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Abstract

Reflection skills have been used in various academic fields to bring self awareness into what has been learned from an exercise. We propose that if an engineering student is aware of the information he or she currently knows as well as what remains to be learned, then that student should possess the ability to more efficiently make the necessary assumptions and gather the appropriated information in order to solve the problem at hand.

Our general premise is that by engaging in active and repeated reflection exercises, undergraduate engineering students will develop stronger reflective judgment skills; and hence, we would anticipate that these students will show initial signs of becoming Schon’s reflective practitioner\(^1\) or achieve higher levels of King and Kitchener’s reflective judgment scale\(^2\). That is, our engineering students will better recognize in the broadest sense the various stakeholders, and how their engineering decisions will impact them, in both the short and long terms.

Here we have studied undergraduate industrial engineering student teams resolving Model Eliciting Activities (MEAs). After completing each MEA, each student was then given a reflection tool (RT) requiring him or her to address several of the ABET professional skills. The students’ reflection responses coupled with the MEA graded group solutions provided a data set for analysis. Student data was coded to determine the quantity of concepts learned, as well as the depth and quality of reflection. From here, based on King and Kitchener’s Reflective Judgment Model, students were categorized into: pre-reflective thinking, quasi-reflective thinking or reflective thinking groups. These categories were then compared with the grades on the MEAs.

I. Introduction

The engineering profession continues to diversify in complexity, location and types of problems as it addresses the major issues impacting society, such as those delineated in the NAE Grand Challenges (http://www.engineeringchallenges.org). Consequently, it is not possible for engineering students to fully learn all the theory and skills that they will need upon graduation. This is one reason for ABET outcome criteria 3(i) – “life long learning,” and why it is becoming increasingly important. We suggest that reflection is one such method that helps to foster life long learning.

Engineering students are expected to make significant progress in learning content knowledge as they go from novices (freshmen) to young practitioners during the process of earning their B.S. degrees. During this time undergraduate engineers begin to refine their problem solving skills and learn to view posed and real problems more effectively and holistically. This growth process
can be enhanced by developing self awareness and self regulated learning skills. Two inventories have been established to measure this: the Individual Development and Educational Assessment System (IDEA) and the Self-Directed Learning Readiness Scale (SDLRS). Both are general, proprietary stand-alone instruments; and can be costly to administer if a large number of students are to be assessed. As an alternative, reflection instruments can be easily designed and incorporated into existing engineering course materials independent of teaching style.

Reflection is a way of thinking that is complex, rigorous, intellectual, emotional, and time consuming\(^3\). As students practice reflection, they become more skilled at being able to re-think what they have learned, make new connections to old knowledge and help move themselves from novice problem solvers to “experts.” Reflection, as a methodology, is often used in medical education, K12 education and teacher preparation. In K12 education, reflection is a common tool to encourage pre-service and in-service teachers to gain greater insight into their instructional methods to improve their own as well as their students’ learning. In engineering education, reflection is an emerging in-process learning assessment\(^4\).

For this particular study, we evaluate industrial engineering students’ “evolution” of their reflection abilities over six Model Eliciting Activity (MEA) experiences during a sophomore semester. As noted, MEAs are realistic, open ended problems that students solve in teams\(^5\). The post-MEA reflection activities help students think about the problem they have just solved with their team and their understanding of the targeted concepts in the MEA. In addition, students are asked to reflect on other more abstract concepts, such as social awareness.

Specifically, we have designed reflection tools that have been implemented in two engineering courses to provide indicators of two outcomes: the learning of targeted engineering concepts and life long learning. The target engineering concepts are specific to the courses (engineering statistics and engineering economics); and growth in reflective ability over time is a surrogate for life long learning.

A. Reflection and reflection tools

There are several definitions for the term reflection. John Dewey (1933) is most often cited for the origins of reflection. Cowan\(^6\) quotes Dewey stating that reflection is “the kind of thinking that consists in turning a subject over in the mind and giving it serious thought.” Rodgers\(^3\) explains further “the function of reflection is to make meaning: to formulate the relationships and continuities among the elements of an experience, between that experience and other experiences, between that experience and the knowledge one carries, and between that knowledge and the knowledge produced by thinkers other than oneself.” If reflection can be defined in a particular way, it can be broken down into repeatable steps, and therefore it can be practiced as a way of thinking and further refined with repetition. Research indicates that reflection is especially important for novices. The act of reflection moves an individual thinker away from self-centeredness to self awareness\(^3\).
Hamilton, et al\textsuperscript{7} describe the application of reflection as a guided activity in which the subject is assisted by reflection tools. “We refer to them as Reflection Tools (or RTs) because, following a problem solving activity, RTs help students briefly record significant aspects about what they have done (e.g., changes that occurred in roles they played, strategies they used, feelings they had, or ways their group functioned).” Cowan\textsuperscript{6} further outlines uses for reflection including: process analysis, self-evaluation, critical incident analysis, open-ended and serendipity. He also suggests a combined process analysis and self-evaluation, which is a goal of RTs particularly when used with engineering problem solving exercises.

\textbf{B. Life Long Learning}

It can generally be agreed that life long learning skills originate during a student’s undergraduate career, but are not be fully utilized until after graduation, making it all the more challenging to evaluate. Mourtos\textsuperscript{8} quotes Candy that “lifelong learning takes, as one of its principal aims, equipping people with the skills and competencies required to continue their own self-education beyond the end of formal schooling.” The two aspects of ABET criteria 3i “… recognition of the need for, and an ability to engage in lifelong learning” are parts of the affective and cognitive domains\textsuperscript{8}. In Mourtos’ study, 14 skills were targeted among which were: find new material on my own, become aware to stay current in today’s world, access information from a variety of sources, read critically, categorize and classify information, synthesize new concepts, model by estimating/simplifying/making assumptions and approximations. In our study, the MEAs employed require students to use many of these skills. As seen in the Appendix, the RT we developed for the study asks students to think and write about these ideas in relation to the MEA they just completed.

\textbf{II. Methodology, Tool Description and Implementation}

A Model Eliciting Activity (MEA) is a realistic, client driven, thought-revealing, model eliciting, open-ended team problem solving exercise\textsuperscript{5}. MEAs are designed according to six principles as scaffolding for students to either: integrate, reinforce or discover new concepts\textsuperscript{5}. Instructors guide the students’ learning and provide targeted feedback; especially if misconceptions exist, which may be observed through students’ self reflection reporting.

A reflection learning exercise was used after each MEA in two courses: Probability and Statistics I for Engineers and Engineering Economy. Both courses are required for industrial engineering students; and there was a large overlap of students in both classes. There were about 50 students in each class, and on average 28 of the students completed the optional reflection after each MEA. The MEAs also had an ethical component\textsuperscript{9} for students to address in their written team solution.

The current reflection tool (RT) is third generation. It contains 13 questions encompassing two primary categories: problem solving process and targeted concepts learned (engineering and professional skills). In the most recent revision, the RT was refined to guide students through a
reflection process by providing key or meaningful words (such as “model” or “ethics”) that are aligned with the targeted engineering concepts and the professional skills of the ABET criteria. The MEAs used in this study were typically built into the course structure as a mini-project, and the RTs were assigned as bonus exercises to better assure compliance and participation.

Upon completion of each mini-project, the MEA was scored using a rubric; and the reflection responses were analyzed to identify concepts learned and overall thoughtfulness of the responses. In all, nine students completed all six RTs between the two industrial engineering courses during one semester, with an additional three students to be studied who completed at least four RTs. A majority of the nine students fell into the categories of both high course and MEA grades, so additional students who did not complete all the RTs were included for analysis.

III. Overview of MEAs

The MEAs were assigned after the concepts were covered in the courses (these are referred to as reinforcer MEAs). The courses were coordinated such that the assigned MEAs did not overlap between the two classes (i.e., the first MEA was assigned in the engineering economy course; the next MEA was assigned in the engineering statistics, etc.). The order that the MEAs were completed is as follows: campus lighting, tires reliability, trees and road safety, Medsafe cardiac devices, dam construction, and CNC machine replacement. Each is briefly described. All the MEAs used in this study also have an ethical component.

A. Engineering Statistics MEAs

Tire Reliability. This MEA entails a set of reliability statistics that a team of students are expected to analyze in advance of preparing a report on the safety of a line of automotive tires. The Tires reliability MEA requires students to develop a general model for determining if a tire production run meets acceptable reliability and then apply that model to specific cases: three different grades of tires are produced; students must determine if each batch is within a “gold” standard. Students must use a given data set to determine the shape of the distribution; use probability plots to analyze the distribution and must fully understand the concept of variance if they are to successfully complete the MEA. The concepts targeted include distributions and histograms. This MEA has an ethical component specific to confidentiality of results. Students are asked to think about under what conditions a recall should be implemented.

CNC Machine Replacement. This is a two part MEA. Specifically, the chief engineer is interested in replacing an aging but quite functional CNC machine with a newer model. He views this as a significant opportunity, especially since the purchase would not come out of his operating budget. Consequently, the chief engineer requests a group of consultants (i.e., the student team) to demonstrate that the new machine will outperform the current one as measured by unit production time, cost, and quality; thus building a strong case for purchase (Part 1). In Part 2, the team is asked to re-do their analyses to show that the replacement is, in fact, better (if the team had concluded that it was not, which is the more appropriate result), or to provide more
specific details if they found that replacement is a better choice. The concepts targeted include: statistical hypothesis testing, use of the mean and variance, economic analysis, and sub-optimization. The ethical component involves how the engineering team should react to the pressure placed on them to come up with a ‘suitable’ answer. Specifically, students are presented with the dilemma of whether or not to delete “outlier” data in order to meet the chief engineer’s demand.

*Medsafe Cardiac Devices or “Test Leads”*. This MEA is designed around the targeted concepts of students’ understanding of the central limit theorem and the basis for sampling and hypothesis testing. A company that makes implantable defibrillators is concerned about defective leads. Student teams must propose a minimum size sample that should be tested to determine if a batch of leads meets specification with a given precision level. The ethical issue involves when to recall already implanted defibrillators if there is concern about the quality of the leads.

B. Engineering Economic Analysis MEAs

*Campus Lighting*. Students are asked to determine which lighting proposal for a college campus is the least costly while addressing the campus community’s safety concerns. Students are given information about the current lighting system on campus: types of bulbs, their cost and amount of light produced. Students are asked to recommend to facilities management a lighting proposal that would not only work for this particular part of campus, but other parts of campus as well. A few crime statistics are also given. The targeted concepts include cost estimation, time value of money, and comparing alternative investments. As an ethical issue, students are asked to think about how the lighting on the campus impacts the campus’ community, but in light of the cost.

*Trees and Road Safety or “Trees”*. This MEA has two parts and is based on an engineering ethics case originally developed by Harris, Pritchard and Rabins. It concerns possible removal of old growth trees along a road through a public forest in order to reduce traffic accidents. Specifically, there has been a series of accidents on a stretch of road through this forest; consequently, the county’s department of transportation has decided to remove the trees. However, a citizen’s environmental group has raised objections. The team must now assist in resolving the dispute. The student groups are provided with accident data which indicate excessive speed may be a contributor to the accidents. Part 2 involves a similar scenario reset in a California State Park that contains redwood trees. Will the team now come up with a different decision? Targeted concepts include: recognizing and resolving an ethical dilemma, investigating the trade-offs between the environment and public safety, economic analysis, as well as data analysis. The obvious ethical issues involve the tradeoff between the environment and human life; and how this may change depending on the type of trees.

*Dam Construction*. This MEA concerns the actual proposed construction of a dam in the South Eastern Anatolia in Turkey. Having approved the initial plans, the Turkish government, for economic reasons, now must reduce the dam’s budget. Alternatives include reducing the dam’s
safety factor by either decreasing its height, substituting certain material or lengthening the time for completing the project. Targeted concepts include: multi-criteria decision making, economic analysis, and international perspectives in economic decision making. The ethical issues imbedded in this MEA are quite rich, especially considering the environmental and societal consequences of building the dam; and the potential impact on relations with neighboring countries, possible terrorist activity, and the impact on a historic area and its ancient architecture.

IV. Analysis and Results

In this paper, we provide a summary of students’ overall impressions of the MEA experiences through their collective reflections. In addition, we have selected twelve students who completed at least four of the six reflections to do an in-depth investigation of their growth (or no growth) in reflection. For this analysis, we investigate student quotes (shown in *italics*) that demonstrate the growth of reflection (or acquiring life long learning skills), along with targeted concepts (both technical concepts and professional skills) that students perceived they are understanding as they self reported in the RTs. Of the twelve students closely examined, six of the nine students are included who completed all six reflections; and the other six completed at least four reflections.

Grounded theory techniques for data coding (grouped into concepts and memos) were used for analysis and generate theories about the student learning gained from the MEAs. For this specific paper, we analyzed a small portion of the students who completed at least four of the six MEAs; and from their responses the students were classified according to their overall growth based on King and Kitchener’s Reflective Judgment model development periods: (1) Reflective, (2) Quasi-reflective, or (3) Pre-reflective. Students were then classified according to their overarching grade in the course and their MEA solution grades. “Lower” scores received grades of B- or lower on the MEA. Eight of the students had a high course grade and four students had a lower course grade (very few students who had lower course grades completed a majority of the six reflections). See Figure 1 below. Of the eight high course grade students, five also were on teams that scored high on the MEAs; in contrast, three who scored lower. Of the four lower course grade students, three also scored low on the MEAs and one scored high on the MEAs.

Figure 1. Distribution of Students between Course and MEA grades
A. General Findings

From the approximately 60% of the students in the class who completed the surveys some background information could be determined. Teams spent an average of approximately three hours on each MEA, with a range from one to six hours. In response to the RT question number 12, “I enjoyed this problem solving experience”, students were mostly “neutral” or “somewhat agree”. However, the satisfaction is higher when the MEA was well designed; fit cleanly into the course structure and timely feedback was provided from the instructor.

Most of the students noticed the ethical issues in the MEAs; however, some ethical dilemmas were more obvious than others. In general, the MEAs raised student awareness of ethical issues in a broad sense noting societal, environmental and in some cases, global impacts. However, it was clear that for engineering students who had not taken an ethics course, more exposure to these concepts would be valuable. Students could identify what concepts they learned and why (by either explaining the concept further or how they recognized mastery of a concept).

Interestingly, except for a few exceptions, student teams did not have difficulty agreeing on a final solution. Students were asked if they were satisfied with their team’s solution, and whether or not their ideas were included in the final solution. We found that teams used several approaches to reach “consensus”: (1) the team agreed on all ideas (ideas were not personal but were group ideas), (2) all ideas were included, or (3) the group exhausted all other possibilities to come up with the best solution. Half of the students had suggestions that did not end up in the final solution, but were mostly satisfied; so it seems that individual ideas were considered even if they were not included in the final solution.

Aspects of each of the eleven ABET outcomes were mentioned at least once by the students. Those most often mentioned were related to:

3a - using software (likely because we asked for generalizable solutions)

3b - analyzing and interpreting data,

3c - working with realistic constraints,

3d - teamwork

3e - problem solving, and

3g - professional writing (we emphasized a memo format), and communication (particularly if there were teamwork issues).

B. Student Growth

To investigate individual’s growth over time, we looked at twelve students who completed at least four MEA reflections. Table 1 provides a summary of each student and his or her
generalized responses in terms of the following: the process(es) that the team used, the individual role(s) assumed in the team, a perception of the main targeted engineering concepts learned, the professional skills he or she felt were used, and a characterization of the response to the ethical and modeling prompts. Each student’s responses were then compared in aggregate to King’s and Kitchener’s definitions of Reflective Judgment collapsed into three development periods: prereflective reasoning, quasi-reflective reasoning and reflective reasoning. Students were given a list of the problem solving stages, targeted engineering and professional skills from which to choose an appropriate response, see Appendix for the RT for questions 7, 8 and 9. The five problem solving stages are: problem identification, model/solution formulation, collecting information and analyzing data, evaluating and revising the solution, and documentation. The targeted engineering concepts depend on the MEA, (although they were all the same for the engineering economy MEAs). For example, the CNC machine’s targeted concepts were: hypothesis testing, standard deviation, confidence intervals, variance, and central tendency. The professional skills are: professional writing, using software (such as Excel), applying engineering concepts, analyzing data, interpreting data, working with realistic constraints, teamwork, solving engineering problems, professional responsibility, ethical responsibility, communication skills, engineering in a global context, engineering in a societal context, engineering in an environmental context, engineering in an economic context and recognition of the need for lifelong learning.

The three development periods from the reflective judgment model are found on [http://www.umich.edu/~refjudg/reflectivejudgmentmodel.html](http://www.umich.edu/~refjudg/reflectivejudgmentmodel.html) and as they summarize them:

**Prereflective Reasoning:** 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. [People who hold these assumptions] believe that what they know is absolutely correct, and that they know with complete certainty. People who hold these assumptions treat all problems as though they were well-structured" (King and Kitchener, 2002)

**Quasi-Reflective Reasoning:** 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. Although they use evidence, they do not understand how evidence entails a conclusion (especially in light of the acknowledged uncertainty), and thus tend to view judgments as highly idiosyncratic" (King and Kitchener, 2002)

**Reflective Reasoning:** 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. They believe they must actively construct their decisions, and that knowledge claims must be evaluated in relationship to the context in which they were generated to determine their validity. They also readily admit their
Table 1. Summarized Student Responses

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<tbody>
<tr>
<td><strong>Student 1</strong></td>
<td>Group discussion Brainstorm</td>
<td>Calculations Analysis</td>
<td>Problem identification, Analyzing data</td>
<td>Confidence intervals, sample size, hypothesis testing, probability plots, reliability, B/C ratios, comparing alternatives, consider all relevant criteria</td>
<td>Software, solve engineering problems, teamwork</td>
<td>&quot;can't put price on a life&quot;</td>
<td>Reflective reasoning</td>
</tr>
<tr>
<td><strong>Student 2</strong></td>
<td>Came up with individual ideas then compromised</td>
<td>Many: data analysis, memo writing, excel spreadsheet</td>
<td>Model/solution formulation, Analyzing data</td>
<td>Reliability, probability plots, none, consider all relevant criteria, hypothesis testing</td>
<td>None Teamwork (on the MEA that had group dissonance)</td>
<td>&quot;putting a price on crime&quot;</td>
<td>Reflective reasoning</td>
</tr>
<tr>
<td><strong>Student 3</strong></td>
<td>&quot;thinking outside the box&quot;</td>
<td>Learned new concepts from group members</td>
<td>Model/solution formulation, Documentation</td>
<td>Reliability, standard deviation, central limit theorem, sample size, B/C ratios, dealing with uncertainty, considering all relevant criteria</td>
<td>Excel, professional responsibility, solving engineering problems, memo writing</td>
<td>Identification with little reasoning</td>
<td>Quasi-reflective reasoning</td>
</tr>
<tr>
<td><strong>Student 4</strong></td>
<td>&quot;realizing we were incorrect&quot;</td>
<td>Excel spreadsheet</td>
<td>Problem identification, Analyzing data</td>
<td>Confidence interval, hypothesis testing, standard deviation, B/C ratios, considering all relevant criteria, dealing with uncertainty</td>
<td>Professional writing, Excel, analyzing and interpreting data</td>
<td>Identification, sometimes with reasoning</td>
<td>Quasi-reflective reasoning</td>
</tr>
<tr>
<td><strong>Student 5</strong></td>
<td>&quot;Worked as a team&quot;</td>
<td>Main ideas contributed Excel spreadsheet</td>
<td>Problem identification, Model formulation Documentation</td>
<td>Considering all relevant criteria, probability plots, B/C ratios, confidence intervals, hypothesis testing</td>
<td>Communication skills, analyzing data, engineering in a global context, engineering in an economic context</td>
<td>&quot;money and lives should not be compared&quot;</td>
<td>Reflective reasoning and Quasi-reflective reasoning</td>
</tr>
</tbody>
</table>

"willingness to reevaluate the adequacy of their judgments as new data or new methodologies become available" (King and Kitchener, 2002)
<table>
<thead>
<tr>
<th>Student</th>
<th>Team Process Roles</th>
<th>Problem Solving</th>
<th>Targeted Concepts</th>
<th>Professional Skills</th>
<th>Ethics</th>
<th>Modeling</th>
<th>Reflective Reasoning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student 6</td>
<td>&quot;Not sure we had the right answer&quot;</td>
<td>Made decisions Calculations Memo writing</td>
<td>Model formulation Analyzing data</td>
<td>Histograms, probability plots, confidence intervals, hypothesis testing, standard deviation, B/C ratios, central limit theorem</td>
<td>Teamwork, communication skills, none</td>
<td>&quot;results of data directly impact if someone will live or die&quot;</td>
<td>&quot;any situation like this one&quot;</td>
</tr>
<tr>
<td>Student 7</td>
<td>&quot;Discussed our individual part answers&quot;</td>
<td>Making decisions Calculations Excel spreadsheet</td>
<td>Problem identification Documentation</td>
<td>Considering all relevant criteria, dealing with uncertainty, uniform distribution, sample means, B/C ratios</td>
<td>Already have these skills, &quot;practice makes perfect&quot;</td>
<td>&quot;Should a tree be sacrificed to prevent crashes?&quot;</td>
<td>&quot;any situation that uses these skills&quot;</td>
</tr>
<tr>
<td>Student 8</td>
<td>Looked at individual parts and worked as a team</td>
<td>Memo writing Researching alternatives</td>
<td>Not clear, stages were not identified</td>
<td>Reliability, dealing with uncertainty, considering all relevant criteria, hypothesis testing, confidence intervals</td>
<td>Excel, professional writing, teamwork</td>
<td>&quot;Vanguard was clearly not the better machine, but they needed a new machine anyways&quot;</td>
<td>&quot;any situation with a set of data that can be modeled&quot;</td>
</tr>
<tr>
<td>Student 9</td>
<td>Analyzed data and formed conclusions as a team</td>
<td>Calculations Excel spreadsheet</td>
<td>Problem identification Evaluating solution</td>
<td>Reliability, standard deviation, probability plots, cost estimation, central limit theorem, sample sizes, hypothesis testing</td>
<td>Engineering in a societal context, realistic constraints, professional writing</td>
<td>&quot;value of human life and importance of natural environment&quot;</td>
<td>Connection with concepts learned in another class</td>
</tr>
<tr>
<td>Student 10</td>
<td>Brainstormed or analyzed data</td>
<td>Research Calculations</td>
<td>Not clear, stages were not identified</td>
<td>Reliability, probability plots, cost estimation, time value money, sample size, comparing alternatives</td>
<td>Using software, engineering in economic context, interpret data, teamwork, apply engineering concepts</td>
<td>&quot;profit or safety&quot;</td>
<td>Application of the ethical issue</td>
</tr>
<tr>
<td>Student 11</td>
<td>Brainstorming and consensus</td>
<td>Discussion Excel spreadsheet Memo writing</td>
<td>Problem identification Model formulation</td>
<td>All, B/C ratios, comparing alternatives, hypothesis testing</td>
<td>None, applying engineering concepts, teamwork, communication</td>
<td>Vague ethical sounding statements</td>
<td>Vague general situation statements</td>
</tr>
<tr>
<td>Student 12</td>
<td>Analyzed data or discussed individual responses then group decision</td>
<td>Excel spreadsheet Discussion</td>
<td>Problem identification Analyzing data</td>
<td>None, confidence intervals</td>
<td>Professional writing, none, ethical responsibility</td>
<td>Vague ethical sounding statements</td>
<td>Vague general situation statements</td>
</tr>
</tbody>
</table>
A summary of each student’s reflection growth is provided next. For our sample, the students were classified according to their various teams’ overall MEA grade across the six MEAs as well as their overarching grade in the two courses, as shown in Table 2. This was done to investigate how performance on the MEAs as well as in the class potentially correlates with their reflective reasoning and growth, categorized as reflective reasoning, quasi-reflective reasoning, or pre-reflective reasoning. Our initial hypothesized reaction is that students with high course grades and high MEA grades should be better at reflective judgment than those students with lower MEA and course grades. As Table 2 indicates, there is a definite association between students’ reflection ability and whether or not they performed well on their MEAs. There is less of an association with their overarching grade in the courses.

**Table 2. Results of Analysis of Students’ Reflective Growth**

<table>
<thead>
<tr>
<th></th>
<th>Low MEA grade</th>
<th>High MEA Grade</th>
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<tbody>
<tr>
<td></td>
<td><strong>Students</strong></td>
<td><strong>Student</strong></td>
</tr>
<tr>
<td>Low Course Grade</td>
<td>10 – Quasi-reflective reasoning</td>
<td>9 – Reflective reasoning</td>
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<tr>
<td></td>
<td>11 – Pre-reflective reasoning</td>
<td></td>
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<tr>
<td></td>
<td>12 – Pre-reflective reasoning</td>
<td></td>
</tr>
<tr>
<td>High Course Grade</td>
<td>6 – Pre-reflective reasoning</td>
<td>1 – Reflective reasoning</td>
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<tr>
<td></td>
<td>7 – Pre to Quasi-reflective reasoning</td>
<td>2 – Reflective reasoning</td>
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<tr>
<td></td>
<td>8 – Pre to Quasi-reflective reasoning</td>
<td>3 – Quasi-reflective reasoning</td>
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<tr>
<td></td>
<td></td>
<td>4 – Quasi-reflective reasoning</td>
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<tr>
<td></td>
<td></td>
<td>5 – Quasi to Reflective reasoning</td>
</tr>
</tbody>
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**Student 1:** High course grade, high MEA scores. This student participated in initial group discussions or “brainstorms”, where the group divided the tasks among its members. In almost all of the MEAs this student conducted the data analysis or calculations, and did not switch roles. Student 1’s first critical points were in the early stages, primarily in clarifying the problem definition; the second critical point occurred in either the data analysis stage or in the final decision stage. Student 1 listed several targeted concepts and skills, and made thoughtful comments about the MEA applications. “I understand better that not everyone has the same way of thinking and what one person values as high another person may not see it necessary.” Another comment about MEAs, “I enjoy these activities because it allows me to see how engineering can be applied in the real world because someday I may have to do a similar study using these concepts.” With regards to ethics, the student indicates, “Yes, since we are dealing with fatalities and you can’t put a price on a life, we need to take any and all extremes to ensure that we are doing all that we can to prevent these accidents.”

**Student 2:** High course grade, high MEA scores. This student spoke about a more dynamic team experience than student 1, indicating that in one MEA there were “compromises” and in another MEA there was a group member with such a strong position that became the group’s solution.
even though not everyone agreed. Student 2 performed many different types of tasks, with the critical points happening later in the problem solving process. This student learned some of the targeted engineering concepts, but did not feel an improvement on the professional skills. The ethics and modeling statements were not quite as strong, but still insightful as the following examples indicate: “We had to decide whether the crime was ‘bad enough’ to warrant a solution which would cost the university a significant amount of money.” “Our solution could be applied to any application where batches of a product need to be inspected before shipment.” In response to the question, “how did you notice this change in learning engineering concepts?” the student said “I noticed it in reflection.”

**Student 3:** High course grade, high MEA scores. This student seemed to gain much new knowledge and skills by being part of a team and working through the processes, as the following quote denotes: “Discussion with fellow engineers and class work in the past two semesters.” This was in response to the RT question “What prompted or helped you gain the concepts better?” The student indicated that the team also learned from experience, from the first MEA “right away we jumped into calculations” to the last MEA, “we looked at all the information before we looked into any numbers”. “Writing a memo is always something that I learn more about with these MEA’s as well as applying engineering concepts learned to solve a problem.” This student’s responses began at an earlier stage compared to some of the other students. This student did not fully move into the next stage because key issues were identified, but without full development or explanation.

**Student 4:** High course grade, high MEA scores. This student discussed how the team process was flawed, either at the beginning or during the middle, indicating that they realized that their calculations were incorrect or they did not understand the initial problem. Student 4’s role was developing the Excel spreadsheet. This student gained from the MEAs both in terms of engineering concepts but also in terms of professional skills, as the examples indicate. “Like the other MEA assignments, this assignment helped me learn professional writing, using Excel and analyzing and interpreting data.” On the other hand, “Because of this exercise, I better understand the concepts of considering all relevant criteria and dealing with uncertainty. I learned these concepts the most from being assigned an incredibly vague task with little-to-no specific instructions.” This student, in particular, was better at identifying ethical over modeling issues, sometimes with additional explanation. “The main ethical issue involved in this project is whether or not you need to follow your boss’s orders even when they are wrong.”

**Student 5:** High course grade, high MEA scores. This student felt the teams worked well together, but provided little details to justify it. Student 5 seemed highly involved in thinking about the solution and working with the Excel spreadsheets. Further, this student was able to connect issues to broader implications, as the following quote clarifies. “I understand how as engineers we much consider the communities needs and not just what is best for us as engineers.” And “I understand the important of considering the alternatives because there are
different benefits to different plans. Comparing them may be difficult, but all differences must be considered to make a good decision.”

Student 6: High course grade, low MEA scores. This student was focused on “getting the right answer” and was uncomfortable with the format of the MEAs. This observation was prevalent in all reflections. Further, this motivation seems to influence how decisions were made and the final solutions determined. “We assumed that you had to prove that the Vanguard was the correct [answer] no matter what the data said so you just had to twist the data and analyze it in a way that proved that point ignoring the data that did not. We did this because it was the assignment.”

Student 7: High course grade, low MEA scores. Interestingly, this student had a ‘know it all’ attitude that permeated in the MEA reflections, as the following statements indicate. “Obviously most of those skills were used but as for if this project helped me to gain this skills I don’t think so…I already have all these skills (communication, teamwork, professional writing). I suppose practice makes perfect however so maybe my skills did improve but if they did I didn’t notice.” Student 7 also noted performing many different roles in the teams. It is conjectured that this student seemed to think he/she knew the answers already, so reflective thinking did not improve over the course of the term.

Student 8: High course grade, low MEA scores. This student was somewhat uneasy with the format of the MEAs, and worried about getting the “right answer” as the following statements detail. “Honestly, homework problems enforce these concepts more then any MEA.” “We’re never really sure what our final answer should look like with these MEAs.” This student was not comfortable with Excel; and therefore his/her role was to write memos and research alternatives. Student 8’s statements about modeling were stronger than his/her statements about ethical concepts, as the following example indicates; “No, the “right and wrong’s” of the issue were fairly obvious,” although no particular details were given about the ethical issues.

Student 9: Low course grade, high MEA scores. This student demonstrated much growth throughout the semester. The individual initially wrote: “This project is the first time I dealt with a project like this.” Towards the end of the term, the student was feeling comfortable with the MEA format, as the statement indicates. “The nature of the project prompted me to gain these skills. I noticed this change when I was trying to form my solution and needed to think ‘outside the box’ of just solving a numerical problem.” This student’s role was to primarily to perform the calculations, and emphasized the team approach to solving problems. Student 9 had thoughtful insight on both ethical and modeling concepts, as demonstrated by the following statements. “When determining the life-span, failure rate or time of a product to an approved standard, this method can be used.” “Yes, there were many ethical issues. I needed to analyze what was a personal benefit and what was a company benefit in this scenario.”
**Student 10:** Low course grade, low MEA scores. For this particular student, it was not exactly clear how the team functioned, nor what role this student played in the team processes. On occasion, this student correctly identified the ethical and modeling concepts, but did not fully explain them. “From the data we saw that there were a set or two of tires that were very unreliable and unsafe. This being said the tires were still on the market for the public to buy.” In addition, there seemed to be confusion between the ethical and modeling concepts, as both are mentioned by the student in the same statement: “Almost any other application where costs are valued against personal damage.”

**Student 11:** Low course grade, low MEA scores. The student indicates that the team process placed a lot of value on brainstorming followed by “throwing out” lots of ideas and coming to a consensus. However, it was not always clear the role this student played in the team process, as student 11 indicates that he/she performed many roles. Further, this student made vague ethical and modeling statements, as the following indicates. “The safety and livelihood of citizens is always the priority, and should never be left out of a discussion involving the public.” Student 11, though, did have a strengthening in learning the targeted engineering concepts, as the example shows. “I understand probability plots better now. I had never created one up till this point, but now I know how they are used, when to use them, and why to use them.”

**Student 12:** Low course grade, low MEA scores. It is not completely clear the roles this student played in the team process. Ethical and modeling statements were general and vague, as shown. “Yes, we felt that if possible, we should leave the environment alone.” “I don’t think that our solution can be used as a model for other situations.” In general, the student seemed disengaged with the MEA process, stating the following. “I didn’t learn very much I feel, these MEA’s in general are just long homework problems as far as I’m concerned, while they help reinforce knowledge and increase experience with skills used in solving engineering problems, they do not teach me very much.”

V. Discussion and Conclusion

Reflection activities are short learning exercises that can easily be incorporated into coursework particularly when used in conjunction with an MEA or other team based assignments. Reflection exercises can provide insight into student learning and the problem solving process while building social awareness and ABET professional skills, and in particular to lifelong learning. Defining, assessing and evaluating mastery of some of these abstract concepts can be difficult, but reflection tools are a promising methodology.

In this preliminary study, we investigated how students’ reflections can be indicative of their reflective judgment and are related to students’ grades on the MEAs. More research into refining the reflection tools, building rubrics and having a wider range of engineering students engage in these exercises is needed. Some further refinement to the reflection tools could involve having
more of the terms better defined and explained (such as each of the ABET professional skills), and asking students directly what some of the abstract terms mean to them (such as lifelong learning or social awareness). Also, to further probe why students did or did not enjoy the MEA exercise.

Further, this study only looked at reflection over the course of one term. In developing life-long learning skills several terms may be needed to cultivate the skill. We are conducting a follow up study that investigates the use of MEAs and reflections in subsequent terms. It is hoped that students labeled as pre-reflective judgment may actually move towards the reflective judgment label. In addition, as students move forward in their thinking about these important concepts, different versions of the reflection tools may be necessary (i.e., different questions could push a student’s thinking further).

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Bibliography

Appendix-Reflection Tool

Reflections on a Learning Exercise

Engineers play an important role in the globalized and as Thomas Friedman put it, an increasingly “flat” world. As future engineering professionals you will make decisions and designs that impact the lives of many people. A lot of your coursework and employment will be based in teams and require you to learn new concepts on your own. Reflection can be a part of your learning process, and this self evaluation will help you understand what you gained from this exercise.

More about “reflection” From Hatton and Smith:

Historically Dewey (1933) is acknowledged as a key originator in the twentieth century of the concept of reflection. He considered it to be a special form of problem solving, thinking to resolve an issue which involved active chaining, and a careful ordering of ideas linking each with its predecessors. Within the process, consideration is to be given to any form of knowledge or belief involved and the grounds for its support1. His basic ideas indicate that reflection may be seen as an active and deliberative cognitive process, involving sequences of interconnected ideas which take account of underlying beliefs and knowledge. Reflective thinking generally addresses practical problems, allowing for doubt and perplexity before possible solutions are reached.

Process Focused Questions

1. Problem solving is a major part of engineering and designing solutions. Problem solving is thinking about and finding answers for a relatively clearly-defined situation for which there are one or more reasonable answers. We are interested in how your team solved this exercise. Please describe the problem solving process that your team used.

2. In engineering problem solving you make assumptions to arrive at a solution. Assumptions are what information and/or constraints that you considered in forming your answer. Please describe the key assumptions that your team used in solving the exercise. Why did you make each assumption?

3. While working on this group project, what did you personally contribute to the problem solving process? Please explain.

4. Did your group have difficulty agreeing on a final solution? How did your group make the decision on what was the final answer?

   Yes      No      Maybe

5. Did you have a method or suggestion that did not end up in the final solution? Please explain.

   Yes      No      Maybe

6. I was satisfied with my group’s final solution. Please explain.

   Strongly disagree      Somewhat disagree      Neutral      Somewhat agree      Strongly agree

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1 Adler, 1991; Cutler, Cook & Young, 1989; Calderhead, 1989; Gilson, 1989; Farrah, 1988
Problem Solving Focused Questions

7. Thompson has outlined some commonly used stages of engineering problem solving that can be categorized as:

a. Problem Identification; i.e., identify and state the problem
b. Model/Solution Formulation; i.e., formulating the problem and abstraction, problem solving approaches, variables, assumptions, constraints and criteria. Modeling the problem: translation
c. Collecting Information and Analyzing Data; i.e., collect information, data and resources. Analyzing and/or solving
d. Evaluating and Revising the Solution; i.e., interpreting results, evaluating potential solutions and selects solution. Reflecting and revising; using feedback and improving
e. Documentation; i.e., writing and reporting

We are interested in your identifying two critical points in your team’s problem solving process that stand out. A critical point is a major change in thinking or an “aha” moment. For each point we want you to identify the stage of the project, your involvement (none, low, medium, high) and when it occurred (beginning, middle, towards the end).

Critical Point 1:

Stage (select one):
- Problem Identification
- Model/solution formulation
- Collecting information and/or analyzing data
- Evaluating and revising the solution
- Documentation

Level of Involvement: (none, low, medium, high)

When in the project did the point occur: (beginning, middle, towards the end)

Critical Point 2:

Stage (select one):
- Problem Identification
- Model/solution formulation
- Collecting information and/or analyzing data
- Evaluating and revising the solution
- Documentation

Level of Involvement: (none, low, medium, high)

When in the project did the point occur: (beginning, middle, towards the end)

Concepts Learned Questions
8. Below are some of the engineering concepts that might have been included in the exercise. Which ones do you now understand better as a result of this exercise? What prompted or helped you gain the concepts better? How did you notice this change?

Bulleted list depends on MEA being used.

- Tires Reliability MEA: reliability, mean, median, standard deviation, histogram, probability plots, percentage, outliers, other (fill in blank)

- Test Leads MEA: central limit theorem, uniform distribution, sample size, means, sample of the means, confidence intervals, variance, sampling distribution, other (fill in blank)

- Engineering Econ MEAs: cost estimation, time value money, comparing alternative investments, B/C ratios, considering all relevant criteria, dealing with uncertainty, other (fill in blank)

- CNC Machine: hypothesis testing, standard deviation, confidence intervals, variance, central tendency, other (fill in blank)

9. Were there any other concepts or skills beyond those mentioned in the previous question that you discovered or now understand better? What prompted or helped you gain these skills or concepts better? How did you notice this change?

Bulleted List (from ABET criteria): professional writing, using software (such as excel), apply engineering concepts, analyze data, interpret data, working with realistic constraints, teamwork, solve engineering problems, professional responsibility, ethical responsibility, communication skills, engineering in a global context, engineering in a societal context, engineering in an environmental context, engineering in an economic context, recognition of life long learning, other (fill in blank)

10. Engineers must face conflicting interests and “gray areas” in decision making. Did you notice any ethical issues (“moral issues and decisions confronting individuals and organizations involved in engineering”, Martin and Schinzinger) that should be considered as part of the solution? Please explain.

   Yes  No

11. According to Bodner, Gardner and Briggs, a broad definition of the term “model” refers to a simplified or idealized description or conception of a particular system, situation, or process, often in mathematical terms, that is put forward as a basis for theoretical or empirical understanding, or for calculations, predictions, etc.; a conceptual or mental representation of something; and the term “modeling” refers to devise a model or simplified description of a phenomenon or system. Harrison and Treagust define modeling as the essence of thinking and working scientifically. Taking this into consideration, what other applications do you think your solution could be applied to? Or what other areas could you apply the skills and concepts you learned in this exercise?

12. I enjoyed this problem solving experience.

   Strongly Disagree  Disagree  Neutral  Agree  Strongly Agree