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Understanding Perceptions of Reflection Among Engineering Educators and Students*

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Reflection is an implicit professional skill for engineers that is embedded within the engineering curriculum, but rarely explicitly taught to or discussed with students. A sample of 114 students enrolled in an engineering capstone design course and 73 engineering educators attending the 2016 Capstone Design Conference were asked, "How do you define reflection?" to shed light on how engineering education stakeholders perceive reflection. Responses were coded utilizing three categorical definitions of reflection: (1) reflection-on-action, (2) reflection-in-action, and (3) reflection-then-action. Results demonstrate that nearly half of all student and educator participants in the sample view reflection strictly as an opportunity to look back on an action. The remaining two categories of reflection, varied between educators and students with a larger percentage of students viewing reflection as a process and a larger percentage of educators seeing reflection as impacting future actions. These findings suggest that a slight disconnect exists between the beliefs of students and engineering educators. Both groups could benefit from a better understanding of what reflection is, which could result in an appreciation gain for regular practice of reflective activities.

Keywords: reflection; engineering design; perceptions

1. Introduction

Reflection within the engineering curriculum is quite prevalent, but rarely discussed among engineering educators or explicitly taught to students. Research on reflection in engineering education has recently been a growing field of study as evidenced by the literature [1], but little has been done to consolidate how engineering educators are embedding reflection into the engineering curriculum. A major effort to bring attention to reflection practices in engineering education began in March 2014 at the University of Washington. Researchers there formed the Consortium to Promote Reflection in Engineering Education (CPREE), a 12-institution consortium funded by the Leona M. and Harry B. Helmsley Charitable Trust [2]. The consortium of institutions, which includes a variety of two and four-year institutions, was created to help promote the use of reflection in engineering education and to ultimately impact student learning through embedded reflection in the classroom [3].

Insights into engineering educator perceptions of reflection were recently examined through educator reflections on their efforts to support reflection in the classroom [4]. The activity of "reflecting on reflection" provided many educators with an opportunity to better understand their own reflective practices and how they bring these understandings to bear in the courses they teach. Our previous work has added to this discussion by providing insights into how students define and perceive reflection [5]. An analysis of engineering student definitions revealed three primary themes: (1) reflection as an activity of looking back at a project to understand what happened (often what went wrong), (2) reflection as a process with a real-time component or, (3) reflection as an opportunity to apply lessons learned to a future project. We later discovered that these definitions closely aligned with a theoretical framework on how some researchers defined the act of reflecting, specifically reflection-on-action [6], reflection-in-action [6], and reflection-then-action [7].

The following paper expands the discussion of reflection in engineering education by providing a theoretical basis for reviewing reflection, a brief summary of reflection use in engineering design, and perceptions of reflection from engineering students and educators. We use the initiatives of CPREE to promote the use of reflection activities in the classroom and our own initiatives through CPREE to engage the engineering education community in a dialog on reflection as a skill for engineering students to learn within their engineering education curriculum

2. Background and theoretical framework

Reflection is a skill considered to be of the utmost importance for any educated practitioner [6–12]. Many researchers and educators utilize Schön's [6] definition, which defines reflection under two conditions: reflection-on-action and reflection-in-action. *Reflection-on-action* is when one stops or pauses to reflect on what was discovered or learned.

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Engineers might look back on lessons learned from a project or experiences they have lived through [6]. Practitioners may utilize this reflection to drive future conversations with a supervisor or team, while students might leverage reflection to discuss outcomes of a project or test with a team or classmate. *Reflection-in-action* is fluid, taking place in real time naturally in professional practice and day-to-day activities [6]. This is the act of thinking about what one is doing while doing it. Schön likens this to "thinking on your feet." As Schön summarizes, the practitioner, ". . . reflects on the phenomenon before him, and on the prior understandings which have been implicit in his behavior" [6]. Engineering students do not bring the same experiences as practicing engineers, which may result in students being less comfortable with this approach to reflection, preferring more time to analyze and contemplate before acting.

There are limitations to these two models offered by Schön. For example, reflection-in-action does not allow for the "solitude and slowness" some may require in a true reflective practice. Reflection-on-action can be viewed as simply an "evaluation" without allowing for true impact of future activities. Rose [7] offers a third model for reflection, *reflection-then-action*, ". . . in which reflection comes first and informs subsequent action."

CPREE offers their definition of reflection as, ". . . exploring the meaning of experiences and the consequences of the meaning for future actions" and argues that reflection is "essential in the development of expertise" [3]. Meanings derived from reflection can be diverging based on the experience and the lens by which the experience is viewed. This approach to defining reflection encompasses all three models supporting the notion that reflection includes looking back, thinking deeply, and planning future action based on the meaning interpreted from previous experiences.

All three models and CPREE's definition argue strongly for instilling the practice of reflection in students. Reflection is in essence a required professional skill of engineering that simultaneously complements the learning of prioritized technical skills. Engineering design by nature of being a structured process, lends itself to inherent reflective practice in parallel with technical learning. The literature suggests that the application of reflection is inherent in design and a skill important for professional practitioners; however, engineering curricula do not regularly provide constant structured opportunities and time for continual reflection to take place. The question of "why" this is the case was posed by Ambrose in her review of undergraduate engineering curricula [13]. Our study looks to help build a foundation that encourages such opportunities to take place regularly and supports Ambrose's argument that emphasizing the need to reflect is important, even with the best of pedagogical techniques [13].

2.1 Examples of reflection in design courses

There has been a noticeable increase in the promotion of reflection in design courses in recent years [1]. A literature review of reflective practices and research revealed specific capstone design performance criteria for reflective assignments, including professional development, teamwork, design processes, and solution assets [14]. Complimentary reflection activities to the design activities were seen to probe each performance factor. Reflection assignments allow students to practice reflection and enable the instructor to assess progress. One such example was Davis et al.'s [14] Transferable Integrated Design Engineering Education (TIDEE) assessments, which specifically target students' reflections to capture their performance on several design and professional development skills highlighted in capstone. These assessments are reflection-on-action assignments that provide students an opportunity to practice reflection. Such assessments complement guides to implementing reflective activities in the classroom. It should be noted that not all reflection activities need to be assessed. Some reflection activities are designed to emphasize the practice of reflection as an engineering skill rather than the scoring of the assignment.

Reflection activities and assignments in engineering design have 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 [15] researched the inclusion of reflection activities within teams, finding that reflecting helped students appreciate 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." Others have reported similar results, finding reflection to be a strategy to teach teamwork while fostering a secondary skill set of reflection [16, 17].

Reflection is also inherently embedded in the design tools that are taught in design courses and utilized by industry. Svarovsky and Shaffer studied how design meetings and design notebooks promote both the development of design skills and reflective practices of professional engineers [18]. Engineering design notebooks can be viewed as a tool for reflection when students are encouraged to document their project work and team meetings with reflection on information discovered. Prompting can guide students to reflect on the design process real-time (reflection-in-action) to document

their ideas and take-away points from that entry [18]. Such an approach is embedded in Ulrich and Eppinger's book on product design and development where they embed methodical reflection on the outcome and process at the end of each stage of the design process [19]. The explicit inclusion of such reflection activities highlights the reflective aspects inherent and embedded within the engineering design practice.

2.2 Application of reflection in design

Examples of reflection in education can be found throughout all fields and disciplines. The specific goal of CPREE was to "catalyze the understanding, development, and use of reflective practices in engineering education" [3]. CPREE has made strides to achieve this goal by mapping current practices and creating a set of over 100 field guide entries documenting faculty use of reflection within engineering. Many of these reflective activities are appropriate for design courses. The field guide entries were created as one to two-page summaries of reflection activities used by engineering educators that could be quick references to assist others in implementing a similar activity/assignment into their own course. The field guide entries include a description of the activity, procedures for recreating the activity, and tips and tricks to provide context and advice based on the educator's experience. Table 1 summarizes several activities from CPREE and other education researchers that are relevant for design courses. Section 2.3 discusses in detail one example reflective activity, the Knowledge Cafe, which has been utilized in design courses as well as at the 2016 Design Capstone Conference workshop.

Table 1. Example activities used by engineering design instructors

Activity	Authors	Description
Design Process		
Concept Generation Process	Davis, et al. [17]	Teams reflect on the process for concept generation and responding to activity prompts (e.g., define process steps, assess status, explain process strengths and propose process improvements).
Senior Capstone Design: Weekly Sprint Reflections*	S. Mohan (Rose Hulman-CPREE Field Guide)	Students write individual reflections and subsequently discuss their weekly "sprints" with their teams in weekly planning meetings. Reflection occurs on what went well and how they could improve the following week.
Electronic Team Journals*	J. Suk (Green River College-CPREE Field Guide)	Students maintain a team journal to reflect on their project and process.
Communication		
Reflection on Senior Capstone: (*Interaction with the client*)*	P. Schuster (Cal Poly-CPREE Field Guide)	Teams reflect on their first interaction with their client using specific questions (e.g., please comment on how interactions with the sponsor could be improved) to gain a deeper understanding of interactions with stakeholders and to improve communication at future meetings.
Informal and Formal Design Reviews*	M. Lande (ASU-CPREE Field Guide)	Students receive real time feedback from instructors on several stages of the design process through information and formal design reviews.
Peer Review of Presentations Using VoiceThread*	K. Csavina (ASU-CPREE Field Guide)	Students peer review one another to broaden the design review critique and to allow students to practice the skill of critical feedback. Individuals respond to the critiques and how they will apply this knowledge to future presentations.
Teamwork		
Team Roles and Responsibilities*	P. Andrist (Green River College-CPREE Field Guide)	Students reflect on their group project experiences and apply a role-based, team framework to ensure success of future group activities
Team Design: Skills Survey*	J. DeWaters (Clarkson University-CPREE Field Guide)	Students reflect on their strengths and weaknesses to help determine their role on the team.
Teamwork and Lifelong Learning*	J. Borgford-Parnell (University of Washington-CPREE Field Guide)	Students identify and use lifelong learning skills to improve engineering team experiences.

* Note: All CPREE reflection activities can be downloaded from the CPREE website at www.cpree.uw.edu/campus-fieldguides.

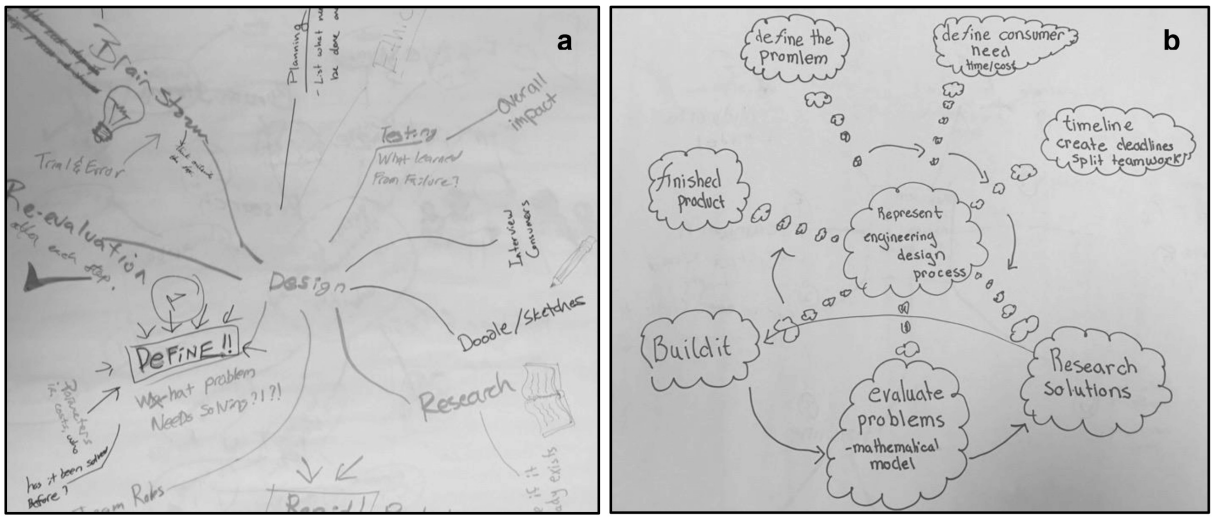

Fig. 1. Sample artifacts created during a Knowledge Cafe (a) mind map created during brainstorming rounds, and (b) final summation in the form of a diagram of the engineering design process.

2.3 Example reflective activity: knowledge cafe

The following example is intended to provide an in depth description of one reflective activity with potential use in design courses. This activity has been implemented numerous times by the authors in their courses and workshops, particularly to discuss the engineering design process or reflection.

A Knowledge or World Cafe [20] is an activity designed to allow large groups to have meaningful dialogues about a topic. The large group is broken down into smaller subgroups, ideally multiples of the group size (e.g., 6 groups of 6 participants each). Participants sit around a table and are each given a marker and two toothpicks (or paperclips). A large working space (e.g., $2' \times 3'$ piece of paper) is placed at the center of the table. The first step each group undertakes is to write the topic to be discussed in the middle of the working space. For example, "what is engineering design?" or "how would you go about designing a car?" Participants are asked to reflect on their past experiences and knowledge regarding the presented question. Group members are encouraged at all times to write and record their thoughts on the working space, via written text or drawings, ideally utilizing a brainstorming approach. The dialogue is constrained using a set number of toothpicks given to each participant. Participants "use" a toothpick each time they decide to share a thought verbally; this step encourages all participants to speak and discourages normally verbose group members from monopolizing the dialogue. The group eventually creates an initial mind map (see example in Fig. 1a) that provides an artifact to communicate their overall thoughts on the topic. Each table is designated a number, and participants are then asked to count-off at their table. One individual is designated the facilitator and takes the number of their table. All participants, except the facilitator, move to the table of the number they just selected essentially creating a set of new groups consisting of at least one member from all previous groups. The facilitator then provides a summary of the previous dialogue. The entire activity repeats again with toothpicks and writing on the working space. It is in this step that each group member represents the previous conversation they had within their previous group. This process affords every individual to learn about each dialogue that occurred within the larger group allowing each table to converge on a set of central themes about the topic. The final phase of this activity is for all participants to return to their original groups to share what they have learned. The instructor asks the teams to come up with the top points from their mind map and share with the class (see example in Fig. 1b where participants were asked to create a shared engineering design process). Sharing is constrained by asking groups to only share what has not yet been shared about the topic. Truly successful Knowledge Cafes typically end with the final group having little or nothing to share. The instructor should conclude with a discussion on the topic that was just discussed. This provides the necessary feedback for students to recognize how they might apply this information in the future.

Many of the reflection activities listed in Table 1 are written assignments guided through prompted questions. These types of assignments lend themselves well to assessment tools. The Knowledge Cafe presented here is different because it relies on the experiences and knowledge of the participants to encourage meaningful reflection that connects learning with "continual interweaving of thinking

and doing" [6]. As Ambrose argues, ". . . students learn by doing, but only when they have time to reflect on what they are doing—the two go hand in hand" [13]. This activity essentially is a group-based, active-learning reflection intended to help participants reflect on and in-action to inform future actions.

3. Research methods

This study sought to understand and differentiate student and educator's definitions of reflection prior to any discussion on the application of reflection in engineering education. If educators appreciate differences in how individuals view reflection, then reflection activities and discussions can be better developed to hone the skill of reflection.

3.1 Data collection and sampling

Data sets representing both engineering educators and students were collected through multiple platforms to obtain a varied sample of participants for this study. Each participant was asked to provide a written response to the question, "How do you define reflection?" The responders were asked to not use outside resources such as dictionaries when providing their definition. The survey was administered to all senior students enrolled in a first semester engineering capstone design course offered in Fall 2015 and Spring 2016. Of 168 students enrolled in the course, a total of 114 students consented to participate in the study, for a 68% response rate.

Engineering educator surveys were administered to participants attending a workshop at the 2016 Capstone Design Conference and to those attending a presentation on student perceptions of reflection at the 2016 ASEE Annual Conference. These engineering educators provided their responses at the beginning of the workshop or presentation session prior to any discussion. A total of 25 consenting responses were collected at the Design Conference and 49 consenting responses from the ASEE Annual Conference. One of the 49 respondents was removed from this analysis due to their involvement with CPREE. The combined sample of engineering educators resulted in a total of 73 consenting responses.

3.2 Data analysis

Data collected from consenting students and educators attending the conferences were analyzed using a multistep qualitative and quantitative process undertaken by three raters. The first step included tabulating and compiling all respective responses into word clouds to identify keywords that could potentially be used to code participant responses. Keywords were identified according to relative size of how they appeared in the word cloud, where larger words were indicative of how often it was used in comparison to the syntax in all responses. For example, the most prevalent word in Fig. 2 is "reflection", which is relatively large due to the fact that it showed up in nearly every response written by the student participants. For students and educators alike, several keywords were used

Fig. 2. Word cloud of responses from EGR 401 (capstone) senior students (created on www.wordle.net).

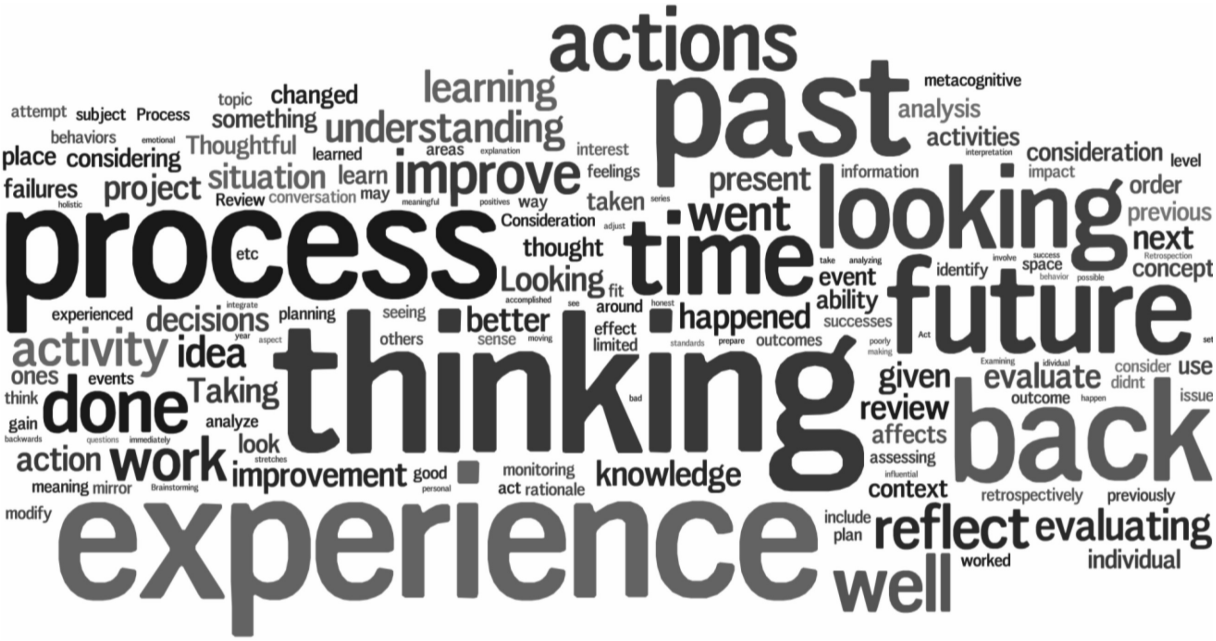

Fig. 3. Word cloud of responses from 2016 Design Conference and 2016 ASEE Conference engineering educators (created on www.wordle.net).

consistently such as "looking back", "process" and "future" as can be observed in Fig. 2 and 3.

Next, an initial set of codes using the compiled world clouds was established. The goal of this coding scheme was to classify the responses into one of the three emergent categories based on the theoretical framework and research previously discussed: (1) reflection-on-action, (2) reflection-in-action, and (3) reflection-then-action. The set of indicator words identified for each assisted in identifying when a response should be coded within a particular category as shown in Table 2. 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.

Each participant's response was then coded into one of the three categories with 2.6% of student responses and 4.1% of engineering educator responses being coded in two or more categories. Questionable responses were independently rated by all raters and discussed until an agreement could be reach as to the appropriate category for the response. Table 3 provides examples of the categories for which student and engineering educator

Table 2. Emergent code words from word clouds and associated reflection category

Question	Category	Code Indicator Words
How do you define Reflection?	**Reflection-on-Action**	Looking Back, Past, Work Done, Previous, Memory, Experience
	Reflection-in-Action	Process, Present, Work Flow, Ideas
	Reflection-then-Action	Future, Improve, Inform, Understanding, Learning

Table 3. Coding scheme for students and educators including examples

Category	Student Responses Examples	Educator Responses Examples
Reflection-on-Action	"Looking back on the past in order to see what was changed for better or worse."	"Looking on past experiences and assessing how it has changed or influenced your life."
Reflection-in-Action	"Reflection is the opportunity to hear everyone's ideas and thoughts on a process to implement [in a design]."	"Pausing in the process flow of work to review successes, failures, next steps, and to better define a course of action."
Reflection-then-Action	"For me, reflection is a process you go through. It is when you have either succeeded or failed at an activity and are now looking back at it to understand what occurred. This is done with the hopes of garnering a deeper understand and experience that you can use for future endeavors."	"Taking time to think about past experiences in order to use these to improve future decisions."

Table 4. Percentage of responses coded for each category

	Reflection-on-Action	Reflection-in-Action	Reflection-then-Action
Students	48.2	35.1	19.3
Engineering Educators	47.9	26.0	32.9

responses were coded. Responses coded in the reflection-on-action category describe reflection as looking back on the past to evaluate the events that transpired, but provide no indication that the information should be used in the future. Responses coded as reflection-in-action provided a viewpoint of reflection as more of a "process"; one that is neither past nor future, but rather, a process that takes place simultaneous to the action or task at hand. Responses coded in the reflection-then-action category demonstrated a perception of reflection as an opportunity to reflect on past events and, subsequently, to inform future actions based on lessons learned. The reflection-then-action responses also demonstrate how context played an important role in the coding scheme, as these make reference to both past experiences and future actions. Though these responses include statements on looking back on the past, it was not coded as reflection-on-action due to the fact that the participants clearly demonstrated a belief that reflection can inform future decisions.

4. Results

Table 4 displays the overall results from both students and engineering educators. The highest percentage (48.2%) of student responses focused on reflection as the act of looking back at previous undertakings. The responses suggest that most students perceive reflection to be a tool utilized only to evaluate past experiences. A moderate percentage (35.1%) of the students saw reflection as an act to be utilized to make real-time decisions while in the midst of a process. Fewer (19.3%) students recognized reflection as a tool that could be used to influence future actions.

The engineering educator responses were widely distributed across the three categories with similar percentage (47.9%) to students describing reflection as thinking about an action that has already occurred. A smaller percentage (26.0%) of educators than students described reflection as a practice that occurs while involved in the process of an action, while a larger percentage (32.9%) described reflection with the intent to then utilize that information in the future.

5. Discussion and Limitations

The objective of both the reflection activities and the survey analysis was to determine if students and engineering educators understood the purpose of reflection and appreciated the skill as a life-long learning tool. The findings of this study suggest that students and engineering educators both view reflection primarily as an opportunity to evaluate what they have done in the past, with nearly 50% of all responses only focused on reflection as looking back at previous experiences. When initially asked to define reflection, a relatively low percentage of students and educators mentioned the future, either in terms of themselves or their project. This suggests that there is not an intrinsic connection between what has been learned from previous experiences and that reflection can be used to inform future decisions. This contradicts what we as educators want students to learn about utilizing reflection as a life-long learning tool that can influence their future. Simple, explicit highlights of the purpose for reflection as a professional and metacognitive skill may help to inform students' perceptions of reflection. Other responses to the survey go beyond reflection on the past, to include descriptions of reflection as a process or something to inform future decisions. These responses are important to recognize as it shows that some students already identify reflection as a skill to be employed. Approximately 30% of students and engineering educators viewing reflection as a process hint that both groups could benefit from additional resources and practice that demonstrate what reflection is and how it can be used as an engineering skill to influence future decisions. Reflection in-action takes place in bounded situations that could be a matter of minutes to weeks or months, i.e., it is dependent on the action [6]. The implication of reflection as a process can support the skill of self-directed learning necessary in today's changing world. The cycle of self-directed learning is briefly summarized as a "basic metacognitive processes in which learners assess the task, evaluate strengths and weaknesses, plan, apply strategies, monitor performance, reflect, and adjust if needed" [21]. This process needs to be supported by deliberate in-class activities and individual writing assignments that allow students to assess and guide their learning [21]. The more we, as educators, understand the fruits of reflection, the better we can design our in-class activities and assignments.

The limiting factor to this study is that we do not know exactly how students and educators feel

toward or value reflection. Anecdotally, students have sometimes been heard to say that reflection assignments are just busy work and potentially believe that such activities are a waste of effort that takes time away from "more important" technical aspects of a design project. The latter sentiment is sometimes also heard from educators while designing courses limited by the academic calendar. Such sentiments were not captured in this study primarily due to the questions asked. There is also the potential that students responding to the survey as a class assignment may have responded in ways that they thought would earn them the highest score, as opposed to recognizing the learning opportunity that occurs when taking an introspective focus through reflection. This is where we, as educators, could better explain the purpose of reflection (as a metacognitive and a professional skill) and diversify the types of reflection activities we require of our students. "In-class engagement can provide an opportunity for analytical and integrative thinking, with immediate feedback from peers and the instructor" [13]. Examples of these in-class activities include the peer instruction strategy, a well-structured case study, or the Knowledge Cafe as described earlier in this paper [22–24]. There are many other ways of doing this in the classroom, but it is paramount that the intervention provides real-time feedback. This feedback is critical in these reflective activities, helping to close the loop with student learning [21].

We believe that despite our limitations, we have provided the groundwork and foundation for future research, including data collection of post-intervention surveys to measure the gains achieved in student and engineering educator perceptions of reflection and better understanding how student, educators and practitioners value reflection (see forthcoming work in [25]). It would likewise be beneficial to assess the frequency and types of reflection activities engineering educators implement into the design courses they teach to determine the effectiveness of these exercises for improving student perceptions of reflection. We hope that these future endeavors will provide greater insights into the future integration of reflection throughout all of engineering education.

6. Conclusion and implications

The practice of reflection in engineering education must be encouraged to help students better understand the significance of reflection as a professional practice. Our analysis of student and engineering educator perceptions provides insight as to what notions of reflection are brought into design courses. It furthermore describes how educator perceptions can be expanded to improve upon the methods by which reflection is taught to engineering students. A higher percentage of students and engineering educators must recognize that reflection is a process and an important engineering tool that is inherent to both past experiences and future actions.

It is also necessary to better understand how reflection can intentionally impact various stakeholders involved in engineering design. Such a skill can be easily developed over the course of an engineering program if reflection is introduced early and practiced regularly 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, both in and out of class, supported by instructor feedback to enhance their learning.

We hope that the work of CPREE and the presented findings in this paper encourage engineering educators to simultaneously improve their own notions of reflection while helping transform student perceptions. This will help to ensure that those in academia more readily recognize the need for reflection as a means for providing guidance on future endeavors. Implementation of the various reflection activities outlined within this paper and through CPREE is just a start.

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