Learning and Professional Development Through Integrated Reflective Activities in Electrical and Computer Engineering Courses

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***Abstract*— This Research-to-Practice Full Paper describes the implementation of integrated reflective activities in two computer engineering courses. Reflective activities contribute to student learning and professional development. Instructional team members have been examining the need and opportunities to deepen learning by integrating reflective activities into problem-solving experiences. We implemented reflective activities using a coordinated framework for a modified Kolbian cycle. The framework consists of reflection-for-action, reflection-in-action, reflection-on-action, and composted reflections. Reflection-for-action takes place before the experience and involves thinking about and planning future actions. Reflection-in-action takes place during the experience while actively problem-solving. Reflection-on-action takes place after the problem-solving experience. Composting involves revisiting past experiences and reflections to inform future planning. We describe the reflective activities in the context of the coordinated framework, including strategies to support reflection and increase the likelihood of engagement and success. We conclude with an analysis of the activities using the CPREE framework for reflection pathways.**

Keywords—reflection, learning cycle, composting, professional development, processor design, embedded system

I. Background

In the Electrical and Computer Engineering Department at Iowa State University, we are redesigning core courses in the sophomore and junior years through a collaborative instructional model and teaching strategies that promote professional formation. Professional formation of engineers refers to the formal and informal processes and value systems through which people become engineers [1]. Professional formation includes development of technical and professional knowledge and skills, of ways of thinking, and of identity as an engineer.

Reflection by students contributes to their learning, professional development, and lifelong learning skills. Simply put, reflection is a process of thinking about and making sense of experiences. Through reflection, a student thinks about their experiences, asks questions, and seeks answers having meaning and practical relevance. Reflection helps a student uncover and refine their mental models. Mental models are conceptual representations used to understand and interact with a problem being solved. For complex problem-solving that is new or abstract to students, mental models are pivotal to learning. They are simplified versions of the concepts they represent and are constantly evolving. Learning processes influence mental models, and improving a mental model can deepen learning. In several electrical and computer engineering courses, instructional team members have been examining the need and opportunities to deepen learning and professional formation by integrating reflective activities into problem-solving experiences.

Reflection has been studied extensively, starting with early theorists [2-4] and more recently in engineering education [5-10]. In this paper, we describe how their work has influenced the design, integration, and analysis of structured reflective activities introduced in two computer engineering courses. One of the members of our collaborative instructional team has extensive theoretical and practical experience with reflection. He applies a modified Kolbian cycle [10,11], and this cycle has guided the development of integrated reflective activities.

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The original Kolb learning cycle is shown in Fig. 1. It consists of four steps of experiential learning, starting with the experience, followed by reflecting on that experience, generalizing concepts about the experience from the reflection, and testing new concepts. Educators observed that students did not fully engage with the testing and experimenting step. Students would try learning and generalizing from their experience while avoiding active experimentation. This common shortcut bypasses in-depth engagement with the cycle. A solution proposed by Cowan is the modified Kolbian cycle, as shown in Fig. 2, which he referred to as coordinating Kolbian reflections. The modified model uses a more integrated set of reflections, including reflection-for-action, reflection-in-action, reflection-on-action, and composted reflection. Schon's work underscores the importance of reflection-in-action to professional formation. With this modified model, students are encouraged to do more in-depth reflections throughout the cycle.

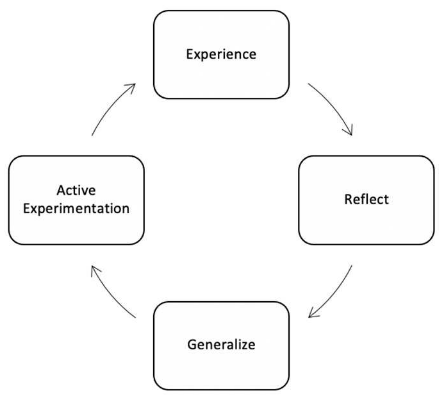

Fig. 1. Kolb learning cycle.

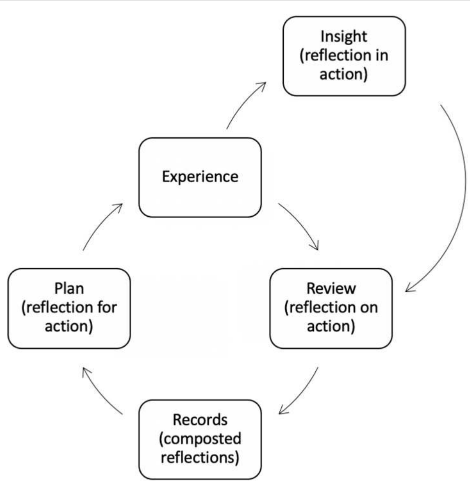

Fig. 2. Modified Kolb learning cycle.

II. Reflection Prototyping

Reflection activities were prototyped by instructional teams, referred to as x-teams, in two courses: CPRE 288, Introduction to Embedded Systems, and CPRE 381, Computer Organization and Assembly Language Programming. CPRE 288 is a prerequisite for CPRE 381, and both are required in the computer engineering curriculum. CPRE 288 is also required for electrical engineering and cyber security engineering majors. The x-team model is being developed and used as part of an NSF Revolutionizing Engineering Departments (RED) grant [12-14]. An x-team includes and supports the instructor of a course. It leverages practices and tools from design thinking and engages in collaborative design and reflection to implement student-centered teaching approaches [15]. Design thinking tools that have helped x-teams better address student needs include empathy maps, personas, and journey maps.

Each x-team identified specific experiences and opportunities for reflection. The CPRE 381 x-team was first to prototype reflective activities using a coordinated reflection framework based on the modified Kolbian cycle in Fig. 2. It prioritized several goals based on personas during fall 2019, developed a prototype, and incorporated activities during spring 2020. The x-teams developed reflective activities to support each step of the cycle, consisting of reflection-for-action, reflection-in-action, reflection-on-action, and composted reflections. Reflection-for-action takes place before the experience and involves thinking about and planning future actions. Reflection-in-action takes place during the experience while actively problem-solving. Reflection-on-action takes place after the problem-solving experience. Composting involves revisiting past experiences and reflections to inform future planning. Questioning, in particular self-questioning by a student, occurs during each reflection step. The activities continued to be refined and used during spring 2021.

In the next sections, we describe the CPRE 381 and CPRE 288 implementations of reflection activities inspired by the modified Kolbian cycle. Our purpose is to describe the activities in the context of the coordinated framework and make observations that might help other educators. We conclude by reflecting on the design of the activities using a reflection framework from the Consortium to Promote Reflection in Engineering Education (CPREE) [5,6,16]. The focus of this paper is on the prototyping of integrated reflective activities by the instructors and x-teams.

III. Reflective Activities in CPRE 381

CPRE 381 is a required junior-level computer engineering course on computer organization and assembly-level programming. This course has a core experiential lab component where students design, test, program, and optimize a processor from basic logic gates all the way to a platform that can execute nearly arbitrary assembly code for a commercial instruction-set-architecture. Once completed, the goal is for students to have complete ownership over a whole processor design.

Students begin to design the subcomponents of the processor starting on the first day of their lab and continue to design, implement, integrate, and test increasingly complex components until they have a base processor design and two performance-optimized processor designs by the 14th week of lab. No solution designs are provided -- the entire implementation is expected to be the direct result of students' own work, thus affording them the opportunity for a deep, intuitive understanding of the entire design. Deadlines, rubrics, and planning structures are set up to encourage students to complete the baseline processor's functionality first prior to moving on to the optimizations. Since the lab assignments directly build on top of the previous assignments, the ability to correct issues in process as well as design are critical for student success, both in terms of producing a functional design and a deep understanding of that design.

Within our department, this course had a reputation of being time-intensive and tedious. Many students in the course reported being overwhelmed by lab work and could not see the connection to the rest of the course and, indeed, their career paths. We began soliciting further feedback from students on where they were spending time, what they would change about the experience, and what they found value in during the experience. Through this feedback, we identified a few common themes. First, students reported great tedium in describing a hardware design as text in a hardware description language (e.g., VHDL) and then having to thoroughly test it using a testbench module. Second, and somewhat contradictory, students had the perception that most student processors just didn't work by the end of the semester. Apparently, students did not link testing to an understanding of confirming that processors work and/or the necessity of confirming components work well prior to integrating them into a final design. Finally, students often complained about a lack of connection between the course material and the labs. For example, they did not see how the initial labs about building components for their processors were connected to the assembly language they were learning nor the eventual processors they were building.

Overall, we began to realize that our students were not thinking about why they were doing the detailed tasks and how those tasks were related to the course itself. Therefore, we began to devise changes to the course to encourage students to think more deeply about their lab work through a series of reflective activities.

A. Course-level Reflective Cycle

We implemented reflective cycles on two levels as shown in Fig. 3 -- the full course-level and the assignment-level.

At the course-level, students arrive at the first lab having had several semesters worth of experience in computer engineering education. They have had experiences with digital logic, C programming, teamwork, and term projects -- all important aspects of this lab experience. The first four weeks of the lab serve as an introductory review, in which students build components needed for future processor designs, but that students already have used and implemented in digital logic. One difference is that these labs have an increased emphasis on HDL implementation and testing. These labs represent both a composted reflection of the pre-requisite courses as well as a partial reflection-for-action for the core content of the lab experience.

When students are done with the introductory labs, they are grouped into larger teams for the term project. They work on a basic processor design -- single-cycle processor -- and two optimized processor designs -- pipelined processor 1 and 2. As previously observed, there is a significant challenge in implementing and testing functionally correct processor designs so higher-level concepts like performance of the design (i.e., the motivation for pipelining) are often lost on students. Therefore, a final, written lab component was added for the 15th lab session that serves as a reflection-on-action and results in a composted reflection of the entire lab experience. This final component included a performance comparison of the three processor designs and a performance analysis of why/when each design

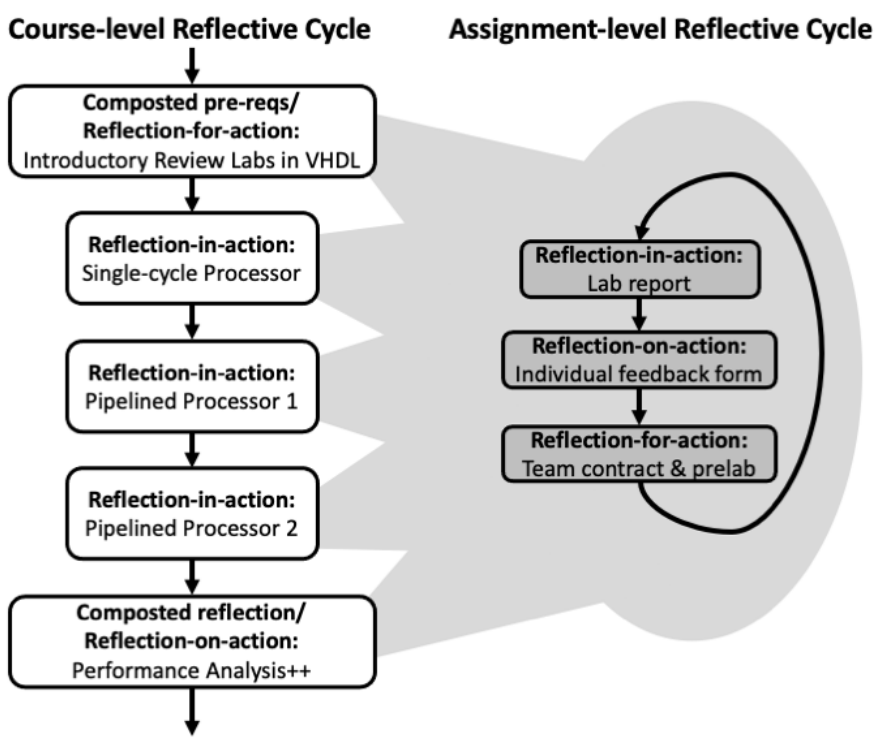

Fig. 3. Reflective cycles in computer organization course.

achieved better performance. Note that the specifics of these designs were unique to student groups and no points were deducted based on having poor performance -- points were given for the quality of analysis. Students were then asked to propose (but not implement) optimizations to best improve the performance of their designs. Finally, students were asked to identify from throughout the entire project what their major challenges were, if/how they resolved them, and how they could avoid/mitigate them in the future. Ideally, this final component effectively serves as a composted reflection of their semester that can be used to strengthen what students take out of their course experience for future courses and their careers (i.e., used for further reflection-for-action).

B. Assignment-level Reflective Cycle

At the individual assignment-level, also shown in Fig. 3, we restructured the individual lab assignments around a reflective cycle. Prelabs and team contracts (for the term project assignments that involved groups) were used as reflection-for-action. In these assignments, students were asked to think about past experiences designing digital logic, using VHDL, and working together on a team to plan the next portion of the lab. Students had a lighter-weight, templated lab report representing reflection-in-action. This is intended to help students complete the labs as envisioned, including the various portions of the design cycle that are needed before a student begins to write VHDL code. Finally, an individual feedback assignment due after the lab report represents reflection-on-action. Here students record the time they spent on various types of tasks (e.g., reading lab materials, designing "on paper", implementing in VHDL, testing, debugging, and writing the lab report), what went well, and what did not go well (for them as an individual, as a team, and with respect to the assignment/course itself).

C. Supporting the Reflective Activities

We recognized that additional time spent reflecting should be balanced with less time on other course tasks, in particular, for the reflection to be meaningful. Therefore, we took several steps to reduce the amount of work in other aspects. For example, we reduced the repetition of learning a multitude of equivalent VHDL constructs during the introductory labs, and we reduced the effort on written lab report components. Effectively we rebalanced reflective time from only reflection-in-action to include more reflection-for-action and reflection-on-action. Additionally, we also took steps to have students continually practice thinking about and communicating, in writing, their experience in the course to instructors with the hope that this practice increased students' effectiveness and efficiency with the reflective process. Examples of these include generating possible exam problems/solutions (reflection-for-action), taking an exam and reflecting on how well they felt it went (reflection-in-action), and then redoing a problem while identifying a misconception or process issue with why they did poorly (reflection-on-action).

The success of the activities is also dependent on the instructor's familiarity and engagement with the reflective cycle and willingness to model it themselves to change their approach to the course. For example, in early iterations, there was not a lot of feedback provided to the students from the various reflective components of the course. When the instructor implemented changes (even relatively small changes such as time of day for deadlines or spacing of deadlines) or even addressed the reasoning behind course design decisions, students responded with more detailed and more insightful feedback. This was then coupled with an increased number of smaller reflective cycles throughout the course. The end result was more students demonstrating a more complete (and correct), more specific, and richer final project.

Students have shown greater appreciation of tying their hard-won design experience back to higher-level concepts such as performance analysis. For example, a student commented, "Seeing the integration of components and having the chance to more deeply analyze the performance of our processors using the knowledge that we gained in lecture over the semester." Notably, comments also indicated that students recognize that process skills -- teaming, communication, and coding standards -- are important for their careers and plan specific ways to improve those skills.

Going forward, given that we observed positive benefits using the reflective cycles in the course, we will continue to employ these components. However, we will modify them in a couple ways. First, in order to bootstrap the process and better allow students to connect to their pre-requisite knowledge, we will use a prelab reflection for the initial lab that will include questions asking students to reflect on and compost their previous lab experiences. Second, as the projects start, we will support more frequent reflection *during* the processor design projects to help students think about problematic behavior when they still have time to change it.

IV. Reflective Activities in CPRE 288

CPRE 288 is a required sophomore-level course, introduction to embedded systems, taken by computer, cybersecurity, electrical and software engineering majors. The course introduces students to hardware and software aspects of embedded systems including microcontrollers, memory, input/output interfaces, embedded programming in C, initialization and configuration of peripherals, polling and interrupt processing, and mobile robots.

The course starts with foundational concepts and skills, then concentrates on understanding and using microcontroller peripherals, and finishes with a project in the lab for an autonomous vehicle application. The final project is introduced early and phased in through class and lab activities. Students work with partners in the lab and then on teams for the final project. The mobile robot in the lab can be controlled with commands from a microcontroller board. The microcontroller board interfaces to input/output devices added to the robot, including an infrared sensor, ultrasonic sensor, and servo motor. In the final project, teams program the microcontroller to move the robot through a test field and avoid obstacles to reach a destination. The lab platform is a complex system, lab work is multifaceted, and students have wide-ranging backgrounds and skills. From the instructor's perspective, lecture and lab content and flow are tightly coupled, however, making these connections is challenging for many students. Students are also interested in the connections to their careers. The course supports learning and professional development in various ways, and there has been a focus on student engagement in designing elements of the course [17,18].

Some members of the CPRE 288 x-team also were involved with the CPRE 381 x-team. The reflective cycles used in CPRE 381 were developed first and served as a prototype for this course. While reflective activities already were in use in this course, the instructional team observed that a more integrated and structured approach to reflection would be helpful in many ways. The course has focused on embedded programming, technologies and design. However, we've noticed that student learning about the system, problem solving, and engineering work are sometimes reflected in their performance in debugging. Debugging is tied to asking and exploring meaningful questions and generally making sense of a complex system. We thus turned to using reflection to make students more aware of key aspects of the lab experience using particular perspectives.

A new reflective cycle and activities were initiated during spring semester 2020 (somewhat curtailed due to the transition to virtual instruction due to the pandemic) and were used again in spring semester 2021 (also virtual but planned accordingly). They were designed by the instructional team, drawing on experiences of team members and research on learning and reflection (as described earlier) and questioning [19-21]. The cycle and activities are integrated into the lab workflow to reinforce learning, problem solving, and lecture-lab connections. There are nine regular labs, one per week, and a lab project over several weeks. Every regular lab has a prelab assignment. A postlab assignment was added as a new reflective activity. When first introduced in spring 2020, a postlab was assigned with every regular lab. However, given student feedback, we scaled back in spring 2021. A postlab was assigned about every two labs (e.g., after labs 2, 4, 7, and 9), and students could choose which of the immediately preceding lab experiences to focus on.

The postlab reflective activity is part of a reflective cycle integrated into the lab workflow. Overall, CPRE 288 is structured using a cyclic workflow to prepare for, do, and wrap-up a weekly lab. Fig. 4 shows a general illustration of the lab workflow for Lab N. For example, consider the work associated with a lab, such as Lab 2 (programming the robot to move).

a) Lab 2 is performed during Week 3. See item (4) in the figure.
b) Lab 2 is prepared for starting in class at the end of Week 2 with an introduction to new concepts and technology. See item (1).
c) Lab 2 is prepared for with a prelab assignment due before lab meets in Week 3. Class time early in Week 3 includes some time for preparation. See items (2) and (3).
d) Students may need to prepare on their own and/or with groups outside of class and lab.
e) Lab 2 is worked on during scheduled lab period during Week 3. See item (4).
f) Students may need to work outside of lab to complete the lab.
g) Lab 2 is wrapped-up no later than the next week, Week 4. Wrap-up may include review in class early in Week 4 and/or a postlab assignment. See items (5) and (6).

Week X	Week Y	Week Z
Lab N-1 in lab (1) Start preparing for Lab N in class	**Lab N in lab** (2) Prelab assignment for Lab N (3) Class time for Lab N prep (4) Lab N during lab period	**Lab N+1 in lab** (5) Review Lab N in class (6) Complete Lab N and postlab

Fig. 4. General lab workflow in embedded systems course.

This results in the following reflective cycle integrated with the lab and based on the modified Kolbian cycle, where (1)-(6) refer to items in Fig. 4:

1. **Reflection-for-action**: (1)-(3)
   - The prelab includes a system sketch. (2)
   - Lab preparation is facilitated using an in-class lab planning activity based on the Question Formulation Technique (QFT). (3)
2. **Reflection-in-action**: (4), (5)
   - The lab experience includes functional, debugging and questioning demonstrations. (4)
3. **Reflection-on-action and composting**: (5), (6)
   - Lab review is facilitated using an in-class one-minute storytelling activity. (5)
   - The postlab includes documentation of three items: prelab planning notes, lab experience notes, and a lab retrospective. (6)

Some of the items in this workflow were already present in the course but were modified to better support the reflective cycle. For example, more emphasis was placed on the system sketch in the prelab. The lab demonstration was extended to go beyond demonstrating functionality only. Other items were added to create a complete cycle, such as the postlab.

A. Reflection-for-action

The prelab assignment, item (2) in the workflow, includes a system sketch as a reflection-for-action activity. The first question of each prelab asks students to sketch a diagram that shows how hardware peripheral(s) being used in the lab activity connect to the microcontroller. The sketch is usually a combination of a high-level block diagram and selected low-level details, such as microcontroller port names and pins. These details are then part of the input/output interface used by the embedded program, thus helping students see the relationship between the hardware and software. The system sketch is then revisited in later steps of the reflective cycle, on exams, and in the lab project.

An in-class planning activity, item (3), asks students to prepare for the lab by asking and prioritizing questions and using

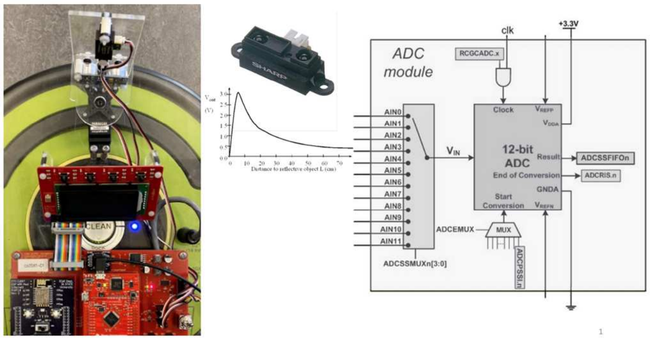

Fig. 5. Sample QFT visual artifact for questioning activity in preparation for a lab.

these questions to think about what they need to know and need to do in lab. Based on QFT, a "question focus" visual artifact is used as prompt for the questioning activity. A sample visual artifact is shown in Fig. 5, which corresponds to the lab in which students program an analog-to-digital converter to read an infrared sensor to measure distance. Concepts associated with this artifact would be previewed in lecture at the start of the workflow under item (1), and then the lecture during the week of the lab elaborates on elements of the artifact. The goal is to help students make connections between concepts in lecture and technologies and phenomena in lab, including asking their own questions in advance.

B. *Reflection-in-action*

During the lab experience itself, item (4) in the workflow, students will demonstrate the functionality of the lab. In addition, we added two other demonstrations, a debug demo and a question-and-answer (Q&A) demo, to specifically draw attention to, make them aware of, and give them practice with these key aspects of the lab experience. For the debug demo, students demonstrate the use of debugging and/or the debugging tool to explain something about the internal workings of their system. For the Q&A demo, students demonstrate questioning skills by answering a useful question, such as a question from lab planning or a question created while doing the lab; and by generating a relevant and appropriately focused question that has some purpose, such as to clarify a topic, understand a relationship, make connections, explore what is and is not known, make judgments, express curiosity, challenge ways of thinking, test new ideas, etc. The debugging and questioning work in lab is also revisited in later steps of the reflective cycle, such as the postlab reflective activity.

C. *Reflection-on-action and composting*

Reflection-on-action includes an informal active learning exercise in class after everyone has participated in their lab session. Organized using a think-pair-share technique, students are asked to join with their lab partner and others in small groups and tell a story about their lab experience. Usually most students would not yet have completed the postlab assignment, however, they can use the postlab questions as prompts for their stories. Given a large lecture class, only one or two groups are asked to report out to the entire class. While this exercise worked better when in-person than virtual, it gets students remembering and talking about their past lab experience and lets the instructor provide immediate feedback.

The postlab assignment, item (6) in the workflow, uses a worksheet to guide students in documenting and reflecting on their lab work and experience. It consists of three parts: 1) prelab planning notes, such as questions and tasks from the QFT lab planning activity; 2) lab notes, such as follow-up on their questions, what they learned from debugging, and updates to their system sketch; and 3) a retrospective on their lab experience. The retrospective is in the form of an after-action review (AAR) [22-25], asking the following questions:

1. What did we set out to do?
2. What actually happened?
3. Why did it happen?
4. What are we going to do next time (to improve)?

To keep the reflection workload more manageable for students, a postlab is not assigned for every lab and instead about every other lab. Students choose what lab work to reflect on from the preceding period.

Other reflective activities in the course are outside of the weekly lab cycle. They support reflection-on-action of specific course experiences and composting of the overall course experience. The purpose of these activities is consistent with the goals of reflection in the course – to help students make connections within the course and with engineering work and be better learners, problem solvers and engineers. These activities include: five whys activity, plus/delta survey, and lab project survey.

Students have the option to get extra credit on problem-solving activities (e.g., homework, exams, project) by using the five whys method (or chain of whys) for structured questioning and root cause analysis [19]. Like the AAR, this method is also an industry practice, which motivates use by students. The following instructions are given for a five whys activity:

Follow the Five Whys method to identify your mistakes and correct them. Submit your work in applying the method, including the why questions you asked and answered along with your revised solution. Also explain what you concluded about the root cause. Any student, regardless of score, can do this assignment. If you had very minor mistakes that don't support a Five Whys analysis of an incorrect solution, then flip this around and ask yourself why you ended up with a correct solution. Think about what knowledge, skills, behaviors or attitudes led to a successful result.

A midterm plus/delta survey is administered with the following questions:

1. What is helping me to learn in this class?
2. What am I doing to improve my learning in the course?
3. What changes are needed in this course to improve learning?
4. What do I need to do to improve my learning in this course?
5. Think about the concepts from the list of concepts. Select a concept that you like and explain why.

6. Select a concept that is, thus far, difficult for you, and explain why or how.

The questions about concepts are intended to make students more aware of the concepts in the course. Lists of concepts are presented every week. Students sometimes see their learning mostly in terms of lab activities (not surprisingly) and have a hard time connecting lab activities to concepts and other class activities and generalizing these to other systems and applications.

Lastly, at the end of the semester, students complete two surveys about the lab project, a team evaluation and a project reflection. In the evaluation survey, in addition to teamwork ratings, students are asked to describe their most significant contribution to the project (any type of contribution), and something they learned about working in a group that they will take into their next group experience and/or the workplace. In the project survey, open-ended response questions include:

- What was the best aspect of the project? Why?
- What would you most want to change about the project? Why?
- What skills, knowledge, and attitudes that you learned during the final project would you expect using in your future engineering work or practice? Why?
- What aspects of the final project that made you feel like an engineer? Please consider any and all activities related to the final project.
- What aspects of the project did not make you feel like an engineer?
- Do you have any other comments about your experiences on the final project?

These questions are intended to have students think about the project and their experience at a higher level, especially from the perspective of being an engineer.

D. Engaging with Reflective Activities

One of the keys to successful reflective activities is having them integrated into the course. The activities in CPRE 288 happen in the regular flow of the course and labs. The purpose of a reflection assignment is communicated to students. As in CPRE 381, students may see that their feedback is listened to. Students may also feel that the reflections are helping them think about the labs and their experience. Overall, students have appeared to be very receptive to and engaged with the integrated reflective activities in CPRE 288.

One indicator of student engagement is the quantity and quality of their reflection responses. For example, out of 228 students in the course during spring semester 2021, 187 students (82%) completed the midterm plus/delta survey. 227 students (almost 100%) completed the final project reflection survey. Each of these surveys was worth only 5 points, and thus students may have seen some value beyond points in doing the reflections. Even by midterm, a culture of reflective practice in the course was being promoted.

In the midterm survey, the average response per student per question was about 30 words, or 1-2 sentences. This included the option to "skip" a question, so some question responses were longer. Samples of responses by different students are given below, illustrating the quality of the responses as well as some direct and indirect effects of the reflective activities.

The labs incorporate a lot of the concepts learned in class and I think that helps me to understand them better.

The labs are probably the best mechanism for learning. I'm a big proponent of "doing" to learn stuff and the labs help me think about the systems we are working with in a cohesive manner.

Completing the labs is providing awesome insight on how to use the software to interact with the robot. The textbook has amazing interactive tools which are helping me reinforce knowledge. And the quizzes are excellent ways to prepare for the exam.

The open homework where we are having to search for sources is very helpful because the sources are full of information I might have missed or forgotten from lecture. The labs are also very useful because we get to put everything we are learning into action and we can see how well we actually know the topics.

I am re-watching parts of lectures that go over topics that I do not feel fully confident in. Additionally, looking at code from the labs helps remind me about how to do certain things that is covered within those labs.

The prelabs and postlabs really are helping me learn. The Valvano and Yerraballi book is also a great resource - I turn to it if I have any questions.

V. Analysis of Reflective Activities

In the preceding sections, we described the implementation of integrated reflective activities in two computer engineering courses in the context of the modified Kolbian framework. In this section, we analyze the activities using the reflection framework developed by Atman, Turns and collaborators in the Consortium to Promote Reflection in Engineering Education (CPREE) [5,6,16]. The CPREE framework focuses on "reflection on experience" whereby a student revisits features of an experience with which they are aware and uses one or more lenses in order to assign meaning to the experience that can guide future action. As such, it describes a set of elements of reflection and includes these in a template used to "unpack" the reflection activity, as listed below. [5]

1. What <u>experiences</u> are emphasized by this reflection activity?
2. To what extent does the reflection activity help students become aware of particular <u>features</u> of the experiences?
3. To what extent does the reflection activity involve students using a particular <u>lens</u> (or <u>perspective</u>) for making sense of the experiences?
4. To what extent does the reflection activity support students in constructing <u>meanings</u> from the experiences?
5. To what extent does the reflection activity support students in identifying <u>future actions</u>?

Combinations of these elements are referred to as pathways of reflection, and any particular experience might lead down different pathways. Like the modified Kolbian cycle, the

CPREE framework emphasizes intentionality, in which students actively and knowingly engage in the process. In addition, the CPREE template addresses evaluating the outcomes of an activity in three areas: accountable disciplinary knowledge, identity, and preparation for future learning. The CPREE work notes that, before evaluating the outcomes, it can be important to understand if the activity engaged students in reflection. Various strategies to support reflection and increase the likelihood of engagement and success are interspersed in the referenced papers.

A. *Unpacking the Individual Feedback Activity in CPRE 381*

One of the reflective activities in CPRE 381 is the individual feedback assignment. Here we "unpack" that activity using the CPREE framework. Starting with the first element, the experience emphasized is the lab work, as the individual feedback is submitted after each lab assignment. In terms of features of the lab experience, specific attention is given to particular technical and non-technical aspects of the lab and their importance to successfully completing the lab. These include the time spent on tasks (e.g., design, simulation, testing), problem decomposition, time estimation, teamwork, and communication. Three lenses are implied in the activity: student opinion (what they liked about the lab and how it could be improved); technical and non-technical engineering challenges; and the quality of teamwork. While different meanings may be constructed by different students, intended meanings include connectedness of concepts, broader view of the design process, and sense of accomplishment. In terms of future actions, the activity prompts students to describe "the most important thing you could do to improve your team's experience, process, or product for the next lab." The feedback form also asks students, "How have you changed your approach to your lab experience?"

B. *Unpacking the Postlab Activity in CPRE 288*

In CPRE 288, we will also unpack a lab reflection, the postlab worksheet. The experiences emphasized in this reflective activity involve preparing for, doing, demonstrating and learning from the weekly lab. Features of the experiences specifically focused on in the worksheet include preparation, questions posed before and during the lab, student's representation of the system, debugging, and what happened in lab and why. The different parts of the worksheet support several lenses. Revisiting and building on prelab work reinforces preparation. Updating the system sketch, questioning, and debugging accentuate the learning process (awareness of what they know and don't know). These also emphasize systems thinking and engineering problem solving. The after-action review part of the worksheet offers learning and improvement lenses. There are many opportunities for students to construct meanings ranging from their understanding of the system, handling unknowns in problem solving, and creating their own stories of success. Regarding future actions, the worksheet concludes with the question, "What are we going to do next time to improve?"

It's important to restate that the reflective activities in CPRE 288 and CPRE 381 were designed by the instructors and x-teams using a process that started with understanding student needs and potential ways to improve their experiences in each course in relation to expected learning outcomes. Unpacking a reflective activity using the CPREE framework helps the instructor double-check that the elements of the activity are in place to support the intended outcomes.

C. *Supporting Reflection in CPRE 381 and CPRE 288*

Lastly, let's consider how the instructors fostered the success of the reflective activities in terms of generally engaging students with reflection and supporting each element of the CPREE reflection pathway. The reflective cycles and activities were integrated into the lab work and schedule. Instructors acknowledged student feedback in the process and shared their perspectives. Students were given some flexibility in the activities. Different modalities for reflection were provided for some activities, such as written, oral, visual, and interactive. Activities were tied to important engineering skills and industry practices and thus future career success as well as success in the course. Students were encouraged to give their opinions and tell their own stories.

Making students more aware of specific features of the experiences being reflected on was supported by prompting students with corresponding questions and tasks. Students were prompted to record specific information, think about or create specific artifacts, use specific resources and tools, and demonstrate specific actions. Instructor and teaching assistant feedback also highlighted specific aspects of an experience. In terms of supporting lenses used by students, the questions used in reflective activities often guided students to try a particular lens, such as learning, preparation, productivity, improvement, systems thinking, engineering problem solving, or professional identity. Given the x-team work with student empathy maps, personas and journey maps, the instructors appreciated the wide array of student experiences, which helped create an environment in which students could construct their own meanings about an experience. Support for future actions was evident in the questions asked and was built into the reflective cycles, letting students think about how to tangibly improve their experience in the course.

VI. Summary

A collaborative instructional team applied a reflection cycle framework to develop and deploy integrated and structured reflective activities in two computer engineering courses at the sophomore and junior levels. The framework consists of cycles of reflection-for-action, reflection-in-action, reflection-on-action, and composted reflections. Although the details of the reflective activities differed, there were several similarities. Both courses used a prelab assignment to support reflection-for-action for an individual lab, as well as a postlab assignment to support reflection-on-action. In addition, both courses had a term lab project with a final assignment serving as a reflection-on-action and composted reflection for the overall lab experience. The courses took different approaches to reflection-in-action. Both courses used a reflection-on-action activity helping students explore why there was an incorrect answer or error in their work. The courses also prompted students to think about professional work in the course, such as teamwork, engineering tasks, and careers. The CPREE framework provided a useful context for the instructors to examine the features and other aspects of the reflective activities they designed.

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