Transforming Challenges into Reflections:
Enabling Metacognitive Development

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Abstract— **A capacity for self-directed learning (SDL) and lifelong learning is widely recognized as an important outcome for today's engineering graduates. Key to SDL is the development of self-reflection abilities, which enable students to critically evaluate learning tasks and contexts, to adjust and adapt their self-regulatory processes to new environments, and to maintain motivation and persistence in the face of difficulties. The purpose of this study is to explore the different types of challenge that prompt reflection for undergraduate engineering students, during their first two years of college. Grounded theory is used to analyze responses of 10 students to 12 surveys administered across two institutions over two years. Data reveal that challenges prompt various levels of reflective practice. Specifically, the three types of challenges emerging from the data are: lack of cognitive freedom in course content, performance on traditional assessment, and specific learning environment. Further analysis reveals that students reflect at different cognitive and metacognitive levels in different learning contexts. Finally, we argue that with proper pedagogical support, reflective practice can be encouraged in all educational contexts facilitating students' cognitive development.**

Keywords—introductory experiences; motivation; self-directed learning; self-regulated learning; reflection; agency

I. INTRODUCTION

The question of persistence in engineering programs, particularly after the first year, has been a topic of much discussion for the past decade [1],[2]. The lack of persistence, particularly among the groups under-represented in engineering, has been attributed to the challenging nature of engineering curricula and students' inability to cope with it, the absence of appropriate pedagogical practices, dissonance between personal and professional identity, and "chilly" climate, among others [1],[3]-[6]. Stolk *et al.* (2010) reported that in addition, students may struggle to make the transition from the structured, instructor-centered high school setting to the more self-directed learning environment expected by college faculty [7]. To this end, this paper examines how engineering undergraduates develop as lifelong learners when introduced to this new environment in their first two years of college. Specifically, we focus on critical reflection as a skill that allows students to internalize an experience and make appropriate behavioral and attitudinal changes to improve their learning.

Reflection is used to critically evaluate learning experiences in order to gain understanding and improve future learning behaviors [8]. Students must proactively think not just about the material they are learning, but also the contextual implications of their learning processes [9]. Though critical reflective moments occur for most students in a variety of contexts, not all reflective processes are equally valuable in terms of students' cognitive and metacognitive development. Recent literature suggests that engagement in reflective practices contributes to students' ability to both make sense of their learning experiences and engage in new ones at a higher metacognitive level [8],[10]. Other studies explore the question of what makes reflection meaningful and critical, noting the implications of reflective depth on students' development [8],[11],[12]. Seibert and Daudelin (1999) maintain that effective reflection cannot occur in the absence of autonomy, appropriate support structures, effective feedback, and, of importance to this work, appropriate challenge [13]. In his meta-study of reflective practices in higher education, Rogers (2001) asserts, "Reflective practices that are intellectually credible can promote resiliency and resourcefulness in the face of life's dynamic challenges and encourage habits of individual and collective attention and analysis that can sustain higher education as it works to address the problems of society" [14]. In other words, a true reflective process and the ensuing development of cognitive and meta-cognitive skills, can only occur if appropriate conditions, including appropriate level of challenge, are presented as part of a student's learning experience [13]-[15].

In the spirit of the work of Finlay (2008), Schraw (2006), Rogers (2001), and Seibart & Daudelin (1999), this study also argues that meaningful reflection is correlated with meaningful changes in behavior [8],[10],[13],[14]. These changes can contribute to a smoother transition to self-directed learning environments in college. This paper investigates challenges that prompt episodes of specific reflection, and examines the cognitive integrity of these reflective moments. Cognitively credible reflections, in turn, prompt regulation of students' learning behaviors and attitudes.

II. METHODS

This work is part of a larger, mixed-methods investigation focused around self-directed learning at two engineering institutions, referred to here as Western Technical Institution (WTI) and Eastern Technical Institution (ETI). WTI is a large comprehensive public university, while ETI is a small private engineering college. The study population consisted of entering first-year undergraduate students enrolled in engineering

programs at the two institutions; students were asked to participate during their first two years in their respective programs. Students at WTI engaged in an engineering program that blended traditional pedagogical practices (lecture or lecture/lab) with modest amounts of hands-on project work in the first two years. Students at ETI participated in programs with both traditional and non-traditional (mostly project-based learning) pedagogy. The data sources for this work include (i) institutional data; (ii) information on course format and pedagogy; and (iii) open-ended responses to a survey instrument about students' development as self-directed learners administered to students during their first and second year in college. Overall, 28 students chose to take part in the study; however, only 10 of them (3 women and 4 men from ETI, and 3 men from WTI) responded to all 12 surveys administered over the two years of the study. Therefore, this paper focuses only on these 10 students' responses to qualitative prompts. Quasi-grounded theory approach was used for data analysis [16]. The data were coded for important concepts and themes and organized into thematic matrices with emergent narrative summaries. We further used a constant comparative method of coding for inductive themes, a process that continued until a saturation point was reached. Narrative summaries were then created around identified themes; these served for within-case and across case comparisons. Final analytical memos served as the basis for the preliminary emergent theory.

III. Results and Discussion

Although our analysis resulted in identifying a number of emergent themes, the focus of this paper is limited to only one. Specifically, here we discuss reflections that are prompted by challenges. Our analysis suggests that students describe three types of challenges: (1) lack of cognitive freedom in course content, (2) performance on traditional assessment, and (3) specific learning environment. Through their description of each challenge, students reveal not only the nuances of the experience itself but also reflect on ensuing behavioral and attitudinal changes, if any. We find, however, that cognitive depth of these descriptions varies widely among the respondents. We discuss each of these challenges in greater detail in the following sections.

A. Lack of Cognitive Freedom within the Course Content

Lack of cognitive freedom within course content emerges as one of the underlying reasons for students' dearth of interest and motivation. Students often describe themselves as having difficulty completing their work, staying focused, or simply being disinterested in their coursework when they perceive no latitude in cognitive experiences.

WTI, with its prescribed traditional curriculum and required introductory technical (e.g., Calculus 1 and Physics 1) and general education courses in the first year of the engineering program, is recognized by students as an environment that offers narrow range of learning experiences. Not only do the WTI students describe absence of freedom in terms of which courses are taken and when, they also convey the lack of cognitive choices within their classes. For example, when prompted about his experiences with self-directed learning Paul shares his disinterest and lack of motivation while taking WTI's general education requirements,

> *For [General Education Requirements], I usually couldn't care less about the information and wouldn't do it if I had the choice.*
>
> - Paul, WTI

Of note is that Paul does not go beyond this brief description; his frustration about the lack of choice in what he does as a first-year student seems to limit his discourse about this experience and the further reflection about what this experience may tell him about himself as a learner and his positioning as a learner within the overall context of WTI. In other words, Paul does not take this reflective episode as an opportunity to consider the ways in which he can engage as a learner even in the absence of "the choice."

Like WTI, ETI prescribes most of engineering students' technical and general education course requirements in the first two years. Interestingly, at ETI, the discourse about lack of students' interest in their coursework and motivation is absent. ETI students experience autonomy by virtue of cognitive freedom *within* the individual courses they take. For example, an ETI student describes cognitive "freedom to choose" and its link to motivation as:

> *... students are given more freedom to choose self-design[ed] topics or assignments...there were some students that took the opportunity to go beyond that and learn a lot on their own (with the support of the professors/etc.).*
>
> - Jennifer, ETI

Jennifer illustrates how an ability "to choose self-design[ed] topics or assignments" encourages students' drive to go beyond the bounds of the course and "learn more," all markers of the development of intrinsic motivation. Although not surprising in light of motivation and self-regulated learning research, e.g. [17]-[21], these preliminary findings suggest that concomitant to the correlation between cognitive autonomy and positive motivational attitude development, there may be an association between cognitive "freedom to choose" and credibility of students' reflections. As in the representative quote above, students perceiving content autonomy at ETI display higher levels pedagogical awareness and meta-cognition in their reflections. Whether a natural part of cognitively autonomous environments or brought about by virtue of students' participation in the study, there seems to be much more cognitive gravitas in reflections of students who report having content-related choices.

B. Performance on Traditional Assessments

Another type of challenge reported by both WTI and ETI students is associated with their performance on traditional assessments. Interestingly, students' discourse about performance is limited to traditional assessment measures only, i.e., there is no discussion about design reviews, project artifacts, self-reflections, etc. As such, it is the performance itself, rather than the assessment method or the students' approach to learning, that students reference in their surveys responses. Such reflections illustrate limited cognitive

development, analytical processes, or discussion of future actions.

For example, here is how a WTI student describes his performance in traditional coursework,

> *I learned from my mistakes (terrible grades) of last year and am now on the path to a successful quarter.*
>
> - Tom, WTI

The characteristically descriptive nature of the quote above is somewhat modified by the use of the word "mistakes." This provides an affective aspect to an otherwise dry statement. Additionally, within the context of this sentence, Tom defines success as the opposite of "mistakes of last year," i.e., in terms of good grades. Beyond this, Tom's reflection carries no retrospective or prospective analysis, for example, a discussion of learning processes he will use to become "successful."

In comparison, an ETI student describes his test-based performance and ensuing actions in the following way,

> *I did miserably on a test that tested conceptual understanding of a previous assignment. [I will be] working harder to learn the material, not just finish assignments.*
>
> - Mark, ETI

Unlike Tom, Mark goes beyond the descriptive and affective reflection to include preliminary analysis of what may have happened and how he may want to remediate the situation. Mark's language indicates a deeper level of awareness than Tom. For example, he reveals that his miserable performance was specifically on an assessment of "conceptual understanding" of his previous work. Moreover, Mark articulates that it is learning of the material rather than finishing his assignments that will afford him real conceptual understanding. Yet we find that this reflection still misses the prospective analysis that may allow for gaining appreciation of specific future objectives, learning outcomes, and processes necessary for achieving positive outcomes.

Of interest, only male students discuss performance as a challenge. Only one woman mentions grades in the college context; however, she uses this reflective episode to juxtapose the performance measure with the learning process that seems to be at the core of what she wants to achieve,

> *If you take a class and just memorize everything and do the bare minimum, you may get a good grade, but you wouldn't have learned the concepts and skills that you'll probably need in the future.*
>
> - Jennifer, ETI

C. *Challenges Associated with Specific Learning Environments*

The final emergent subtheme is related to the challenges students report in relation to the learning environments they are immersed in. In this regard, our data indicate that students' reflections are prompted by two types of classroom environments: traditional and non-traditional.

In response to the question about what prompted their reflections, students highlight the type of environment, including pedagogical practices used by faculty. Here an ETI student discusses challenges he faces in a traditional learning environments,

> *My professors this semester have very varied lecture style[s] that rarely works for me.*
>
> - John, ETI

John recognizes that he is unable to learn effectively from the traditional lecture classroom. His discourse indicates lack of agency in this environment, i.e., rather than probing the ways in which he may learn better, he passively accepts the experience. For example, John does not discuss actions he can take to improve his learning, the reasons why this pedagogy may not be working for him, or strategies that may work for him.

In comparison, students in non-traditional classrooms reflect on the role of faculty, problem solving processes, course scaffolding, and teamwork. For example, here is how an ETI student reflects on her experience in a non-traditional classroom,

> *After running into too many problems with our initial idea to warrant continuing with it, we began discussing different strategies and approaches we could try.*
>
> - Jennifer, ETI

Unlike John, Jennifer demonstrates pronounced sense of agency that allows her team to tackle a problem encountered in a project-based learning environment. In the quote above, Jennifer and her team identify the problem and pinpoint processes by which they can solve it. There are deep retrospective and prospective aspects to Jennifer's sentiment. The sense of agency provided by non-traditional classrooms seems to facilitate more meaningful reflection. Although challenging, non-traditional environments have a potential to promote development of higher cognitive integrity.

IV. Conclusions, Implications,and Future Work

The three themes discussed in this paper are a subset of a larger set of emergent themes from this dataset. Our analysis indicates that students in non-traditional learning environments may have opportunities for deeper reflections. More specifically, challenges of problem- and project-based learning environments could allow for improved metacognitive skills [22], as students must engage reflectively as they develop a sense of agency in these more self-directed learning contexts. It has also been found that students who are autonomy oriented will engage in reflective behavioral practices; therefore, supporting more student choice within a classroom may promote meaningful reflection [17]. Our analysis indicates that harnessing the classroom environment to promote useful reflection after challenges can lead to changes in learning strategies.

We find that meaningful reflection can come from a variety of experiences, mainly those with high levels of cognitive autonomy, as well as non-traditional learning

environments. Because some environments are more naturally suited to promote meaningful reflection than others, it is important to consider how reflective practices can be encouraged in all educational contexts.

Future work includes exploring two additional emergent themes: student reflections on the fast paced nature of college, and student reflections on working alone. Interesting questions also arose around non-dominant emergent themes, such as self-efficacy and participation in extra-curricular activities. Due to the limitations of the collected data, we were unable to fully explore the role of gender in the dataset in this preliminary investigation. It is the goal of our ensuing work to include gender as an explicit independent variable in the analysis.

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