Assessing Student Understanding of Reflection in Engineering Education

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Abstract

The use of reflection in engineering education is often used but with little investigation to the utility or effectiveness in engineering education. Efforts made by the Consortium to Promote Reflection in Engineering Education (CPREE) have drawn attention to how reflection is used in the engineering curriculum. What is unknown is whether students recognize why their courses embed reflection activities. The following paper assessed student conceptions of what it means to reflect and why they are asked to reflect in their project-based design courses. Our intended goal was to see if students understood what reflection is and appreciate reflection as a lifelong skill rather than assignments to be graded or a waste of time. Our findings suggest that most students see reflection as an opportunity to look back at what they have done. A subset of students also saw reflection as a process or something that will impact future actions. Students mostly associated reflection with positive actions rather than focusing on mistakes and failures. They saw the main intent of reflection as being learner-centered, with some seeing reflection as having impact on a design project, their profession, life, or the particular class in which they were asked to reflect. This explicit look at student conceptions of reflection within a design context provides faculty with an understanding of what students bring to their class and how they can frame reflection activities to better compliment their students learning.

Introduction

Documenting the use of reflective practices in engineering education has been a recent undertaking by the Consortium to Promote Reflection in Engineering Education (CPREE); 12 partner institutions around the United States led by the University of Washington (UW). Faculty involved with CPREE are promoting the use of reflection activities and assignments on their campuses and are engaging their colleagues in conversations about the benefits of reflection in education. CPREE has amassed a large database of reflection activities and assignments from these faculty in their National Field Guide, which can be accessed on their website, www.cpree.uw.edu. Here educators can find examples of reflective practices across the CPREE partner institutions, which can be used in conjunction with supportive literature to sell other faculty on the educational benefits and gains in student learning. The efforts by CPREE have sparked excitement and fostered increased use of reflective practices throughout engineering education. Increased use has been coupled with an increased rate of reflection publications at the ASEE Annual Conference and Exposition – under 100 in the early years (1996 – 2013) to over 350 at the 2014 conference. The increased trend suggests that educators are including more reflection opportunities in the classroom and value reflection as an important aspect of educating future engineers.
Important to this discussion is what we mean by reflection. CPREE defines the act of reflecting as “…exploring the meaning of experiences and the consequences of the meanings for future action…” and emphasizes the need for reflection in developing skill sets needed as an engineer. Reflection activities can help facilitate the learning process, both in and outside the classroom, and can promote habits of lifelong learning. The question still remains as to how students view reflection as part of their engineering education and as a professional skill. The beliefs our students develop about reflection are heavily impacted by previous experiences and how educators frame such activities. Students need to be taught that reflection is more than just an activity of thoughtfully looking back at an experience; it is a process that helps us to make meaning of experiences that can be applied to and used for the future. Reflection as a process must be taught to students so that they are guided to better understand and utilize this skill attributed to successful engineers and professionals in general. An initial framework offered by the CPREE team includes specific elements of reflection – experience, features, lens, meaning, action, intentional, and dialectical – and provides examples of how these elements might frame students use of reflection in a homework assignment. Context and examples of these elements of reflection are found in Integrating Reflection into Engineering Education.  

**Reflection and Design**

The use of reflection in engineering design has been used to promote not only contextualization of the design process, but also to foster professional skill sets encountered in design course experiences. Hirsch and McKenna found that reflection activities helped students appreciate principles of and strategies used by effective teams. Students were given a pre and post-course reflection assessment to, “identify and discuss the factors that contribute to successful team performance.” Their work supported others that found reflection as a strategy to teach teamwork, while fostering a secondary skill set of reflection.  

Ulrich and Eppinger conclude each step of their *Product Design and Development* processes with a reflection. The reflection asks the designer to “reflect on the results and the process” pertinent to that phase of the design process (e.g. concept selection) and emphasizes that key questions should be asked to identify strengths and weaknesses in the process. The explicit integration of reflection as a key component of the design process fosters a necessary skill set in engineers.  

Others found reflection inherently embedded in the design tools utilized in design courses and industry. For example, Svaroovsky and Shaffer studied how design meetings and design notebooks promote both the development of design skills and reflective practices of professional engineers. Turnes et al. investigated the explicit use of electronic reflective essays that scaffolded content to help students reflect on and to develop an appreciation of design experiences. Researchers at the University of Queensland used a broader implementation of reflection in
design spanning reflection journals, portfolio reflections, team learning opportunities through peer assisted learning sessions, and team reflections.\textsuperscript{11}

The overall literature of reflection in engineering and engineering education is sparse. Turns et al.\textsuperscript{2} noted this gap and suggested we go beyond engineering education – medical schools, nursing schools, and teacher education – to gain an understanding of how other professions view and utilize reflection. Further research is clearly needed to understand the use of reflection in engineering education. Turns et al. suggest one approach to address this gap in the literature is to conduct specific research framed by the \textit{Integrating Reflection into Engineering Education} framework, specifically to address the question of “what could be done to support students engaging in reflection?” We approach this question by asking how students understand reflection and the use of reflection in their classes. The following study takes a look at reflection activities embedded throughout the project-based design curriculum at Arizona State University. This investigation assessed the self-reported conceptions of second-year and senior students’ on what it means to reflect and why they believe reflection activities have been embedded within their design curriculum.

\textbf{Research methods}

\textit{Sample}

Two project-based design courses were selected to be included in this analysis: 1) first semester, second-year use-inspired design project course (EGR 201), and 2) first semester, senior engineering capstone design course (EGR 401). EGR 201 enrolled 213 students (177 consenting responses; 83\% response rate) during the Fall 2015 semester, while EGR 401 enrolled 168 students (115 consenting responses; 68\% response rate) combining the Fall 2015 and Spring 2016 semesters.

\textit{Data Collection}

The student sample in each of the selected courses were all asked to respond to the following questions in class:

1. How do you define reflection?
2. Why do you think reflection activities are used in your engineering design courses throughout your curriculum?

These questions were administered to all students enrolled in the Fall 2015 offerings of EGR 201 and the Fall 2015/Spring 2016 offering of EGR 401 courses. Students in EGR 201 undertook the activity after completing two introductory mini-projects and prior to their final project. Students in the Fall 2015 EGR 401 undertook the activity at the end of the semester, after having completed several reflection activities related to engineering design, while students in the Spring
2016 EGR 401 section completed the activity during the first day of class. (Note: Spring 2016 students in EGR 401 will be asked to complete the same activity at the end of the semester for a future pre/post comparison).

**Data Analysis**

Data collected from consenting students in EGR 201 and 401 were analyzed using a multi-step process run by three raters. The first step included tabulating and compiling all responses into word clouds to expand an initial list of codes derived from the CPREE definition of reflection (Figures 1 & 2).

![Figure 1](www.wordle.net).

**Figure 1.** Word cloud of responses from EGR 201 & 401 students for Question 1 (created on [www.wordle.net](http://www.wordle.net)).

![Figure 2](www.wordle.net).

**Figure 2.** Word cloud of responses from EGR 201 & 401 students for Question 2 (created on [www.wordle.net](http://www.wordle.net)).
Next, a preliminary set of separate codes for each question was established using the word clouds to identify predominate themes. Each question was coded using a different strategy. The goal for coding in Question 1 was to classify overall responses into one of three emergent categories: 1) reflection as the act of looking back in the past, 2) reflection as a process, and 3) reflection as a means for future improvement. These responses were framed by three different models that describe the relationship between action and reflection: 1) reflection-on-action\textsuperscript{12} – reflection occurring after the action, 2) reflection-in-action\textsuperscript{12} – reflection and action occur simultaneously, and 3) reflection-in-action\textsuperscript{13} – reflection influencing future action.\textsuperscript{12} Reflection-on-action is used to describe the act of looking back in the past, which aligned with the first emergent theme. Reflection-then-action described using reflection to impact future actions, which aligned with the third emergent theme. The model of reflection-in-action partially aligns with the second emergent theme, but was ultimately not used to describe reflection as a process in order to better represent student responses.

Table 1 provides examples of student responses for each of these codes. Each response was coded into one of three categories with 33% percent of responses being coded in multiple categories (2 or 3). Rarely were responses coded solely using the reflection-then-action code. A set of indicator words was identified for each category to help in identifying when a response should be coded within a given category. These indicators were not used at face value, meaning a response did not necessarily fall within a given category just because an indicator word was present. The indicators were framed within the context of the response.

Question 2 coding looked at identifying: 1) what was the association of the response (positive focus on learning from reflection vs. sole focus on negative aspects like mistakes made or what was done wrong), and 2) who or what was the intention of the reflection (e.g., learners, course content, life, engineering profession, or the educator). Indicator words were also used for this coding scheme. Again, Table 1 lists examples of student responses for this question.

The final step involved each of the three raters using the preliminary set of codes to code a set of 10 total responses (5 responses from each course) for both questions. The raters then met to discuss how they coded each of the responses, providing reasoning for each coding decision. Discussions between the three raters were used to modify the coding scheme and establish general agreement in how each code would be used going forward. Five additional responses for each question were then coded by the three raters as a team to ensure agreement had been met. The remaining responses were then divided amongst the raters to be individually coded.
Table 1. Coding scheme for Q1 and Q2 including examples.

<table>
<thead>
<tr>
<th>Question</th>
<th>Codes</th>
<th>Example of Student Responses - senior</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1: How do you define Reflection?</td>
<td>Reflection-On-Action</td>
<td>“Reflection is when you look back at something that was previously done and you look for the pros [and] cons and ways to improve what had been done.”</td>
</tr>
<tr>
<td></td>
<td>Process</td>
<td>“Reflection is a process in which individuals [or] groups summarize what happened after an activity or project. It is a type of discussion by individuals to talk about important lessons learned during the entire activity.”</td>
</tr>
<tr>
<td></td>
<td>Reflection-Then-Action</td>
<td>“A Reflection is a way of looking back at a past event to figure out what was done properly, what could be done better, and what will be done in the future to fix the mistakes that were made.” (Note: coded as both Past &amp; Future)</td>
</tr>
<tr>
<td>Q2: Why do you think reflection activities are used in your engineering design courses throughout your curriculum?</td>
<td>Association</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Positive</td>
<td>“I think that [reflections] are used to stimulate thought in students and to teach us that it is important to think about what we have done and how we can improve ourselves by looking at the past.”</td>
</tr>
<tr>
<td></td>
<td>Negative</td>
<td>“There are a few reasons [to reflect] but mostly to understand your own shortcomings or your team's shortcomings and improve on the process. [Reflection] also helps in being an active member versus being an observer.”</td>
</tr>
<tr>
<td></td>
<td>Focus or Intention of Reflection</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Learners</td>
<td>“To force students to stop and think about why something is done or what is important or relevant rather than just going through the motions and having [to write] answers to questions or precisely define bullet points to hit.”</td>
</tr>
<tr>
<td></td>
<td>Project / Design / Assignment</td>
<td>“They allow us to take time to self evaluate and instill change for future projects.”</td>
</tr>
<tr>
<td></td>
<td>Class / Educator</td>
<td>“Instructors would know what their students are thinking about [for] the course or project. They could improve some points for the next project.”</td>
</tr>
<tr>
<td></td>
<td>Life / Profession</td>
<td>“In order the better yourself as an engineer and help you improve on skills.”</td>
</tr>
</tbody>
</table>
Results

Question 1 (Q1): How do you define reflection?
The overall sample of students (N = 292) across the second-year and senior courses did not vary greatly in how they defined reflection (Table 2). The majority of responses focused on reflection as the act of looking back at previous undertakings (approximately 71% for all groups). A higher percentage of second-years described reflection as a process and/or an activity for use in the future than seniors. No significant differences were found for any of the three codes suggesting that second-year and senior definitions of reflection did not vary across groups.

<table>
<thead>
<tr>
<th></th>
<th>Looking Back</th>
<th>Process</th>
<th>Future</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sophomores</td>
<td>70.6</td>
<td>50.8</td>
<td>21.5</td>
</tr>
<tr>
<td>Seniors</td>
<td>70.4</td>
<td>41.7</td>
<td>15.7</td>
</tr>
<tr>
<td>All</td>
<td>70.5</td>
<td>47.3</td>
<td>19.2</td>
</tr>
</tbody>
</table>

Question 2 (Q2): Why do you think reflection activities are used in your engineering design courses throughout your curriculum?
Analysis of Q2 included an assessment of association and intention (Table 3). The responses of the overall sample were overwhelming positive (85.6%) in association, i.e., students focused on reflection as something to be used for improvement and growth as opposed to focusing on reflection as a way to reveal negative consequences of learning (e.g., mistakes). Senior responses displayed significantly more positively associated responses than second-year students ($\chi^2 = 4.491$, df = 1, $p < 0.05$). Less than a quarter of the sample included negative associations in their response to Q2 with second-year students referring to such aspects slightly higher than seniors. No significant difference was seen between groups.

<table>
<thead>
<tr>
<th></th>
<th>Associations</th>
<th>Focus or Intention of Reflections</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Positive</td>
<td>Negative</td>
</tr>
<tr>
<td>Second-Years</td>
<td>81.9</td>
<td>25.4</td>
</tr>
<tr>
<td>Seniors</td>
<td>91.3</td>
<td>18.3</td>
</tr>
<tr>
<td>All</td>
<td>85.6</td>
<td>22.6</td>
</tr>
</tbody>
</table>
An investigation of focus or intention of reflection, i.e., who or what the reflection was intended for revealed a high percentage of students (61.6%) seeing reflection in their courses as intended for learners (e.g., themselves or their peers). A consistent percentage of little under a quarter of the student responses in both the second-year and senior students keyed into reflection as being intended to impact the project, design, or other aspect of the given course in which the reflection activity was being undertaken. Small percentages of students at both levels made reference to reflection activities being intended to impact their overall lives as professional engineers or for the purpose of informing the educator about the course itself. A higher percentage of second-year students provided a response referencing life and/or the engineering profession, while seniors displayed a higher percentage of responses regarding the course. None of the codes used to analyze focus or intention of reflections displayed significant differences between the sample of seniors and second-year students.

Discussion and Implications

Our intended goal for both the reflection activity and our analysis was to see how students understood reflection and appreciate the skill of reflecting as a lifelong learning tool. In class we discussed reflection and the purpose of specific activities after the survey of questions noted in this paper; this provided an assessment of student beliefs prior to any intervention. Previous observations made and statements on end of semester evaluations in both courses suggested that students simply viewed all reflection assignments as just a grade or a waste of time. Responses in the past to various reflection activities revealed a high percentage of students approaching these activities as if they were a problem set with one correct answer. Students tended to submit responses geared toward what they thought the instructor wanted as opposed to focusing on what was most important to them. For example, when seniors were asked to reflect on their experiences and provide their definition of engineering design, many students used Google-generated definitions of engineering design, even though these students progressed through a curriculum with design embedded into every semester within a set of project-based courses. The opportunity to make meaning of past design experiences seemed lost or not retained.

Our findings suggest that students view reflection mostly as an opportunity to look back at what they have done in the past. In fact, approximately 40% of the responses only focused on reflection as looking back. A far smaller set of responses went beyond reflection as a lens to look at the past to include description of reflection as a process or something to inform future decisions. Responses that described reflection as a process provided added depth as to how one goes about reflecting as opposed to simply stating that it looked back and/or impacted the future. These responses are viewed as students identifying reflection as a skill rather than simply an activity to be done because the instructor assigns it. The approximately half of our student sample viewing reflection as a process suggests engineering students need to be explicitly educated about what reflection is and how it can be used as an engineering skill rather than
simply assigning reflection activities without context. This is particularly important for students to recognize this skill as a component that can inform their future decisions. The low percentage of students mentioning the future, either in terms of themselves or their project, suggests they do not see a connection between what they have experienced and how it can impact their future experiences.

The purpose of reflections in engineering design courses was generally viewed by students as having positive associations with learning. Here was the only place we saw a significant difference between seniors and second-year students, in that seniors had a significantly higher percentage of responses coded as having positive associations. Only around 20% of students made any mention of reflection as a tool to focus on mistakes or failures. This implies that one in five students viewed reflection as a means to learn from their mistakes, yet did not appreciate a broader context of making meaning of the entire design experience. Overall, the majority of students saw reflection activities as assignments that were intended to help them or their classmates as learners. This finding is encouraging because it suggests students see value for themselves from reflection activities and refutes the notion that most students just see reflection as a waste of time or a grade. It was discouraging, however, that only 28% of students saw reflection as a way to inform their design project or as a way to impact the engineering profession. Very few students saw such activities as simply being a tool for educators to receive feedback from students that could result in curricular change.

Conclusions

The combined results of how students define reflection and why they believe reflection is part of their engineering design courses is generally encouraging, but can be improved. The practice of reflection in our students must be cultivated to help them better understand the power of reflecting. It is one thing for students to respond positively to questions posed in this study; it is another thing for students to actually act on these thoughts. A higher percentage of students need to recognize reflection as a process and an important engineering tool that is contingent on past experiences and future actions. This is especially relevant to design courses, since the engineering design process is iterative in nature and requires thoughtful reflection on the results and on the process as the design advances. Students also need to better understand how reflection can be intended to impact various stakeholders ranging from self to an actual project. Such a skill can be easily developed over the course of an engineering program if reflection is introduced early and regularly practiced throughout the curriculum, within and beyond engineering design courses. This is only possible if the faculty agree to provide students with regular opportunities to reflect; the approach in each course being specific to the course structure. Our findings provide a foundation for engineering educators in CPREE and beyond to provide their students with appropriate discussions of what it means to reflect and how it can be used in their daily and professional lives.
Acknowledgement
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Bibliography