting generally aligned with the goal of the assessment. In terms of teamwork issues, the most common topics were found to be related to member roles and responsibilities, team goals and organization, and communication issues. With respect to the two primary goals for reflection, for learning and improving practice, most reflections were found to relate to practice—reflecting for the purpose of affecting a situation or action. Few reflections were found to be for the sake of learning exclusively. In terms of the models of reflection, this may best be described by Schön’s model of reflection-in-action, as opposed to reflection-on-action.

The implication of this concept of realization is significant in terms of lifelong and self-directed learning. To be self-directed learners, practitioners should recognize the importance of addressing surprises and felt difficulties early so as not to flounder for significant lengths of time, as students in this study did prior to prompted reflections. That is, while the models speak to the impetus for reflection, no mention is made regarding the need to teach students to take action on surprises, difficulties, or contrasting ideas. The reasons for students’ lack of initiative, overall, may in fact be based on their motivations for the class and project, their dispositions for learning, and their knowledge of teaming concepts. These issues concerning realization may represent areas to address with students in order to improve their reflective practice and to promote concepts for self-directed learning.

Clarification

Clarification refers to clarifying the events and thinking leading up to or surrounding an issue; e.g., recalling situational events, facts, and thoughts. Schön describes this as thinking
about the surprise event and the thinking leading to the surprise and iterating back and forth between the surprise and thinking (asking *What is this?* and *How have I been thinking?*). Some students discussed instances of clarification. From Example #3 above on participation, the student mentioned that he often discussed teaming issues with his roommate, comparing and complaining about their two groups. Through these discussions, teaming issues were certainly clarified to the teammate. This student also mentioned that he discussed this same issue with one other team member. This latter discussion was short with little stated clarification on the root of the problem. A solution was negotiated “*spur of the moment,*” as he said.

As with the prompt for realization, the course assessments were found to cause students to clarify their teaming problems most often as the assessment required them to first describe an issue. From Example #5 above on attitude, the student describes his reflection after receiving the feedback from his teammates: “*I started thinking ‘Have I really done that?’*” and, “*I started thinking about ideas that other people have come up with...*” and finally, “*I realized that I really have been doing that.*” These comments indicate that this student was clarifying and validating the feedback given to him by his teammates, including his thinking regarding the issue which he was unaware of prior to the assessment.

As a general observation concerning the process of clarification during students’ reflections, it appeared that, while there were exceptions, many students did not attempt to clarify the problem or their thinking surrounding it. The process does appear, though, to be valuable for those who did so.

*Analysis*
As seen in Table 11, the analytical phase of reflection is multifaceted and can be articulated many ways. Schön suggests that it is somewhat of a meta-analysis, or thinking on the thinking leading to a surprise. As stated in the model of Boud et al., this analysis may involve associating new ideas or knowledge to a current problem. The models of Moon and van Manen indicate that it is to be a process of making sense of or understanding the problem. However defined, it seems that critical analysis is a logical step in the progression from a “realization” to a “new perspective.” However, there is not a full consensus in the literature that this is the case. Some scholars have argued that new perspectives are gained through a more intuitive, as opposed to a rational, process. This argument will be given more attention in the New Perspective section below.

From the student Example #2 above concerning personal communication, the student made several references to critical thinking: “Am I really doing that?... Why am I not doing that?... It could be my fault too.” These comments indicate the student was trying to make sense and find meaning by analyzing the problem, through questioning her actions and thoughts. The student did not indicate that she deliberately questioned her thinking on the thinking leading up to the problem, but her self-reflection of “Why am I not doing that?” may be just that. That is, clarification may be seen as the what of one’s thinking (What was I thinking?) whereas analysis may be seed as the how or why (Why was I thinking that?), as in this case. The key to this reflection, which was noted as a good example, seems to be in the prompted why questions.

Overall, most student accounts of their self-directed reflections did not include analysis of their problems. The TIDEE assessments did prompt students to analyze an issue, but it appears that lack of motivation and predetermined dispositions highly affected their efforts.
Most models of reflection suggest an element of synthesis during reflection. As compiled in Table 11, this refers to making meaning of an issue as well as a plan to move forward. Schön states this as restructuring strategies of action and understandings. Integrating relationships, included in the model of Boud et al., can be seen as the synthesis of external information for the purpose of making meaning. Mezirow’s model includes the task of interpretation to make meaning/understanding. Dewey’s model includes the process of generating hypotheses of possible solutions—e.g., suppositions, conjectures, guesses, hypotheses, theories of a variety of alternative suggestions. The category label of Synthesis fits with these ideas as one is building upon earlier stages of clarification and analysis in order to move toward a proposed solution, which is then validated during the next reflective step.

As mentioned above, Example #2 on communication gives an instance of a student trying to make meaning and move forward. She clarified and analyzed the issue, made hypotheses as to the cause by interpreting her actions, thoughts, and emotions, as well as those of others (assigning cause to her lack of motivation and effort to engage others and communicate), and then suggested a plan forward: explicit goals for how and when she would communicate.

Several others examples above illustrate instances where individuals and teams as a whole made corrections to a teaming problem. In Example #1 above, one student’s comment was “We were so overwhelmed we needed some kind of track to follow, and then we kind of regrouped and realized that we need to stop and make specifications and start thinking about the criteria that we need to meet.” This resolution was prompted and directed by a course assignment and, after hearing from several perspectives on this issue, it is not clear if students
attempted to make meaning from this. For example, no student discussed their interpretation of the meaning of the issue, although, in following up further with students on this, some did describe this as a teaming issue they had learned from, which related to the importance of assigning clear roles and responsibilities. It could be that students had not consciously assigned meaning to this prior to the interview. That is, when asked what they had learned as a result of the experience, most students appeared to be thinking of this for the first time.

**Validation**

Validation was found to be an important and explicit aspect of reflection for each of the authors whose models are referenced in Table 1. Validation refers to the verification, or corroboration, of one’s beliefs resulting from the prior reflective steps of clarification, analysis, and synthesis.

Instances of students validating their beliefs are given in the examples above. One particular case included a student member checking his beliefs about his teammates with his roommate: “Is it sensible to be thinking this way?” This student was validating his belief by reviewing his situation and his thoughts and actions and then questioning his concluding thoughts based on these—all with an outside perspective. Another instance was found from the student who validated and accepted constructive feedback from his team.

The course assessments in which students critiqued their teammates on teaming issues appeared to prompt the most validation as students seemed to want to rebuff the critiques or to justify them at times. As mentioned, several students indicated that this feedback from teammates resulted in a new perspective with regard to the issue (e.g., one student learned of the need to be more “tactful” and open-minded when communicating, as discussed above). This was
likely not the case for all students, as a conclusion based on student discussions. The most likely, and obvious, reason could be related back to motivation and dispositions.

New Perspective

This category refers to the gaining of a new perspective as a result of the experience and reflection on it. Several students discussed what they had learned from participating in the project. Examples include: the importance of roles, team communication, inter-personal communication, approachability, and organization. In terms of changed perspectives, one student stated his initial view of teamwork as follows:

Student: [I thought teamwork was] everyone just doing their [own] work. As long as everybody does what they're supposed to do, it should be easy.

This student also admitted that his initial thoughts on project success were similar to that of teamwork: as long as all members complete their assigned tasks, there should be no problems and the project should succeed as expected. Near the completion of the project, this student indicated that he realized the difficulty of teamwork and its importance to a project’s success. He discussed the critical role of dynamics and the ease in which it can change and negatively impact a team’s performance, motivation, and commitment. This represented a new perspective gained by the student due to the capstone project: his belief in what teamwork was and its importance were changed and he was quite aware of this. It’s not known to what degree, if any, this student reflected on this issue.
Other students with somewhat similar initial thoughts on teamwork as the student above also indicated lessons learned about teamwork through the capstone project, as indicated with the following comments.

*Student 1:* …a common language among team members. Business people don’t use the same terms as engineers…. One thing I’ll take with [me] is that when you talk to other people, make sure you talk to them in a language that they’re familiar with; don’t dumb down the language but just make sure you talk to them in a manner in which they can understand you fully so that you can get your idea across. You can’t use all this technical jargon and expect [other disciplines] to understand.

*Student 2:* Teamwork takes work. It doesn’t just happen.

*Student 3:* Teamwork requires an open mind

*Student 4:* …to define the scope up front.

In terms of the models in Table 11, a new perspective results in a change in one’s foundational beliefs regarding a concept, typically through challenging the validity of one’s premises (also called critical reflection), as defined by Mezirow (1991). It was clear from discussions with students that some had a changed perspective as a result of the project. It’s not clear, though, if students openly and consciously questioned or invalidated their original beliefs, or, if instead, their responses were the result of “on-the-spot” analysis to the interview question.
Some authors have questioned Mezirow’s theory regarding perspective transformation and the role of critical reflection, with particular contention with the emphasis on rationality. Taylor (1998) stated that “critical reflection is granted too much importance in a perspective transformation,” suggesting that critical reflection is “too rationally driven” (p. 33-34). Another view of transformative learning is that it is an “intuitive, creative, emotional process” (Grabov, 1997, p. 90). As stated, it’s not known whether students’ new perspectives were rationally derived or subconscious, but many did, in fact, learn a great deal about teamwork through their experience. As an element in the reflective process, the implication of this question on rationality pertains to teaching and assessing reflection for project learning and lifelong, self-directed learning. Teaching students to challenge the validity of premises, or to reflect on the nature of their knowledge, as defined by van Manen (1991), could at least provide some direction in transferring what was learned to a broader context.

SUMMARY

The goal of this study was to describe the teamwork-related reflective practices of students within a capstone course. In doing so, elements of teamwork common to engineering design teams were first defined and examples of student accounts for each were then presented. Next, student accounts of their reflections on teaming issues were discussed in the context of these general categories of teamwork. Lastly, common conceptions of reflection, from broad definitions to theorized models, were then analyzed and discussed explicitly with respect to the student reflections. The comparative analysis was intended to determine the degree in which existing models applied to students’ reflective practices. The motivation for this study is in developing pedagogical resources, such as assessment instruments and learning modules, which
facilitate reflection for learning and professional practice. The following are summarizations of the existing models of reflection and their congruence with student reflections and of the reflective practices of students participating in this study.

**Existing Models of Reflection**

The models chosen for analysis in this study, presented in Table 11 and the Appendix, were selected because of their emphasis in depicting the cognitive processes involved in reflection, important for the teaching and learning goal of the study. As a first step in the comparative analysis of reflective models to student accounts, the models were analyzed for general commonalities. Six categories were found to represent all of the models quite well and included the following: realization, clarification, analysis, synthesis, validation, and new perspective. This synthesis of the models provided an effective way to visualize and compare each model with respect to the others and to the student reflections.

One disparity found with the models, conceptually, is the different purposes intended by the authors. The models of Dewey and Schön appear to emphasize practice, as can be seen by their references to “a surprise” and “a difficulty,” as well as with the elements involving the generation of alternative suggestions and solutions. The other models seem to stress reflection for learning as indicated by their stronger references to understanding and meaning. Mezirow states that reflection is for both purposes, which he defines as correcting distortions in beliefs and correcting errors in problem solving. For the capstone course, both of these purposes are important as reflection is intended to help students and teams improve their immediate performance as well as facilitate learning of teaming and design skills and knowledge. For either case, the *process* of reflection can be found to be that of validating beliefs—as defined explicitly
by Mezirow and Dewey. The other models of reflection in Table 11 can also be seen to include the concept of validation of one’s belief as the central function.

Each of the models was found to include elements corresponding to student reflections, although none could independently represent student reflections completely. That is, no model included all six of the derived categories. The overall intention of each author, though, was that reflection is the process of making meaning of an issue or idea followed by validation of the final belief. Each author tended to define these reflection steps, or, as termed above, to operationalize reflection, slightly different. The comparing and contrasting of each model in light of the six categories allowed for a wider perspective on the meaning of each category, which, in turn, helped in defining and describing student reflections. With the exception of Dewey and Schön, each author also included the sixth step regarding a new perspective of some sort. The exclusion of this element by Dewey and Schön appears to be due to the problem-based nature of their model, as opposed to reflection for learning. The six categories derived from the models are summarized in Table 12 below.

**Reflective Practices of Capstone Design Students**

Evidence of student reflection was found for each of the six categories of reflection above. Students were found to realize problematic teamwork issues, clarify and define them, analyze the issue and their thinking regarding them, integrate additional information and organize their thoughts, make suggestions for paths forward (in both actions and beliefs), validate their resulting beliefs, and reach new perspectives concerning the importance of teamwork. No student described a reflection that incorporated all six of these categories, though. Additionally, as an informal, holistic evaluation of the quality of students’ reflective practice, it
Table 12. Categories of reflection

<table>
<thead>
<tr>
<th>Reflection Process Category and Definition</th>
<th>Example Reflective Questions</th>
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<tbody>
<tr>
<td><strong>Realization</strong></td>
<td></td>
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<tr>
<td>Becoming aware of a troubling situation or a contrasting idea or belief and realizing the need to reflect.</td>
<td>What are the symptoms? (ex. a discomfort; a perplexing idea)</td>
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<tr>
<td><strong>Clarification</strong></td>
<td></td>
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<tr>
<td>Reviewing the problem or contrasting belief; recalling one’s beliefs or thinking leading to issue.</td>
<td>What is the problem? What or how was I thinking about it before?</td>
</tr>
<tr>
<td><strong>Analysis</strong></td>
<td></td>
</tr>
<tr>
<td>Critiquing beliefs, thoughts, actions; drawing on experience, knowledge, and the perspectives of others; searching for root causes of problem or contrasting belief; making sense of the problem/belief.</td>
<td>Why was I thinking that? How do I know what I know?</td>
</tr>
<tr>
<td><strong>Synthesis</strong></td>
<td></td>
</tr>
<tr>
<td>Making meaning of the problem or belief by developing conjectures, hypotheses, conclusions, and/or paths forward using available understandings and information.</td>
<td>What does this mean? How should I proceed/believe?</td>
</tr>
<tr>
<td><strong>Validation</strong></td>
<td></td>
</tr>
<tr>
<td>Virtually testing conjectures, new beliefs.</td>
<td>Is this solution/belief correct? What evidence supports this?</td>
</tr>
<tr>
<td><strong>New perspective</strong></td>
<td></td>
</tr>
<tr>
<td>Shift in paradigm by questioning underlying fundamentals/theories. Viewing issue/concept fundamentally different; associating it to larger context.</td>
<td>What have I learned as a result of this? Were the theories used appropriate? How does this apply more generally?</td>
</tr>
</tbody>
</table>

could be argued that students generally reflected at a low level on their own. That is, most accounts of student reflections could be found to include only a few of the six elements, and, in some cases, only one. A general conclusion may be that students often did not analyze their thoughts prior to making moves forward; for example, when making major decisions to “fix” a teaming issue. This conclusion can also be extended to the category of validation; students rarely attempted to validate their concluding beliefs regarding a teamwork lesson learned.

Prompted reflections, through course assessments, did appear to walk students through some of the reflection categories/steps. Most often, this was found to include the processes of realizing a troubling teamwork situation, clarifying the issue, and suggesting moves forward. Students who were motivated to develop their skills and knowledge were found to reflect greater
as a result of the prompted course assessments. That is, these students continued to reflect on the issue they had discussed in the assessment even after the assignment was submitted and they were found to include additional categories in their reflection, such as analysis of their thoughts leading to an issue and validation of their final beliefs.

One further conclusion regarding student reflections is that, most often, students did not appear to know to address issues that were troubling to them or which contrasted with their beliefs. Students and teams appeared to flounder until prompted to reflect on the issue through course assessments.

RECOMMENDATIONS

The six categories presented in Table 12 represent suggested reflective process steps for students to apply during their capstone design team project. The hypothesis is that by teaching students the philosophy and process of reflection (e.g., goals, direction, and process steps/categories), students will be more likely to reflect more often and at a greater level: incorporating more steps and toward validating beliefs and learning. In addition to teaching students the knowledge and concepts of reflection, it is also important to address the dispositions needed, such as open-mindedness and whole-heartedness. Further, a key may be in instructing students to know to use this reflective process when encountering a novel problem or contrasting belief—analogous to teaching students to use the engineering design process when encountering a design problem. Knowing to reflect and how to reflect would appear to be important concepts in self-directed learning.

A next step would be to test this suggested reflective process and teaching strategy in the classroom. Will this facilitate student engagement and learning regarding teamwork or other
design areas? To what extent do student motivations and dispositions concerning “soft” skills affect their propensity to engage in reflection? Further study could address questions such as these, seeking validation and curricular implications of the reflective process determined by this study.

ACKNOWLEDGEMENTS

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REFERENCES


APPENDIX

Appendix A. Models of Reflection

Table A1. Existing Models of Reflection from Literature

<table>
<thead>
<tr>
<th>Dewey (1933)</th>
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<tbody>
<tr>
<td>1. [Problem/Awareness] a felt difficulty (a problem, perplexity, hesitation, doubt, possibly as a shock)</td>
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<tr>
<td>2. [Definition] its location and definition (clear understanding of the problem)</td>
</tr>
<tr>
<td>3. [Hypothesis/Suggestion] suggestion of possible solution (supposition, conjecture, guess, hypothesis, theory, cultivation of a variety of alternative suggestions)</td>
</tr>
<tr>
<td>4. [Reasoning about Implications] 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)</td>
</tr>
<tr>
<td>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)</td>
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<table>
<thead>
<tr>
<th>Schön (1987)</th>
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<tbody>
<tr>
<td>1. Realizing a surprise during a task</td>
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<tr>
<td>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</td>
</tr>
<tr>
<td>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</td>
</tr>
<tr>
<td>4. On-the-spot experimentation… in order to think up and try out new actions intended to explore the newly observed phenomena, testing tentative understandings of them, or affirming the moves invented to change things for the better</td>
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<table>
<thead>
<tr>
<th>Boud et al. (1985)a</th>
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<tbody>
<tr>
<td>1. Returning to experience</td>
</tr>
<tr>
<td>2. Attending to feeling</td>
</tr>
<tr>
<td>3. Reevaluation of experience</td>
</tr>
<tr>
<td>4. Outcome / Resolution</td>
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<table>
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<tr>
<th>Thorpe (2004)b</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Awareness</td>
</tr>
<tr>
<td>2. Critical analysis</td>
</tr>
<tr>
<td>3. New perspective</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mezirow (1991)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Habitual action</td>
</tr>
<tr>
<td>2. Thoughtful action / Understanding</td>
</tr>
<tr>
<td>3. Reflection: interpretation to make meaning; understanding what is meant validating ideas</td>
</tr>
<tr>
<td>4. Critical reflection: challenging validity of ideas / presuppositions (premise reflection: to</td>
</tr>
</tbody>
</table>
validate premises); challenging established definition of problem; paradigm shift; reassessing the way the problem is posed and our orientation to perceiving, knowing, believing, feeling, acting

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)

Moon (1999)b
1. Noticing
2. Making sense
3. Making meaning
4. Working with meaning
5. Transformative learning

a Adapted from Mann, Gordon, & MacLeod (2009, p. 598)
b Adapted from Thorpe (2004, p. 329)
Chapter 6

Summary, Conclusions, and Recommendations

SUMMARY

In chapter two, an assessment structure and methodology was presented for assessing outcomes related to engineering design processes and solution assets for capstone design courses. The methodology is a suggested process for developing assessments and includes defining (1) the purposes for assessment, (2) the performance targets, (3) methods for observing student performance, and (4) a means for scoring and making interpretations of student performance. The structure is a framework for assessment implementation in the capstone course for assessments related to design processes and solution assets (important design products generated throughout a design project).

The structure developed in this study was based on three design phases common to all engineering disciplines: a problem scoping phase, a concept generation phase, and a solution realization phase. The three selected phases were synthesized from a literature review of several texts, journal articles, and conference proceedings applicable to multidisciplinary student capstone courses. The assessment structure establishes a comprehensive, yet practical, timeframe for assessing design skills and knowledge applicable to the corresponding design phase. A total of six assessments are outlined—three formative and three summative. The three formative assessments include Problem Scoping Processes, Concept Generation, and Solution Realization. The three summative are the Defined Problem, Selected Concept, and Proposed Solution assessments. The three formative assessments are intended to be implemented mid-phase, each
corresponding to the appropriate design phase. Likewise, the summative assessments are intended to be implemented at the end of each design phase, and again, as applicable to the design phase.

The rationale for this suggested structure is based on the need for both formative and summative assessment in teaching and learning. The formative assessments allow instructors to see how students and teams are performing in terms of design processes. The mid-phase implementation timing is optimal (versus beginning of phase or end of phase) since this gives students and teams time to get engaged in the design activities associated with that particular phase. As students are often inexperienced with design and design teamwork, problems and misunderstandings will likely surface by mid-phase, allowing instructors time to offer constructive feedback. Student engagement in problematic situations is ideal for fostering critical and reflective thinking (as opposed to following precise instruction, with no reflective experiences), as well as constructive feedback following this independent thinking and reflection. The mid-phase timing then allows for revisions and/or improvements to be made to design processes prior to moving on to the next phase. This approach of continuous and relevant assessment is intended to minimize the “bottlenecking” that occurs with student projects toward the end of their course. As a result of continuous assessment and improvements, it is hoped that students will be more effective and efficient, resulting in more time spent on a wider array of design tasks, and therefore learning more and gaining more design experience (i.e., mishaps and “bottlenecking” reduce or even eliminate involvement in other design activities, decreasing learning experiences).

The three summative assessments provide the opportunity for students to gain experience producing real design project deliverables: specifications, concept reports and presentations, final
formal reports, etc. Instructors can document the deliverables, or assets, for program assessment needs, as well as use the opportunity to provide formative feedback to students.

TIDEE’s assessments are intended to be used within multiple engineering disciplines, such as mechanical, civil, electrical, bioengineering, general engineering, and others. Therefore, transferability and generalizability are important features. The structure described has been developed with this goal in mind and the three-phase system should prove to be general enough for all traditional disciplines as well as detailed enough to effectively assess required outcomes.

Chapter four presented a study on the inter-rater agreement (IRA) of seven TIDEE assessments: Team Member Citizenship, Team Processes, Team Contract, Growth Planning, Growth Progress, Growth Achieved, and Professional Practices. Two faculty and two teaching assistants scored samples of student work from each assessment. Each rater was given rater training prior to scoring student work, which consisted of Frame-of-reference training and Rater-Error training. Results from the IRA study are intended to serve as evidence for validity (as reliability is required for validity) as well as to suggest areas for improvement.

Chapter three and five presented a study on the reflective practices of engineering capstone design students with regards to teamwork. An understanding of how students do and should reflect on experiences is significant as it is often stressed as a key to learning (Dewey, 1933; Gagnon & Michelle, 2006; Kolb, 1984; Mezirow, 1985; Moon, 1999; Seibert & Daudelin, 1999; Thorpe, 2004). As the capstone course is intended to provide semi-authentic design experience to students prior to professional practice, plenty of opportunities arise for students to engage in reflection for learning. A challenge often discussed in the literature on reflective thinking is that the process is not well defined or operationalized, providing little guidance on how students are to reflect—especially so in the context of engineering design and teamwork. To
provide a foundation for instruction and assessment on reflective practices, this study sought to describe the current reflective practices of engineering capstone students. Specific research questions were (1) What are the reflective practices of engineering capstone design students with respect to teamwork? and (2) How well do existing models of reflection represent the reflective practices of students?

To answer these questions, a qualitative research study was conducted. For research question one, participating individuals offered accounts of how they reflected on teamwork issues throughout their projects. For research question two, following a modified analytic induction approach, existing models and conceptions of reflection were used as initial hypotheses that were then verified and/or reformulated to fit the student data. Chapter five described student reflective practices in the context of teamwork elements common to capstone design experiences. Student reflections were also discussed with respect to reflective process steps from the literature. Conclusions for this study are presented in detail below.

Lastly, for this study a list of codes was generated from existing reflection models and concepts and can be found in Appendix A. Appendix B includes the contact summary sheets used for each data collection event, which is a guide for summarizing results following interviews, observations, and document reviews and a process common to qualitative research. Additionally, as this study includes work with human subjects, the Washington State University Institutional Review Board (IRB) was contacted and after review of the study, an exempt status was given to the research. The IRB memorandum stating this exemption status is given in Appendix C.

CONCLUSIONS
Assessment Structure and Methodology Study

The methodology for developing design-related assessments presented in chapter two was based on current assessment development practices suggested in the literature. The assessment structure presented was based on a review of the general objectives and outcomes related to design processes and products in multidisciplinary capstone courses. The combination of formative and summative assessments developed for this structure represent a suggested set that will benefit capstone students and instructors by allowing for constructive feedback at critical project milestones. It is also suggested that the timeframe of this assessment structure represents an effective learning cycle: students are provided constructive feedback, relevant to their current design processes, while in the midst of experiential learning activities. The summative assessments allow for the documentation of student achievement of professional knowledge and skills, as required by programs and ABET.

Inter-rater Agreement Study

The assessment structure and methodology are first steps in the assessment development process. The testing presented in chapter four represents one of the final steps in this process. Testing is needed to ascertain that assessment data collected and interpreted provide accurate and appropriate information relevant for the purpose(s) of the assessment. The results presented for seven TIDEE assessments suggest that all seven assessments have acceptable agreement for the purpose of formative assessment. Specifically, this is indicated with exact agreement percentages greater than or equal to what would be expected by chance alone, which was 20%. In addition, for the within-one-point criterion, all assessments were found to have agreement percentages around the 90-95% range, which is much higher than the statistical chance agreement of 52%.
For the Growth Achieved assessment, which is intended for summative use, the exact agreement was 40% for both faculty and teaching assistant (TA) raters and 90% within-one-point for both rater groups. Also for this assessment, Pearson’s correlation was found to be 0.36 for faculty and -0.06 for TAs. Since the Growth Achieved assessment is summative in nature, the above agreement values may suggest improvements are needed in order to ensure scores and interpretations accurately reflect student performance.

**Reflective Practices Study**

This section presents four main conclusions drawn from the reflective practices study. The conclusions support the goals and research questions for this study, as presented above.

**Conclusion One:** Two major purposes for reflection can be generalized as (1) to correct a problem—either immediate or long-term, and (2) to validate/invalidate a belief—either one’s own or those suggested by others. Schön (1983) coined the term *reflection-in-action* as reflection on immediate problems for the purpose of reaching an understanding of the problem and one’s thinking, leading to appropriate actions forward. Mezirow’s (1991) idea of instrumental learning is similar, which he states is to correct errors in problem solving. The idea of including *beliefs* as a purpose for reflection also follows from Mezirow, which he terms *communicative learning*, which is reflection to correct distortions in beliefs. In this study, it was found that students reflected on both problems and beliefs related to teamwork. For instance, a common teaming problem was found to be coordination of activities (e.g., meetings, work sessions). A long-term problem addressed by one student was that of personal communications with team members, in which this person described ongoing reflections for continual self-improvements. A teaming belief that many students reflected on was their belief in the meaning
and value of teamwork; several students came to a new understanding of what teamwork is and how it can affect their own performance and the performance of their project. The inclusion of both concepts is important for instructional purposes, so that students understand that reflection can be beneficial to their actions and in forming/reforming what they know (or hear) and how they came to that understanding.

**Conclusion Two: Engineering capstone design students do reflect on their teaming issues, but their reflections and reflective processes are not systematic and do not include each suggested cognitive process as defined by existing models of reflection.** From the models suggested in the literature, student reflections were found to include only a partial set of the steps proposed by the author. For instance, from Schön’s model, after encountering a problematic situation, students may have proposed a solution and action steps forward, but did not always attempt to clarify the situation fully or critically analyze their own thinking leading to the problem. This observation supports claims from the literature that the process of reflection is unclear and that people (students in this case) need clear direction on the purposes for reflection as well as clear process steps, operationalized to the specific context (Boud, Keogh, & Walker, 1985; Getliffe, 1996; Moon, 1999; Thorpe, 2004).

The existing models reviewed and included in this study were not found to represent the reflections of students completely. Each model appeared to drive toward the common goal of validating a belief or new idea (e.g., as with a proposed solution forward), but none could be used directly for instruction in capstone courses on how to reflect and for what purposes. From the several models and definitions/concepts of reflection reviewed for this study, a final suggested process has been synthesized which includes the processes relevant for the context of engineering capstone design courses and students. The six suggested process steps, or categories,
include realization, clarification, analysis, synthesis, validation, and new perspective. All accounts of student reflections included at least one process step from this list, although, as mentioned, no individual reflection was found to include all steps. It is suggested that the use of this set of reflective steps will enable students to reflect more systematically and completely, resulting in (1) deeper learning of teaming concepts (and likely other design-related concepts), (2) solutions to teaming problems that are more thoroughly planned and based on rationale decisions, and (3) perspectives of teaming concepts (i.e., their original or revised beliefs) that are tested and founded on solid reasoning.

As a final thought on the proposed set of six reflective process steps, this set, as well as each of the reflective models, may be taken as a hierarchical set of mental activities for reflecting. One exception may be with regard to the final step, new perspective, which may or may not be applicable for a particular reflection. Validation of one’s beliefs may be the final step, as no new perspective is made. The significance of this is in instructing students of the goal for reflecting, which is to validate beliefs and make moves forward in one’s thinking and actions, and not always to form entirely new perspectives.

**Conclusion Three: Informal evaluations from this study suggest that students may be considered to have low levels of reflective practice/thinking.** Overall, most students participating in this study gave accounts of little engagement in reflection. Most reflection accounts described only one or two reflective process steps. In addition, even with accounts of reflective processes considered higher-level (e.g., validation and new perspective), none were found to be based on all of the lower-level precursor processes. That is, students who attempted to validate an idea or proposed action plan usually did not indicate that they had given much
effort, if any, in truly clarifying root cause(s) of the problem/contrasting idea, or in analyzing their thoughts or drawing on external perspectives and knowledge prior to validation.

The conclusion that students’ reflections may be considered low level is based on apparent percentages of reflective activities relative to the full range of process steps, as with any of the models from the literature or the synthesis of these models presented in Table 12. As stated, this is an informal evaluation and no systematic study was conducted to this end. This conclusion, though, does align with other evaluations in the literature on the level of reflective thinking of students in design-related projects. Huyck, Bryant, and Ferguson (2009), for example, quantified the reflective thinking of students who were working on service learning projects. Using King and Kitchener’s Reflective Judgment Model (RJM), the authors indicated that students’ reflective thinking was, on average, between stages 3 and 4 on the RJM scale—between pre-reflection (no reflection) and quasi-reflection (some reflection). A similar study by Slivovsky et al. (2004) indicated the same results in which students’ reflective thinking levels were found to be between pre-reflective and quasi-reflective thinking, which are considered low levels of reflective thinking.

**Conclusion Four: While external prompting is helpful and necessary for getting students to engage in reflective thinking on teaming issues, open-minded and whole-hearted dispositions are most important for deeper and more effective reflections.** Students were found to self-reflect (taking initiative to reflect on issues) at times, but the most common cause for their reflection was external course prompts/assignments. Students may have in fact engaged in more reflections than what they had accounted for during interviews for this study, but most of the accounts described by them were a result of prompted course assignments. Additionally, many students specifically stated that they did not reflect on their own on teaming
issues unless required to do so by the course assignments. Therefore, it is logical to conclude that, even within the limitations of this study, most students do not engage in self-reflections. One factor for this, as suggested by several students, is that professional skills, such as teamwork and reflection, are not considered by them to be “real” or important skills or activities of engineers. In contrast, business students from the study were found to be more receptive to the idea of reflection and indicated that reflection was addressed in many other courses in their curriculum. This inclination for reflection expressed by business students, though, did not appear to correlate to deeper or higher frequencies of reflections than engineering students in this study.

Students who were found to gain the most from reflection—e.g., who learned considerably more relative to others through reflection—tended to engage in more of the reflection process steps indicated above and, most significantly, appeared to have whole-hearted and open-minded dispositions. As defined by Norton (1997, citing Dewey, 1933), open-mindedness refers to a willingness to consider other ideas and practices and whole-heartedness refers to the willingness to devote oneself physically, mentally, and emotionally. Open-mindedness is commonly stated as an important disposition needed for teamwork. As an example found during this study, one student, upon receiving constructive feedback from his team regarding his poor attitude, was quoted as saying “Have I really done that?” while reflecting on the team feedback. As a result of this open-mindedness, this student went on to make improvements to his attitude toward others and the team and described this incident as a significant learning experience, as described in chapter five.

A similar account was reported in chapter five for a student who was described as whole-hearted. In this case, the student, after prompted to improve on a professional development skill, went far beyond what was required from the course assignment and was found to engage in
several of the reflective process steps, through her own initiative. The outcome was very beneficial to the student, who expressed significant learning and insights regarding teamwork and communication as a result of the experience and reflections. Whole-heartedness and open-mindedness were found to be optimal dispositions for deep and effective reflection.

In summary, the reflective practices study with capstone design students gave insights into how students reflect and enabled existing models of reflection to be placed in this context. This understanding of reflection in this specific context provides an initial step in developing a cognitive model of students’ reflective practice followed by assessment instruments which may be used for teaching and assessing this skill in capstone courses.

RECOMMENDATIONS

The structure and methodology study presented in chapter two was developed based on desired capstone assessment outcomes and on the literature related to design processes and products. The goal for this work was to present an assessment philosophy that would be effective in enhancing teaching and learning. Recommended assessment instruments have been developed and the next steps would be to test the value of this structure with respect to the intended goals. Potential research questions may relate to the value of the assessment structure to the needs of students, instructors, and programs involved with capstone design. A second focus should address the validity, including reliability, of the assessments in serving the purposes for which they were developed—both formative and summative.

The IRA study (chapter four) addressed one validity concern: agreement of scoring between raters. Suggestions for improvement included revisions to the performance scales/rubrics and improvements in rater training—specifically, frame-of-reference (FOR) and rater-error training (RET). Additional validity concerns could also be addressed, including the
value of the formative assessments to stakeholders and construct validity for the summative assessments, to determine the degree to which these assessments measure the intended outcome.

Results from the reflective practices study (chapter three and five) could now form the basis for a cognitive model, an assessment instrument, and an interpretation model for evaluation of student reflections. The six process steps identified in Table 12 could form the performance dimensions for an analytic evaluation rubric. This set of criteria would be instructive to students and capstone faculty by providing a clear direction for the goals and process steps of reflecting. Another approach would be to integrate the process steps listed in Table 12 into a single, holistic evaluation dimension in existing TIDEE rubrics. Performance levels, for example, would consist of all six process steps and evaluation would be based on a holistic observation of student performance responses. This approach would fit well with TIDEE’s existing structure as assessment observation tasks currently elicit reflective responses from students. With this approach, it is expected that specific feedback to students on reflective practices would have an immediate effect on the level of student reflections, in terms of completeness and structure.
REFERENCES


APPENDIX

Appendix A. Reflection Code List

Teamwork issues
- Communication
- Participation
- Coordination
- Monitoring
- Values
- Attitudes

Reflective process steps
- Impetus/motivation/reason for becoming aware of an issue
- Defining an issue
- Thought process on issue (experimenting; hypotheses; reasoning)
- Factors affecting thought process (situation, others, emotions, knowledge)
- Past experiences with issue
- New learning
- New perspective
- Making meaning
- Outcome, action

Levels of reflection
- Pre-reflective, quasi, reflective
- Habitual, thoughtful, reflective
- Everyday thinking, reflecting on events/incidents, reflecting on personal experience (to understand through interpretation), reflection on nature of knowing
- Association, integration, validation, appropriation
- Noticing, making sense, making meaning, working with meaning, transformative learning

Others
- Too busy
- Something learned
- A surprise
- Specific teamwork issue
- Reflection-in-action
Appendix B. Contact Summary Sheet

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<thead>
<tr>
<th>Contact:</th>
</tr>
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<tbody>
<tr>
<td>On teamwork</td>
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<tr>
<td>On team reflection</td>
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<tr>
<td>On individual reflection</td>
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<tr>
<td>On assessments</td>
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<tr>
<td>Insights from this contact</td>
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<tr>
<td>New questions or directions for next contact</td>
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<tr>
<td>Summary of main reflective practices</td>
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<tr>
<td>Summary of main teamwork issues</td>
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</tbody>
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Appendix C. Institutional Review Board (IRB) Approval for Study

MEMORANDUM

TO: Denny Davis, MICHAEL TREVISAN, Shane Brown, ROBERT GERLICK and Jennifer Lebeau

FROM: Patrick Conner (for) Kris Miller, Chair, WSU Institutional Review Board (IRB) 3005

SUBJECT: Approval of Amendment to Exempt Study: IRB #09853, Activity #005

DATE: 12/17/2008

The IRB staff have evaluated the proposed amendment to the Exempt study, "Capstone Engineering Design Assessment: Development, Testing and Adoption Research" IRB #09853 and have determined that the amended study procedures remain exempt from IRB review under 45 CFR 46 (b) (2).

The study procedures have been amended to include:

1) Addition of post-assessment questionnaires.
2) Addition of focus groups.
3) Addition of interviews.
4) Addition of surveys.
5) Addition of Robert Gerlick and Jenny LeBeau as co-investigators.

You may conduct the study, as amended above, without further IRB oversight. Your department shall maintain oversight of the project.

Further changes will require that a new Request for Amendment form be completed and submitted to the IRB.

If you have questions, please contact the Institutional Review Board at (509) 335-3668. Any revised materials can be mailed to Office of Research Assurances (Campus Zip 3005), faxed to (509) 335-6410, or in some cases by electronic mail, to irb@wsu.edu.

Review Type: Amendment
Review Category: Exempt
Date Received: 12/15/2008
ORGD No.: N/A
Agency: N/A