Beyond the Technical: Developing Lifelong Learning and Metacognition for the Engineering Workplace

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Introduction

Per the Accreditation Board for Engineering and Technology (ABET, Inc.), the capacity for life-long learning is critical for success in engineering practice (ABET, Inc., 2016)\(^1\). Metacognition is key to the development of life-long learning, yet is rarely directly addressed in engineering education. Metacognition, defined as “knowledge and cognition about cognitive phenomena” (Flavell, 1979, p. 906), is a higher-order thinking skill and provides the key to developing life-long learning skills necessary for ABET and for an effective work career. This paper will report on the authors’ study of the development of metacognition and life-long learning skills of graduates of the Iron Range Engineering (IRE) program, an innovative problem-based learning program that integrates metacognition instruction with engineering content. The IRE program offers a unique setting for studying developing metacognitive skills in engineering students who, as part of their curriculum, solve ill-structured, real-world problems.

In this paper, we report on the results of interviews with recent IRE graduates who are now working as engineers. We interviewed these graduates to ascertain:

- How their IRE preparation in metacognition helped them (or not) to transition to the engineering workforce.
- How and to what extent are graduates using the lifelong learning and metacognition skills developed at IRE in their current positions.

The general question that guided our analysis is: How do metacognitive skills developed in an undergraduate engineering program translate into lifelong learning in the workplace?

We discuss our results in terms of the explicit metacognitive instruction used by the IRE program and the extent to which these strategies may contribute to the success of their engineering graduates in the workplace. We will further discuss how these instructional activities could be used as a model for engineering educators to improve the readiness of students to be flexible, independent, life-long learners.

Life-long learning and its importance

As a conceptual innovation, self-directed, lifelong learning precepts are found in both ancient Greek text and early educational theorist works including John Amos Comenius among others. Modern scholarly conversation after 1945 framed the concept as “lifelong education” and today is discussed as “lifelong learning” (Knapper & Cropley, 2000). Philip Candy explains that lifelong learning “includes all aspects of education and training - formal, non-formal and informal - at all ages and stages of life, irrespective of where it occurs and who organizes it” (Candy, 2000, p. 101). Active lifelong learning empowers self-directed learners with an adaptive ability to rapidly respond to a variety of changing landscapes. Recognition of those adaptive benefits is prompting greater integration of self-directed lifelong learning components into various higher education programs.

In engineering, ABET has stated that the capacity for life-long learning is critical for engineering practice and is a required outcome for engineering accreditation (ABET, Inc., 2013). However, this explicitly stated need for life-long learning skills for engineers dates back to before its inclusion in the ABET requirements. Specifically, Smerdon’s work (1996) argued for the need
for engineers to be life-long learners based on the relatively short half-life of an engineer’s technical skills, the rapid changes in technology, and resulting changes in the specific niches in the labor market. Even two decades ago, Smerdon was recommending that engineers (and thus engineering educators) should treat their careers and skill sets as being dynamic and constantly requiring updates.

**Metacognition and Its Importance**

Metacognition is “knowledge of one’s knowledge, processes, and cognitive and affective states; and the ability to consciously and deliberately monitor and regulate one’s knowledge, processes, and cognitive and affective states” (Hacker, 1998, p. 3). This definition identifies both declarative and procedural components of metacognition (see Figure 1). Metacognitive declarative knowledge consists of a person’s knowledge or beliefs about: (a) one’s cognitive and affective states and the states of others; (b) a task, its demands, and how those demands can be met under varying conditions; and (c) strategies for accomplishing the task and how and when to use them (Flavell, 1979). Metacognitive procedural knowledge consists of both monitoring and control components. Metacognitive monitoring refers to processes that are “directed at the acquisition of information about the person's thinking processes” (Kluwe, 1982, p. 212). These processes involve a person’s ability (a) to identify the task on which one is currently working, (b) to check on current progress of that work, (c) to evaluate that progress, and (d) to predict whether the expected outcome will be attained (Flavell, 1979). Metacognitive control refers to processes that are “directed at the regulation of the course of one’s own thinking” (Kluwe, 1982, p. 212). These processes involve a person’s ability (a) to allocate his or her cognitive resources to the current task, (b) to determine and direct the steps to complete the task, (c) to set the intensity or (d) the speed of the work task (Flavell, 1979). Both declarative and procedural components of metacognition are necessary for students to become “self-regulatory organisms who are capable of assessing themselves and others and directing their behavior toward specified goals,” (Hacker, 1998, p. 10) that is, to become in control of their thinking and direct those cognitive processes towards identified learning goals.

Although metacognitive strategies are linked to effective learning as well as life-long learning, few researchers have studied the metacognitive capacity or development of metacognition in engineering students. The most pertinent studies concern the role metacognition plays in engineering problem solving and design in a school setting. One study used verbal protocols to compare strong and weak problem solvers in engineering statics and found “substantial differences in the use of self-explanation” between the two groups (Litzinger et al., 2010, p. 337). In another study, a small sample of students solving engineering statics problems showed an improved understanding of the problems (measured by verbal and written protocols) after an intervention featuring metacognitive instruction (Steif, Lobue, & Kara, 2010). And, metacognitive instruction has shown student gains in problem solving and design skills in several other studies (Hanson & Brophy, 2009; Koretsky & Kelly, 2011; Krause, Kelly, & Baker, 2012; Newell, 2004; Pappas, 2009; Zheng, Shih, & Mo, 2009; Zheng & Yin, 2012).

**Why are Metacognition and Life-Long Learning Important in the Engineering Workplace?**
Several studies have shown that there is a gap between what graduating engineers can do and what employers want. Although a diverse set of skills is required to be a successful practicing engineer, there is agreement that engineers are hired and rewarded for solving ill-structured problems (Jonassen, Strobel, & Lee, 2006; Loyens, Magda & Rikers 2008). Ill-structured problems require the ability to generate a variety of novel solutions (no single solution is necessarily right or wrong) and to decide which solution is the best for the given problem in the given context (Jonassen, 1997). That is, because engineering problems are ill-structured with multiple solution paths, and many engineers work with great autonomy, graduating engineers must have the metacognitive skills necessary to negotiate the problems they encounter in practice.

Recently graduated engineers agree with the importance of problem solving abilities on the job. Passow (2012) found that problem solving was one of the top ABET competencies that graduated engineers value. This same study found that life-long learning was ranked in the middle in terms of perceived importance, but the study also found that life-long learning can be positively tied to the highest ranked competencies, including problem solving. In Schon’s (1983) work on the “reflective practitioner,” he describes that professionals consistently face “messy” problems that require reflecting on one’s actions. Such reflections can affect both current performance and the continued professional development of that professional. For engineers solving problems, these questions would include Have I seen a problem like this before? How is it similar to/different from those problems that I have solved? What lessons did I learn from solving that problem? What are the critical elements of the problem? How much do I know about the ideas in this problem? Answering these questions requires engineers to reflect on their problem solving activities and become aware of the effectiveness of their approaches – thus the need for metacognitive skills.

The ability to be a successful life-long learner flows from these metacognitive skills and reflections. Further being able to activate life-long learning skills and strategies is necessary for being a successful problem solver. In essence, life-long learning requires one to be able to take actions based on the reflective questions of metacognition. With the inclusion of life-long learning in the ABET outcomes, there have been some studies of this skill in an engineering education setting. For instance, in a Louisiana Tech University first-year engineering program, a project based curriculum where students design, develop and diagnose solutions in a self-directed manner is being utilized to study the extent those activities help promote lifelong learning (Hall et al, 2009). There have also been efforts to assist with the development of engineering curriculum geared towards lifelong learning (Martínez-Mediano & Lord, 2012).

Given the inter-relatedness of life-long learning, metacognition and necessary workplace skills, we chose to pursue this research. We next describe the Iron Range Engineering program, which provided the context for our study.

**Iron Range Engineering Program**

The context of our study is the Iron Range Engineering undergraduate program (IRE). The IRE program in Virginia, Minnesota, is a collaboration between Itasca Community College (ICC) and Minnesota State University Mankato. IRE is a unique, completely problem-based learning
curriculum for upper-division (junior and senior) students. Rather than studying about engineering in traditional engineering courses, IRE students work in teams to solve complex and ill-structured industry problems in mining, milling, and manufacturing. There are no courses in the IRE curriculum; rather, every semester students generate (with the help of faculty) a series of syllabi that describe how they will meet the required technical and design competencies that comprise the IRE curriculum. A majority of IRE learning and assessment activities are organized and indexed by the aforementioned team-based, semester-long industry projects. For example, an IRE team designed and implemented a condenser performance test to be applied to a power plant’s power generation condenser. To solve the problem, students learned cycle analysis, conduction heat transfer, convection heat transfer, heat exchanger design, engineering economics, and studied the environmental implications, all in the context of a real deliverable for a major client. Other student learning occurs individually or in student-organized small groups. Students have a wide variety of resources available to them to support their learning. These resources span the spectrum from printed materials and electronic libraries to external practicing experts and faculty.

In both the industry-based projects and in individual learning, students must use self-direction to determine how to best proceed to complete their tasks. Given the self-directed nature of the IRE curriculum, the faculty recognized the need to support students’ development of metacognitive skills. To structure this support, students regularly engage in explicit metacognitive focused reflection activities. For instance, at the end of completing a competency, students complete a metacognitive memo. “Metacog” is the term students use for both the metacognition process and the summary memo they write at the end of each competency. The process includes organizing their learning as it happens, reflecting on the learning on a frequent basis, making qualitative judgments on the quality of the learning, and then making regulative changes based on the judgments. The memo documents the learning process. These processes and memos externalize specific aspects of metacognition including awareness of actions and reflections on what one does and does not know. IRE’s unique focus on using industry engineering projects as the means to learning engineering combined with their support of developing metacognitive skills make the program an excellent venue for the current research.

Methods

Data Collection
IRE’s first cohort graduated in December 2011. IRE personnel provided us with contact information for the first through fifth cohorts. We contacted the alumni during the fall 2016/winter 2016 timeframe with our interview request via email. For this data collection we focused on graduates for the first three cohorts as we wanted to speak with graduates who had been in the workforce for three or four years. These graduates would have had more work experiences, allowing them to provide data on a more complete transition to the workplace.

This resulted in contacting 18 alumni. Of those, 15 responded and agreed to participate in the interview. Table 1 shows the distribution of our interviewees.
Table 1. Alumni Interviewed

<table>
<thead>
<tr>
<th>Cohort Group</th>
<th># Interviewed</th>
<th># Women</th>
<th>Time in Workforce</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (– December 2011)</td>
<td>8</td>
<td>2</td>
<td>4 years</td>
</tr>
<tr>
<td>2 (– May 2012)</td>
<td>4</td>
<td>0</td>
<td>3.5 years</td>
</tr>
<tr>
<td>3 (– May 2013)</td>
<td>3</td>
<td>2</td>
<td>2.5 years</td>
</tr>
</tbody>
</table>

We used a semi-structured interview protocol composed of open-ended questions and follow-up prompts with the alumni interviewees. For the interview, we contacted participants via internet voice conferencing, which allowed for digital recording of the interviews. We asked questions concerning:

- Their employment history since graduating from IRE
- The nature of their current job assignment.
- How they went about learning to do their job tasks. We probed for specific strategies (e.g. look things up in books or on the web, talk to fellow workers).
- Their definition of metacognition.
- Their perception of how they use metacognitive skills (or not) in their work.
- Their perception of how IRE’s focus on metacognition may have impacted their ability to transition from school to the workplace.

Interviews generally lasted between 15 and 25 minutes.

Data analysis Process

The interview data was transcribed and analyzed using Dedoose, a cloud-based qualitative analysis tool (www.dedoose.com). We conducted thematic analysis (Braun & Clarke, 2006) to identify the translation patterns of IRE curriculum into lifelong learning in the workplace. As shown in Table 2, the initial coding was analytically structured around interview questions. We focused on three categories of codes: School-to-Work Transition, Metacognition Usage in the Workplace, and Performance Comparison between IRE and non-IRE graduates. Under the three categories, we created 14 codes such as Promotion History and First Task Strategy and applied them to three samples to test inter-coder reliability. We resolved coding inconsistencies and refined coding practice by walking through each code together. Then the second author completed coding the remaining data.

Following the initial analytic coding, we examined coded data repeatedly with the guidance of the research question, defining, comparing, and connecting code properties and dimensions across codes and cases. For instance, when participants commented on Differences between Schools and Workplaces, majority of comments consisted of the sense of Responsibility, Freedom, Clients, and the need for Self-Learning (properties) (see Table 2). Participants perceived higher Responsibility and Freedom in the workplace, but similarly perceived the presence of Clients and the need for Self-Learning across IRE and workplaces (dimensions). We connected these properties and dimensions to the perceived IRE strengths to reconstruct the aspects of IRE environments that translated into lifelong learning in the workplace. Through such a cycle of analytic induction, we detected and refined themes across codes and cases and developed an explanation of the phenomena under study. In the next section, we provide findings under each theme.
<table>
<thead>
<tr>
<th>Category</th>
<th>Code</th>
<th>Properties (Dimensions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>School-to-Work Transition</td>
<td>Differences between Schools and Workplaces.</td>
<td>Responsibility (low &lt;-&gt; high); Freedom (low &lt;-&gt; high); Clients (Yes); Self-Learning (Frequent)</td>
</tr>
<tr>
<td></td>
<td>First Task Type</td>
<td>Type (Authentic &lt;-&gt; Shadowing)</td>
</tr>
<tr>
<td></td>
<td>First Task Strategy</td>
<td>Example (Information Seeking; Help-Seeking; Making Relationships; Metacognitive Regulation; Other)</td>
</tr>
<tr>
<td></td>
<td>Strength of IRE Preparation</td>
<td>Example (Real Project Based Curriculum; Self-Learning; Professionalism; Communication; Metacognitive Focus; Other)</td>
</tr>
<tr>
<td></td>
<td>Weakness of IRE Preparation</td>
<td>Example (Technical Skills; International Focus; Other)</td>
</tr>
<tr>
<td></td>
<td>Self-Directed Learning Readiness</td>
<td>Rating (Poor; Good; Excellent)</td>
</tr>
<tr>
<td>Metacognition Usage in the Workplace</td>
<td>Metacognition Definition</td>
<td>Application (Learn-to-learn Skills &lt;-&gt; Problem Solving Skills)</td>
</tr>
<tr>
<td></td>
<td>Usage Examples</td>
<td>Example (Information Seeking; Conflict Management; Other)</td>
</tr>
<tr>
<td></td>
<td>Metacognitive Knowledge</td>
<td>Kind (Self-Knowledge; Task-Knowledge; Strategy-Knowledge; Monitoring (Before/During/After Task); Control)</td>
</tr>
<tr>
<td></td>
<td>Metacognitive Strategy</td>
<td>Example (Writing; Questioning; Checklist; Feedback-Seeking; Other)</td>
</tr>
<tr>
<td></td>
<td>School-Work Differences in Metacognition Usage</td>
<td>Time (Secured time for metacognition &lt;-&gt; speedy); Content (Learning &lt;-&gt; Jobs); Perception (assignments &lt;-&gt; everyday component)</td>
</tr>
<tr>
<td></td>
<td>Value of Metacognition</td>
<td>Value (low &lt;-&gt; high)</td>
</tr>
<tr>
<td>Performance Comparison between IRE and Non-IRE Graduates</td>
<td>School-to-Work Transition Comparison</td>
<td>Learning Speed (low &lt;-&gt; high); Supervision (yes &lt;-&gt; no)</td>
</tr>
<tr>
<td></td>
<td>Metacognition Usage Comparison</td>
<td>Resistance to Change (low &lt;-&gt; high); Learning (from scratch &lt;-&gt; from past experience); Thinking (Piecemeal approach &lt;-&gt; Big Picture); Professionalism/Communication (poor &lt;-&gt; good)</td>
</tr>
</tbody>
</table>
Results and Discussion
All participants stated that their first task in the workplace involved some unfamiliar aspects—contexts, job functions, local systems, language, interrelationships, and project management to name a few. However, a majority of them (13 out of 15) were placed into work right away, requiring them to learn their jobs from scratch. Julian (gender neutral pseudonyms used throughout) explained her/his first task as follows:

They immediately put me in with having to develop software using a program I never used before. I spent a week and I have to utilize that program. I asked a couple of other engineers there for help and I taught myself how to use it. In less than a full month I had already made a program that helped out the company.

Next, we will address results for our guiding questions:

• How their IRE preparation in metacognition helped them (or not) to transition to the engineering workforce, and
• To what extent are graduates using the lifelong learning and metacognition skills developed at IRE in their current positions?

When we queried the interviewees about the value of their IRE metacognitive training in the workplace, nearly all participants (13 out of 15) agreed that this training was crucial to their successful self-directed learning in the workplace. Further, regarding our first question, participants agreed that IRE preparation helped them to succeed in self-directed learning for tasks in the workplace. We detected two themes, or patterns explaining how IRE curriculum with a metacognitive focus translated into life-long learning in the workplace: (a) similarity between IRE projects and the workplace environments, and (b) developing a mindset open to uncertainty. Though these themes are interrelated, we explicate each theme separately.

Theme 1: Similarity between IRE projects and the workplace environments
IRE organized a majority of learning and assessment activities by semester-long industry projects in which students “had to go through an actual design process working with clients to produce deliverables.” By engaging in a similar experience to workplace activities, participants practiced and developed non-technical “professional skills” as well as developed positive mental conditions for self-directed learning and metacognition. Nine participants strongly emphasized that these industry projects with clients was one of the most unique parts of IRE that enabled a smooth transition into the workplace. By engaging in the industry projects, participants could develop “a feel of what I would be expecting (in the workplace)”; they needed little “baby-sitting” from supervisors. Participants also developed communication skills, which enabled them to “understand needs,” “tap into people’s wealth of knowledge,” and “seek feedback” from others.

Moreover, industry project environments created positive mental conditions that prepared participants in varying ways to be motivated and confident to self-learn and self-evaluate in the workplace. Working with clients in real-world contexts enhanced a sense of responsibility and professionalism:

It was in our interest to do well since we were working directly with clients, we had to take on a professional role with how we dressed and communicated. At IRE it was a
more professional environment and I have to assume that makes the transition easier. (Drew)

The sense of responsibility kept them motivated to take initiatives in learning and self-evaluation:

It (IRE experience) helps you to push yourself so you know your limits, what you can handle. It’s also important to say ‘No, I actually can’t do this or to say ‘I can do that, but just to let you know, this will then suffer.’ I think that’s something that helped in the preparation for going into the workplace. (Kelly)

Such experiences that presented students with challenging tasks (but with support available from faculty mentors) made participants “confident to learn something completely new,” something they “didn’t have a class on”:

Before that (IRE experience), I would have been really nervous going into this situation… but that’s what you had to learn at every single semester working at different locations and having different projects. That’s what I do daily, so I’d say that part of it (IRE experience) really helped me. (Taylor)

**Theme 2: Mindset open to uncertainty**

Though only five participants made comments regarding this theme, possibly the most critical aspect of IRE preparation and its impact on how graduates work relates to fostering a mindset open to uncertainty and ambiguous situations. At IRE, students did not follow pre-defined paths of learning; rather they created their own syllabi given industry projects, created their own resources, and adapted their learning paths to changing situations. Such ill-structured and dynamic nature of tasks often caused confusion and a sense of being lost. One participant made a negative comment on that aspect: “our learning environment was fast paced and very adaptive but it was very easy to lose focus…It set up environments of being a jack of all trades but master of none.” However, four other participants stated that this same environment prepared them to be flexible, adaptive, and thus helped them to be successful in their future workplaces. This effect seems to be rooted in their conceptual and attitudinal change regarding tasks.

Most of all, participants developed a dynamic task conception that every task involves constant change and should be examined within the larger work contexts. Therefore, they did not focus on the surface or current features of a task as part of a routine practice and were not satisfied at “how it is now.” Rather, they critically examined an interrelated whole to address and improve a bigger task context. Peyton depicted how her/his approach was different from other new hires at the first job:

I was putting the puzzle pieces together as I was learning about the plant. Those things may not be particular to my (current) job but could be particular to a project in the future. I was able to think big picture, put that into perspective, use that puzzle piece. I wanted to see how my job fit in with other jobs with other pieces of the plant. It helped me to understand how to better contribute. The other associates didn't really seem to have that foresight and kind of seemed very focused only on what they were doing, if it related to them, only if it related to them. They didn't care about the other side of things. I think their lack of that awareness kept them in their hole of their one job and from being expanded contributors.
In addition, participants developed resiliency to the possibly overwhelming experience of ever-changing situations:

I think one of the biggest things (IRE preparation) is the feeling of being overwhelmed. You need that feeling because when I graduated I thought it would go away. It doesn’t, it actually gets worse. So, I think that’s a really good prep and something that IRE should keep. (Kelly)

Some even learned to enjoy the ever-changing nature of their tasks—“I like managing organized chaos.” These experiences that required them to persevere seem to have helped them to raise their standards, embrace change, and experiment with new possibilities. This is evident in Kelly’s comments on comparing her/his attitude with other new hires at her/his first job:

I worked with people who haven’t gone through the IRE program and I think biggest difference related to metacognition is some resistance to change and keeping how they normally do something...(on the other hand, I am) willing to admit (I) can always be better.

Two themes emerged regarding our second question concerning the extent graduates are applying lifelong learning and metacognition skills developed at IRE in their current positions.

Near and Far Transfer of Metacognitive Skills

At IRE, students regularly engaged in explicit metacognitive activities. Individual instructors and resources were available to scaffold these processes. As participants transitioned to the workplace, however, they adapted their metacognitive practice in scope and strategies to a varying degree. The differences in the adaptations help us to understand the differences in the extent to which the graduates are applying the metacognitive skills learned at IRE to their positions. We describe this difference as near or far transfer of metacognitive skills. Transfer refers to learning in one context and applying it in another.

Nine of our participants defined metacognition as more of “learn-to-learn skills; this is just the way they were introduced to metacognition while at IRE. This group used metacognition in the workplace in “near transfer” ways. That is, they spoke of using their metacognitive skills predominantly on engineering problem solving activities (again just as they had at IRE) to judge and apply their best learning approaches and strategies. For instance, this interviewee describes how he/she used metacognitive strategies to be aware of the best problem representation approach to use.” “It helped me understand how I retained information the best. So I used a white board to create diagrams and drawings.” This type of application of metacognitive and lifelong learning skills is very much congruent and similar to what these learners did while at IRE and represents “near transfer”. Near transfer means that the new setting where one is applying the learned skill is very similar to the original setting. In their work setting they had not grown much beyond what and how they used their skills at IRE.

On the other hand, six interviewees used metacognition beyond the scope of the technical aspects of their engineering problem solving, applying metacognitive techniques to manage conflicts, relationships, or the entire process of project. “the content (of metacognition) is a little different. Now it is more about how I actually manage projects that I am trying to learn from and look back on.” This indicates that these graduates had done more “far” transfer with their skills -- applying them to a broader set of applications than had been shown to them while at IRE.
While such different usage patterns merit further study of inhibitors and enablers of metacognition, it is notable that the extended definition and usage of metacognition exemplified by the second group showed a broader impacts on workplace projects. Users of metacognition who focused on their engineering problem solving reported that they “saved time” by quickly learning or acquired “long-term memory” by using learning strategies that they preferred. On the other hand, participants who applied metacognition more broadly reported impact that extended beyond the current problem being solve to other aspects of their work, such as “learning from (previous) projects”; “minimized mistakes”; and “thinking of big pictures” for future projects.

Adapting Metacognition and Life-Long Learning to Meet Job Constraints
The second theme for the question of extent of use refers to how graduates adapted the IRE skill set to meet job conditions. For instance participants described how in the workplace they needed to internalize metacognitive regulation to adapt to fast paced workplace projects. Six participants commented on the change from explicit support at IRE to no formal support for metacognitive regulation in the workplace:

- You have more time as a student…without professional pressure on your shoulders … we had a lot of guidance on what to do and how to do it and we got feedback on our metacognition. We were able to talk to Ron (lead instructor) about things and ask him questions. On a job, you don’t have that luxury of feedback or guidance most of the time due to that time crunch. (Peyton)

Most of the strategies were internalized (“re-evaluating the way you approach things stuck with me”) and simplified:

- Rather than writing a general reflection or something, instead you can sit there and think about it in your head. You do it quickly and then you can revert to that the next time you use that process. It’s not as formal just because you don’t necessarily have the time to do that. (Kelly)

This theme showed that metacognitive reflective activities that were explicitly “scheduled” whilst at IRE, graduates adopt and implement in varying ways once in the workplace. The fact, however, that the graduates continue to practice these skills and even extend their application to the non-technical aspects of their work, even in modified forms, is support for their value.

Summary of Discussion
The IRE program operationalizes the relationship between metacognition and life-long learning. Explicit metacognitive development activities create a habit of reflection that is necessary to develop life-long learning skills – and to be aware of their development. Figure 1 depicts how this may work. The three components of metacognitive control shown in Figure 1 – evaluate, monitor and plan -- are from Ertmer and Newby (1996). At IRE, students are supported in becoming aware of and applying these control mechanisms predominantly through two tools—“Metacogs” and “Metachrons.” A “metachron” is simply a log that students complete periodically during their competency work to keep track of what methods they are using to self-direct themselves through the learning of a particular competency; they also log the approximate time spent on that method. As explained previously, metacogs (short for metacognitive memo) are reflection statements that students complete at the conclusion of their work to complete an
engineering competency. These memos contain, essentially, a summary of the steps and methods the students used, and an evaluation of these methods. Both of these methods are supported via one-on-one sessions with faculty advisors who read and probe students on the content of these tools. These tools are used throughout the entire IRE curriculum so the reinforcement of metacognitive skills is consistent.

Returning to Figure 1, we posit that our data show that these IRE activities seem to result in both perceived value (13 of 15 reported seeing the value of the metacognitive and learning reflection skills they had learned at IRE), and that they indeed took skills away from IRE that have helped them to engage in life-long learning activities (see Theme – Adapting to workplace).

Figure 1. IRE Tools Support Metacognition and Provide Foundation for Life-Long Learning

Limitations and Conclusions

This study examined via qualitative interviews how the metacognitive skills that are explicitly scaffolded and supported during the IRE curriculum are sustained in the workplace and support life – long learning activities beneficial to the engineering workplace. And although the IRE learning experience has many parallels with what graduates must do on the job (see Theme 1 above), our study also highlights the need for those skills to be applied in a somewhat different way.

We recognize the limitations of the current study. Sample sizes to date are too small to allow us to compare interviewee results by the number of years they have been working. As we continue to collect data we hope to be able to add this dimension to our analysis. We are also in the process of gathering data on IRE graduates from their workplace supervisors. Such data will
allow us to compare supervisor impressions of these IRE graduates with the graduates’ own self-assessment as well as provide the opportunity to collect impressions of comparisons of IRE graduates to graduates of traditional engineering programs regarding their abilities to transfer effectively and efficiently to the workplace. As discussed above, some of our participants discussed how the evolving nature of the IRE curriculum and the “normal” evolutions of the open-ended projects that they worked on for industry clients resulted in their being more open and comfortable with uncertainty that they encounter in their work environments. Given that prior studies have found that the ability to solve “open-ended” and ambiguous problems is the most important skill that engineers need to be prepared for (Jonassen, Strobel, & Lee, 2006), we see this finding as significant and worth further exploration.

Common sense and our personal experiences with the rapidly changing nature of technology and what we “know” about the world, lead us to conclude that no curriculum can teach students all that they need to know to be successful in their future careers. Regardless, the temptation to cram as much content into a course of study as possible is hard to resist. IRE has chosen to forgo some time that might be otherwise spent on content, to develop in their graduates an awareness of and skills for practicing metacognitive reflection and strategies. These skills and attitudes, paired with the essential attitude to value and practice them empower these graduates to engage in lifelong learning activities in their professional positions. This study of IRE graduates in the workforce provides evidence of the value of this approach showing that these engineers see the value of these skills, continue to practice them (albeit in modified ways from when at IRE), and show evidence of being at an advantage in the “learning to learn” activities that are necessary in their jobs.

References


Pellegrino, J.W. (2006). Rethinking and redesigning curriculum instruction, and assessment: What contemporary research and theory suggests. Retrieved February 3, 2017 from [https://pdfs.semanticscholar.org/d8a8/ba50f94dab996de8382e91c7a6c7e91b757.pdf](https://pdfs.semanticscholar.org/d8a8/ba50f94dab996de8382e91c7a6c7e91b757.pdf)


