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Identifying curriculum factors that facilitate lifelong learning in alumni career trajectories: Stage 1 of a sequential mixed-methods study

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Abstract

This research paper presents the results of the first stage of a sequential mixed-methods study exploring the impact of undergraduate curriculum on lifelong learning outcomes in alumni career trajectories. Engineering graduates need a lifelong learning mentality and skillset that will enable them to address complex sociotechnical challenges (some of which have yet to be predicted) and navigate a changing labour system. Fostering these lifelong learning competencies through curriculum design has been a challenge in engineering programs. While scholars have documented curriculum and pedagogy intended to develop lifelong learning skills in students, assessment methods are typically short-term. On the other hand, studies of alumni have provided some insight into career trajectories and workplace learning, but rarely connect these outcomes back to undergraduate experiences.

To span these broad and complex concepts, we are performing a sequential mixed-methods study that aims to contribute to a better understanding of curriculum factors that facilitate lifelong learning in the career trajectories of engineering graduates. This first exploratory, qualitative stage is guided by three research questions:
RQ1: What role does lifelong learning (specifically informal, self-directed learning) play in alumni career trajectories?
RQ2: How do alumni characterize the influence of the undergraduate curriculum on their lifelong learning motivations and strategies?
RQ3: What other individual or program factors do alumni identify as influential for lifelong learning?

Semi-structured interviews were performed with 24 program alumni to understand their experiences of the program and their career trajectories. Thematic analysis identified lifelong learning outcomes including the ability to learn quickly and independently and confidence in these abilities. Curricular features of interest for lifelong learning include breadth of content, an emphasis on math and science fundamentals, and high workload. A literature review identified theories and instruments related to the concepts under study. The interview and literature findings were synthesized into a conceptual framework intended to serve as the basis for a subsequent survey.

The interview findings and resulting framework provide several contributions to engineering education research. The conceptual framework constructed for this work provides a structure of high-level relationships that could apply to a range of alumni studies, threading together many disparate areas of research. It also begins to identify where there are gaps in the literature in respect to these relationships.

1.0 Introduction

This paper presents findings from the first stage of a sequential mixed-methods study on lifelong learning. Lifelong learning abilities and attitudes have been highlighted as essential for engineering graduates' employability and career success given the pace of technological change and the prevalence of career transitions [1], [2], [3], [4]. In the United States, Canada, and other regions, lifelong learning outcomes are tied to accreditation requirements, although there has been much debate about the criterion in the context of ABET accreditation (e.g. [5]). Lifelong learning is conceptualized and measured in numerous ways, and there are still large gaps in our understanding of how undergraduate programs can prepare students to be effective learners throughout their careers [6], [7], [8]. We conducted interviews with 24 alumni of a multidisciplinary engineering program to capture their retrospective perceptions of the program, learn about their career trajectories, and hear their perspectives on the program's long-term impacts. Through an iterative process of inductive and deductive thematic analysis, we created a conceptual framework that formalizes concepts, constructs, and relationships to be explored via survey in the second stage of the research. This paper presents our interview research methods and findings, including aspects of engineering curriculum and learner disposition that appear pertinent to lifelong learning in the career context. It also discusses some of the challenges of the sequential mixed-methods approach, such as moving from a qualitative framework to develop a large-scale survey.

The current research is motivated by a larger curriculum realignment initiative in an undergraduate engineering program, Engineering Science, at the University of Toronto, a large Canadian research institution [9]. Engineering Science emphasises both breadth and depth in its curriculum, bridging theoretical math and science and engineering specialization. The program begins with two years of foundation courses at which point students select a major to specialize in for their final two years. While the study findings may not apply directly to other engineering programs, we expect that some of the curriculum factors we identify as influential for lifelong learning may be of interest to a broader array of institutions, educators, and researchers aiming to support the development of lifelong learning competencies in engineering graduates.

2.0 Literature Review

This literature review provides a high-level introduction to the concept of lifelong learning and presents a framework for assessing long-term learner outcomes of curriculum experiences. Additional literature is incorporated when discussing the interview findings in Section 5.

2.1 Lifelong Learning

This research aims to contribute to an understanding of the impact of different program-level curricular experiences on lifelong learning in the career context. We use the term "lifelong learning orientation" to refer to an individual's disposition towards lifelong learning, including motivations and strategies [10], [11]. While maximal definitions of lifelong learning consider learning in all strands of life, such as recreational pursuits and civic engagement [12], [13], this research focuses on informal, self-directed learning as it applies to career trajectories and transitions [14], [15], [16]. Lifelong learning knowledge, skills, and attitudes can be developed through explicit instruction [17] and also emerge or shift in response to curricular context [18] or transformative experiences [19]. While scholars have documented curriculum and pedagogy intended to develop lifelong learning competencies in engineering students [8][20], assessment methods are typically short-term and tied to a particular course. On the other hand, studies of alumni have provided some insight into career trajectories [1] and workplace learning factors [14][15], but rarely connect these outcomes back to undergraduate experiences of a complete program.

2.2 Assessing Long-Term Program Impacts

Identifying the impacts of engineering programs for graduates is a challenging area of research. As a theoretical framework, we use the Planned-Enacted-Experienced model of curriculum [21] which is a student-centred, process-oriented conception appropriate for studying program-level curriculum impact and graduate attributes [22] for the purpose of improving teaching and learning [23]. The model addresses the different perspectives and actors in curriculum design, delivery, and experience (Figure 1). Starting at the outermost level, accreditation bodies and program leadership may encourage or require that programs address lifelong learning as part of the planned curriculum, while individual university instructors ultimately choose whether and how to address it in their courses (curriculum enacted). Finally, individual students' experiences of this curriculum and instruction will differ again.

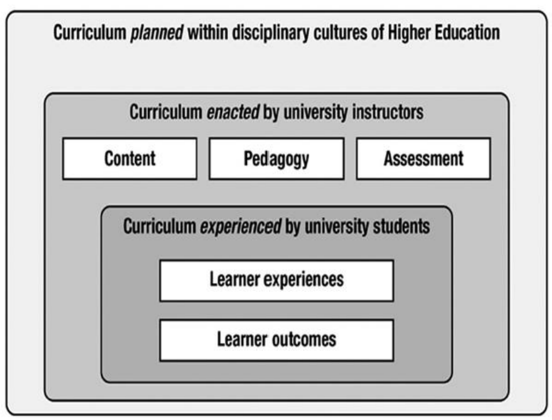

Figure 1: Planned-Enacted-Experienced Curriculum (from [22])

This model has been used to understand gaps between enacted curriculum and experienced curriculum for current students; however, we use it to assess whether and how lifelong learning outcomes persist for graduated students in the longer term [24] and to investigate the impact of planned, enacted, and experienced curriculum in career trajectories. In this stage of our research, we focus on experienced curriculum and lifelong learning-related outcomes to identify specific features of the planned and enacted curriculum that appear to have interactions with these outcomes. This contributes to the body of literature on university impact (e.g. [25]).

3.0 Methods

This paper reports on part of a larger mixed-methods study driven by pragmatism. In this exploratory stage, we use thematic analysis of 24 alumni interviews to identify patterns relating curriculum and lifelong learning and integrate literature to build a conceptual framework.

3.1 Overview

The objective of this research is to contribute to a better understanding of curriculum factors that facilitate lifelong learning in the career trajectories of engineering graduates. The overall study follows a sequential mixed-methods approach [26]. Stage 1, presented here, uses thematic analysis of alumni interviews to generate a conceptual framework of relevant constructs and relationships to be investigated in the Stage 2 alumni survey. Stage 3 will use qualitative methods to understand alumni perspectives and experiences of these phenomena in greater depth.

This work is guided by three research questions:
RQ1: What role does lifelong learning (specifically informal, self-directed learning) play in alumni career trajectories?
RQ2: How do alumni characterize the influence of the undergraduate curriculum on their lifelong learning motivations and strategies?
RQ3: What other individual or program factors do alumni identify as influential for lifelong learning?

3.2 Interview Approach

As part of a larger curriculum realignment study involving program instructors, chairs, and alumni, we developed a semi-structured interview protocol to gather stakeholders' perspectives on many facets of the program. The institutional research ethics board approved these interviews. Four different interviewers with an understanding of the program and prior qualitative interview experience conducted the interviews virtually via video conferencing software and recorded, transcribed, cleaned, and anonymized the transcripts. Interviews typically took 60 minutes, with questions addressing the purpose and distinguishing characteristics of the program, teaching and learning experiences, career pathways, and other facets included depending on the participant profile. This research focuses on interview data collected from a sub-group of alumni participants and analyses questions that addressed concrete experiences during or after the program. Notably, the interview questions did not address lifelong learning directly, although in some cases the interviewer followed up on the topic if it was brought up by a participant. The complete list of questions analysed is presented in Appendix A.

3.3 Participants

Since this first stage will be followed by a population-wide survey of program graduates, we strategically selected interview participants to ensure a mixture of perspectives. In addition to recruiting alumni who have maintained close ties to the program and generally have a positive outlook on their time as students, we also recruited alumni who completed the program but hold mixed or negative opinions on that experience. This targeted selection was enabled by the research team's long-term ties to the program as staff and graduates.

We analysed 24 alumni interviews in this study, as summarized in Table 1. Participants graduated between 1981 and 2020, representing a range from recent graduates to those with 40 years of post-graduation experience. Similarly, they represent a range of engineering disciplines offered by the program over the years. Nine participants work in industry, eight consider themselves entrepreneurs, and seven work in academia (including four who now hold instructional or leadership positions in the Engineering Science program). Seven participants are women. While we made attempts to recruit women as well as men, we did not make broader efforts to diversify participants in terms of race or other demographic factors; this may be a limitation in the research that will be addressed in the survey stage.

Table 1: Summary of Interview Participants Organized by Graduation Year

Identifier	**Graduation Year Range**	**Gender**	**Engineering Discipline**	**Occupation**
9919	1981-85	Man	Aerospace	Academia
9927	1981-85	Man	Materials/Nanoengineering	Academia
9940	1986-90	Man	Nuclear	Entrepreneurship
9939	1991-95	Man	Electrical/Computer	Mix
9950	1996-2000	Man	Aerospace	Academia
9904	1996-2000	Man	Electrical/Computer	Entrepreneurship
9915	1996-2000	Man	Electrical/Computer	Entrepreneurship
9951	1996-2000	Man	Electrical/Computer	Academia
9949	2001-05	Woman	Aerospace	Industry
9952	2001-05	Woman	Biomedical	Industry
9921	2001-05	Man	Engineering Physics	Entrepreneurship
9936	2001-05	Man	Materials/Nanoengineering	Industry
9918	2001-05	Woman	Materials/Nanoengineering	Industry
9925	2006-10	Woman	Aerospace	Industry
9955	2006-10	Man	Biomedical	Industry
9941	2006-10	Man	Electrical/Computer	Entrepreneurship
9956	2006-10	Man	Electrical/Computer	Entrepreneurship
9932	2006-10	Man	Energy Systems	Academia
9933	2011-15	Man	Aerospace	Entrepreneurship
9907	2011-15	Man	Energy Systems	Academia
9929	2011-15	Woman	Energy Systems	Industry
9953	2011-15	Woman	Energy Systems	Academia
9946	2016-20	Woman	Energy Systems	Industry
9903	2016-20	Man	Engineering Physics	Industry

3.4 Analysis

One researcher performed the analyses. Since this is the first stage of a mixed-methods study which seeks to identify important patterns for the subsequent survey, rather than contribute extensively to theory, we did not involve multiple coders.

The researcher first reviewed the complete transcripts and wrote memos to identify sensitizing concepts across the data set [27]. The researcher then performed an iterative thematic analysis process [28] coding the anonymized transcripts in NVivo. This began with inductive coding of eight interviews, categorization of these initial codes, and review to determine that these broad categories aligned with relevant literature concepts (experienced curriculum, career trajectories, lifelong learning, incoming characteristics, and learner dispositions). The researcher deductively coded a further four interviews to finalize categories within each component of the framework informed by the literature. Finally, the researcher coded all 24 interviews using these categories, and also coded for relationships between lifelong learning categories and other categories.

4.0 Results: Interview Themes

In this section, we use the research questions to structure our presentation of the patterns found in the dataset. This includes themes related to 1) lifelong learning in alumni career trajectories, 2) influential curriculum factors for lifelong learning, 3) additional themes addressing individual and program factors (overview provided in Table 2). Prevalence is discussed at the level of the data item i.e. did a theme appear in each individual interview [28] and participant identifier codes are included in parentheses. Engineering Science stakeholders often refer to the program as “EngSci”; this language is included in the transcripts. A tabular summary of the connections between these themes and concepts from the literature is presented in Section 5, where we then formalize these relationships in our conceptual framework.

Table 2: Summary of Themes

1. The role of lifelong learning in alumni career trajectories	**2. The influence of the undergraduate curriculum on lifelong learning outcomes**	**3. Other individual or program factors**
• the ability to learn quickly and independently • a sense of confidence in one’s learning abilities • the benefits of lifelong learning for multidisciplinary work and innovation	• learning how to learn comes from overall experience • confidence/fearlessness comes from overall experience; specifically challenge, rigor, workload • foundational knowledge base comes from teaching from first principles	• challenge suits intrinsically-motivated, independent learners • teaching from first principles suits curiosity, desire to understand in depth; applied/design courses support real-world understanding (tension)

	• learning abilities (and curiosity) comes from teaching from first principles • multidisciplinary thinking comes from breadth; limitations to ways of thinking due to STEM emphasis (tension)	• different levels of preparedness or abilities to adapt to program

4.1 *What role does informal, self-directed learning play in alumni career trajectories?*

Three main themes emerged in relation to lifelong learning after graduation: 1) the ability to learn quickly and independently, 2) a sense of confidence in one's learning abilities, and 3) the benefits of lifelong learning for multidisciplinary work and innovation. Notably, six participants (9903, 9927, 9932, 9933, 9951, 9953) did not bring up lifelong learning abilities in relation to their careers at any point in the interview, suggesting that they possibly have not developed these skills to the same extent, have less of an awareness of them, or do not consider them to be an outcome of their Engineering Science program experience.

A common theme (9 participants) was **the ability to learn quickly and independently**. Alumni identified the benefits of this ability for their current work, for example, "*Does your job require learning and the answer is 'definitely'. And so just being able to learn quickly*" (9936). Others also attributed it to their broader careers: "*I could just pick up any textbook, any new topic and learn it within a week kind of thing. Like, maybe surface level but I could still, you know, I could, I had the skill set to do the quick learning*" (9952). One participant identified the metacognitive awareness that enables such skills: "*A lot of it to me is about, it's like both, okay, the ability to work or study long hours, and then the ability to sort of figure out how to work smarter at the same time*" (9941). Another expressed how their lifelong learning ability enabled them to build expertise in new areas and capitalize on that knowledge: "*If you're passionate about something, like, let's say take commodity trading, if you carve out a niche, you know, and you dive deep like we just spoke about, then you kind of know something a lot better than that most people in the market and then you can definitely make a lot of money that way because you're really getting paid for your specialist knowledge*" (9936).

A second theme (8 participants) was a sense of **confidence** in one's ability to handle a variety of learning situations in their careers. This was commonly referred to as "fearlessness" or having the ability to survive anything. As one alum explained, "*The thing that you get out of EngSci in the end is that survival skill. I honestly feel after having completed EngSci that it's just like, there's nothing that someone can throw at me, that I cannot do. I might not be super good at it. But I will do it.*" (9952). This includes making major career transitions, as another participant noted: "*Just you're never fearful of learning a new thing. […] That gives you the opportunity to not be afraid of changing not only careers but industries*" (9940). The sense of confidence also benefitted alumni facing uncertainty in entrepreneurial risks: "*I've definitely done a lot of* *throwing myself into weird unknown situations since. Like, I've been starting a company and kind of been like, well, I mean, I don't know, let's go!*" (9956).

Related to these themes, 17 participants articulated **benefits of lifelong learning for multidisciplinary practice and innovation** in their careers. Specifically, how their lifelong learning abilities have enabled them to develop understandings of multiple subject areas, supporting multidisciplinary approaches or integrating across multidisciplinary teams to contribute to innovation with the connections they make. As one entrepreneur said, "*I'm not a good electrical engineer, I'm probably the worst electrical engineer on the planet. But I understand a little bit of electronics and power electronics and markets and law and like knowing a little bit of lots of things to know how to connect … Somebody needs to be the person that bridges all these different things together into something useful*" (9915). Others reinforced the central role of lifelong learning in creativity: "*Even now I'm seeing, you know, ways that I make sense of connecting things in a way that other people don't necessarily do*" (9925) and innovation: "*If you can make those connections yourself, then what you're learning, these fundamentals, allow you to do things that just … There is no simple formula for, there isn't a known way of doing it*" (9939) emphasising the importance of bridging disciplines or making connections to generate the new knowledge required to solve novel problems.

4.2 *How do alumni characterize the influence of the undergraduate curriculum on their lifelong learning motivations and strategies?*

Coding for relationships between curriculum factors and lifelong learning themes elicited some preliminary patterns. Sometimes participants attributed their abilities or confidence to their overall experience of the program's curriculum while in other cases participants identified the impacts of specific factors such as the program's emphasis on building from first principles and fundamentals, its breadth of content, and its challenging nature.

Sixteen of the participants addressed **the overall impact of the program** on their lifelong learning abilities. As one more recent alum explained, "*I think, at the end of the day, [EngSci] teaches you how to learn on your feet and get the job done. And that's what you need to be able to learn everything else you need to learn.*" (9929). Participants often articulated this as a combination of ingrained learning skills and a broad knowledge base that the program's curriculum developed, for example, "*When you're working, you're able to understand things a lot better and you're also able to figure things out a lot better on your own because you can draw on this past knowledge that you have both in terms of how to learn how to learn, and also those fundamental skills in theory*" (9946). A particular lifelong learning skill the program supports is expanding one's knowledge base into new domains "*… just by reading 400 page books, you know, over a few weeks. Again, the same thing with EngSci that you just never forget, you just learn how to learn.*" (9940). One possible interpretation of this theme is that the program biases some graduates towards a content-focused conception of learning.

Six alumni attribute their confidence or fearlessness to the overall experience of the program. As one simply stated, "*I think that has everything to do with EngSci training.*" (9940). Another explained, "*I do think there's value to, like, an undergraduate program that, like, teaches people a lot, challenges them but also, frankly, just builds confidence in in people. … And I think, like, you know, I think it's probably the sum total of what happens in EngSci*" (9955). Another elaborated on how their experience of the program's curriculum expanded their intellectual comfort zone: "*It definitely taught me to not be intimidated by any kind of technical problems. Although not that I struggled with that, in general, but […] before I did EngSci, I did think certain things were kind of like, well, I'm probably never going to be good at that. And then I became, you know, I no longer thought that. It was like, oh, like, anything is within my reach if I just spend a little bit of time working on it, and so it made the world of, like, of knowledge and of science feel at my fingertips, in a way that I didn't previously feel.*" (9921).

More specifically, there was a trend of alumni (7 participants) attributing their confidence to having made it through **the program's challenge** ("*being pushed*"), rigour ("*intensity*"), and associated workload. They also connected lifelong learning abilities to these characteristics since the only way to get through the program was to figure out how they learn best and adopt strategies to adjust to this intensity: "*When you're drinking from the firehose, and you kind of have no choice but to learn to cope with it and work effectively, efficiently*" (9941). Some articulated how they themselves or their peers had more difficulty with this as they had not developed these capacities prior to university, contrasting those who "*already are, like, whatever semi-genius person, then you'll be fine, it'll be great, like, all opportunities afforded to you*" against those "*in a situation where, like, for whatever reason … just random factors cause you to be in a bit more of a sink or swim kind of situation, then that can be very difficult and painful*" (9955).

We also identified connections (10 participants) between lifelong learning abilities and the program's emphasis on **teaching from first principles or scientific and mathematical fundamentals**. There is some distinction between the implications for lifelong learning. In some cases, participants appreciated the general first principles approach of "*understanding the basic underlying concepts and key questions to ask*" (9955) when embarking on a new topic. Others appreciated the knowledge base they had gained from this aspect of the program, i.e., the deep understanding of fundamental mathematical, scientific, and engineering content it promoted: "*what's really important more so is the fundamentals, and I think the fact that we took Thermodynamics, and, like, Introduction to Power Systems, and all those different courses gives you good fundamentals to learn new knowledge*" (9946). Often, an individual appreciated the combination of using the first principles approach and the broad knowledge base to broach a new topic: "*I think seeing so many different fields kind of modeled mathematically often gives me like a well of like metaphor to draw on when I'm trying to understand a new domain*" (9956).

Overlapping with this last theme of a 'fundamentals' knowledge base, we found extensive connections (17 participants) between **the program's breadth** and the multidisciplinary work and innovation enabled by lifelong learning skills: "*Giving students the opportunity to study and* *understand so many different things before they major on their specific area of focus is really valuable because you see those interconnections and you see the similarities across the disciplines as well*" (9925). At the same time, some participants criticized the program for reinforcing a highly analytical mindset that set them back in their ability to understand and appreciate other ways of knowing: "*We don't experience … the relevant disciplines to help you in that type of non-traditional career path. And those disciplines aren't necessarily just scientific or engineering in nature they're just different approaches to problem solving and different mechanisms of thinking*" (9933).

4.3 *What other individual or program factors do alumni identify in relation to lifelong learning?*

During analysis, individual learning dispositions emerged as an important theme in relation to an alum's experience of the program. The effectiveness of the program for lifelong learning appears to be dependent on incoming learner dispositions and other characteristics. Coding for relationships between the learner dispositions category and curriculum factors, we found interesting patterns.

The program's challenging reputation has and continues to attract ambitious and high-achieving high school students. Of the alumni interviewed, some saw it as a steppingstone towards a good job ("*I thought that by going to the most difficult program, I would get the most, the best job. And by working the hardest, I would get the best job. And reality is actually quite opposite*" (9936).) while others were more interested in engaging in the learning: "*I feel like EngSci is really only the place if you actually just enjoy learning for the sake of learning. Because if you don't enjoy learning, you're not going to have a very good time because there's lots to learn*" (9929). One participant who did not have a good time preferred taking courses in other departments, where it was "*easier to digest the information,*" (9918) and another had to dedicate all their time to achieving their desired grades: "*I had a bunch of extracurriculars that I was involved with in high school. And I just simply had to drop all of it*" (9952). Those who had a more balanced experience (5 participants) often described themselves as "*lone wolves*" in high school, being highly self-motivated and autonomous in their learning.

In relation to the first principles and fundamentals approach, participants discussed an inherent curiosity ("*I was always a person that needed to, you know, I kept asking why, why, why?*" (9936)) and preferred gaining "*a deep fundamental understanding as opposed to an operational understanding*" (9927) of things. In an ideal case, this was enabled by the ability to "*just listen and in real time I process things … to understand connections not facts*" (9939). In contrast, some alumni drew more value from design courses: "*whenever you have tested something you've seen something in action, it's definitely easier to talk about it and talk about it competently*" (9949) and saw a divide between themselves and their peers who were "*good at math*" and "*hated design*" (9946).

For alumni whose lifelong learning benefitted from the program, we saw patterns of pre-existing lifelong learning dispositions which were reinforced by their experiences. In contrast, alumni who had less positive experiences struggled to adapt or felt unprepared for the modes of learning the program required. The emphasis on theoretical fundamentals over applied design courses seems to privilege certain types of learners but it is not clear how this may impact lifelong learning.

4.4 Findings Summary

Through the themes emerging from RQ1, RQ2, and RQ3, we observe complex interrelations between curriculum factors and lifelong learning skills and dispositions. When effective, the program's breadth of fundamental content taught from a first principles approach and assessed in a rigorous manner appears to provide a knowledge base and thinking approach that strongly enables lifelong learning in STEM-related domains. An important consequence of this curriculum design is its intense, heavy workload that implicitly challenges students to understand and work to their own learning strengths and develop strategies around learning quickly; these reportedly carry over as lifelong learning confidence and skill after graduation. While some alumni find they can transfer these abilities to other domains, others find the mathematics, science, and engineering perspective limiting. Finally, these curriculum factors may play to the strengths of some students while others who lack pre-existing learning skills struggle to adapt to and benefit from the program.

5.0 Discussion

In this section, we tie our findings to relevant literature and present an emerging conceptual framework. We briefly discuss limitations to the interview findings and the challenge of using these findings as the basis of a survey instrument.

5.1 Connecting Themes to Concepts in the Literature

The themes discussed in the previous section align with literature concepts of learning orientations [10], experienced curriculum [22], and individual difference factors [25], as well as a new consideration that we are calling 'career enablers'. This is summarized in Table 3, where we depict the alignment between our research questions, themes, and concepts/relationships. We elaborate on these concepts/relationships in the following sections.

Table 3: Summary of Themes and Connections to Concepts from the Literature

Research Question	**Theme**	**Concept/Relationship from Literature**
1. What role does lifelong learning (specifically informal, self-directed learning) play in alumni career trajectories?	the ability to learn quickly and independently	lifelong learning orientation
	a sense of confidence in one's learning abilities	lifelong learning orientation
	the benefits of lifelong learning for multidisciplinary work and innovation	career enablers

How do alumni characterize the influence of the undergraduate curriculum on their lifelong learning motivations and strategies?	learning how to learn comes from overall experience	experienced curriculum ↔ lifelong learning orientation
	confidence/fearlessness comes from overall experience; specifically challenge, rigor, workload	experienced curriculum ↔ lifelong learning orientation
	foundational knowledge base comes from teaching from first principles	experienced curriculum ↔ lifelong learning orientation
	learning abilities (and curiosity) comes from teaching from first principles	experienced curriculum ↔ lifelong learning orientation
	multidisciplinary thinking comes from breadth; limitations to ways of thinking due to STEM emphasis (tension)	experienced curriculum ↔ lifelong learning orientation
RQ3: What other individual or program factors do alumni identify as influential for lifelong learning?	challenge suits intrinsically-motivated, independent learners	undergraduate learning orientation ↔ experienced curriculum
	teaching from first principles suits curiosity, desire to understand in depth; applied/design courses support real-world understanding (tension)	undergraduate learning orientation ↔ experienced curriculum
	different levels of preparedness or abilities to adapt to program	individual factors; undergraduate learning orientation

5.1.1 Lifelong Learning Orientations

There are various conceptualizations of individual lifelong learning characteristics. The themes we identified, “the ability to learn quickly and independently” and “a sense of confidence in one’s learning abilities,” resonate with dimensions of lifelong learning ‘orientations’ in existing work, for example, four out of five dimensions of the Transferable Learning Orientations (TLO) tool [10]. The ability to learn quickly and independently, identified in our analysis, ties to transfer (makes connections), outcome motivation (self-motivated), and organization (learns independently). Confidence in one’s learning abilities ties to self-efficacy (confident). Together, these represent a lifelong learning orientation. Although the original TLO tool was developed for use by students in specific undergraduate courses [10], it is grounded in rich theory and builds on instruments that have been modified for the workplace (e.g. [29]) and thus seems applicable to our work.

5.1.2 Career Enablers

As described, a recurring theme in our data was “the benefits of lifelong learning for multidisciplinary work and innovation.” Engineering education literature focuses on the role of lifelong learning in keeping skillsets up-to-date in response to technological change [7] but this is typically conceptualized in relation to a disciplinary knowledge base. In addition to this role, we identified lifelong learning's importance as enabling success in multidisciplinary settings and in support of innovation. This is an underexplored area that we plan to investigate further.

5.1.3 Experienced Curriculum ↔ Lifelong Learning Orientations

A common conclusion in lifelong learning studies is that students are more likely to develop effective lifelong learning orientations if strategies are explicitly taught across a program [17]. This is not something that alumni identified; instead, they described developing abilities and confidence in response to other curriculum factors.

One factor was the experience of breadth and mutlidisciplinarity. Research investigating the impacts of curriculum breadth on lifelong learning outcomes does not seem to exist, but we hypothesize that it could support transfer by allowing for more connections to be made due to exposure to disciplinary differences within the bounds of engineering.

Another factor was the program's challenge, rigour, and associated workload. Rigor has been defined and investigated in connection to lifelong learning for liberal arts students [30] but not engineers. There are concerns in engineering education about the negative consequences of heavy undergraduate workloads [31], although most participants in this study ultimately saw benefits from it.

The program's first principles approach is mirrored in other settings (e.g. [32], [33], [34]) however its benefits for learners have not been investigated [35]. It appears to encourage conceptual understanding and 'deep learning' which would benefit transfer and other lifelong learning dimensions. A potential tension emerged between the first principles teaching and design courses, as there seemed to be a disconnect between theory and practice across the curriculum, at least in some graduates' experiences. Again, implications for engineering graduates' lifelong learning outcomes are unclear.

5.1.4 Individual Factors ↔ Undergraduate Learning Orientation ↔ Experienced Curriculum

Our analysis indicated that pre-existing learner dispositions and prior experiences influenced curricular experiences in various ways, which may have effects on motivation and success as undergraduate students as well as long-term lifelong learning outcomes. This may also indicate curriculum factors that advantage or disadvantage students depending on their past experiences and cultural capital [36].

According to university impact researchers, there are three broad influences surrounding program impacts: 1) incoming/pre-university characteristics, 2) institutional and other environmental factors that may interact with curriculum, and 3) other outcomes that may interact with the factors being researched [37]. Incoming characteristics and demographics can influence interpretations of the planned/enacted curriculum (i.e. experienced curriculum) [23] as well as education and career outcomes [25]. From the lifelong learning literature, incoming characteristics can also influence pre-existing learning orientations [19]. There is a continuous feedback loop between experienced curriculum and learning orientations; learning orientations can influence how students experience curriculum, while curricular experiences can influence learning orientations [38].

Prior work investigates approaches to learning demonstrated by engineering students in foundational courses and programming courses [18]. Building on the frequently used (and criticized [39]) “Approaches to Learning” model [40], [38] in which learners take either a “surface” approach (to avoid failure or do the bare minimum) or “deep” approach (to develop understanding), the resulting model introduces a new aspect of strategy in which students work through many assigned or unassigned problems. In some cases, this is with the intention of memorizing how to solve different types of problems, while in other cases this is with the intention of understanding why solution methods work or their underlying concepts. This model appears relevant to understanding how alumni typically approached learning during their undergraduate programs, and whether this changed in response to the program’s curriculum.

Outside of the formal curriculum, co- and extracurricular experiences, including High Impact Practices [41][42] can be highly influential. It is important to isolate these effects when assessing the impacts of the core curriculum on lifelong learning outcomes.

5.2 Resulting Framework

The following diagram (Figure 2 – see next page) illustrates the themes and relationships that emerged in our analysis and incorporates some additional considerations from the literature. It is shaped by the Planned-Enacted-Experienced model of curriculum [22] as discussed in the introduction, with curricular experiences influencing long-term graduate outcomes for lifelong learning and career trajectories. Career trajectories [1] are also associated with disciplinary curriculum [25] but vary greatly at the individual level [43]. Graduates bring the lifelong learning skills and attitudes (orientations) developed as students to the workplace [44] and these evolving lifelong learning orientations support progression and mobility within career trajectories. Lifelong learning orientations may be motivated by and/or support enablers such as workplace responsibilities or career goals.

Each box represents a high-level concept containing multiple constructs that interrelate. For the second quantitative stage of our mixed-methods research, we will develop a set of scales enabling us to measure each construct and analyse the interactions between constructs, especially to interrogate some of the specific relationships identified in the interviews. Due to a lack of existing instruments, questions that measure the importance of different lifelong learning factors in enabling ones’ overall career trajectory (enablers) could be developed further to formalize and validate a new instrument. This conceptual framework provides a structure of high-level relationships that could apply to a range of alumni studies, threading together many disparate areas of research.

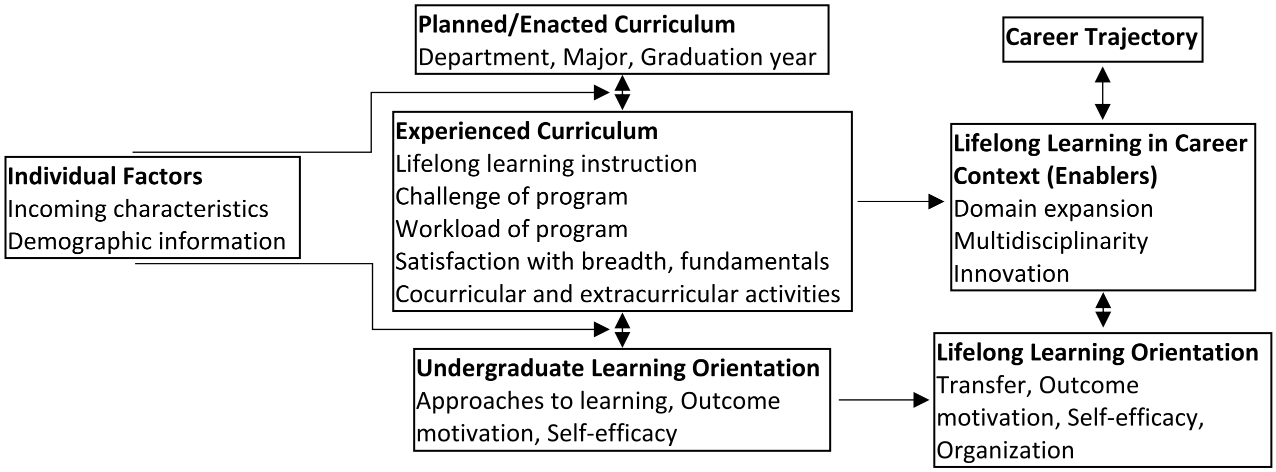

Figure 2: Conceptual Framework Integrating Interview Findings and Literature

5.3 Limitations

There are limitations to our work that may have implications for the findings, formulation of the conceptual framework, and future work. These come from the program context and changes, participant selection, and the interview questions and analysis.

While Engineering Science continues to promote theoretical understanding, the program has placed greater emphasis on design in more recent years due to accreditation requirements and other motivators. Curricular experiences of more recent graduates may differ from those of earlier graduates who did not experience cornerstone, middle-year, or capstone design courses as opportunities to apply their theoretical knowledge or learn through different modes. There have also been program, faculty, and university-level efforts to provide greater support for learners, so students in the past may have been more unsupported in navigating and adapting to the challenge of the program. Finally, as in any study that looks at program-level effects, it is challenging to isolate curriculum effects from the larger student experience including extracurriculars and internships. We will attempt to address this in the survey by collecting data on co- and extra-curricular engagement.

As discussed in the methods section, we do not expect that our selection of participants allowed for a representative sample of the full alumni population, nor addressed the experiences of underrepresented groups. While we made a point of selecting alumni who had different sentiments towards the program, we did not use purposive sampling to ensure representation and variation across other important factors. Some participants commented on the impacts of their status as a recent immigrant or a woman on challenges they faced during their curricular experiences, and we would have liked to explore these experiences further. For the survey, we plan to collect detailed demographic data and compare characteristics of the sample to the population to identify any imbalances.

The formulation of the interview questions and the analysis approach also have important implications. The interviews focused on the program more so than on lifelong learning, and we suspect that the questions asked may have influenced alumni towards conceptions of lifelong learning that focus on cognitive and practical development to the exclusion of relational and emotional development [45] as these domains were only addressed by a small minority of participants and did not emerge as dominant themes. On the other hand, alumni may hold this perspective because of their undergraduate training and/or career trajectories. As future work, we could focus our analysis and reporting on less prevalent themes and explore these further through subsequent stages of survey and interviews.

5.4 Challenges in the Sequential Mixed-Methods Research Approach

Our exploratory, qualitative research resulted in a complex framework. Translating this rich conceptualization of curriculum impacts on lifelong learning into a survey instrument that will reach a larger sample of the population is a challenge. According to university impact researchers, peripheral factors like incoming characteristics are influential [37], so simplifying the framework seems ill-advised. As an additional point of complexity, knowledge, skills, and attitudes associated with the lifelong learning competency can influence one's ability to reflect on their competence [46], meaning that research study participant self-reports may vary in depth and reflexivity depending on their lifelong learning orientations.

Developing a survey through a mixed-methods approach presents trade-offs between implementing best practices for reliability and validity [47] (e.g. asking the same question multiple ways) and survey length. While most constructs have relevant validated measurement instruments (e.g. [48], [11], [49], [50], [51], [52]), these are typically lengthy (often a minimum of 40 questions each) and compiling them into a single survey is not feasible, especially given issues of over-surveying and low alumni response rates [53]. Other survey-based research projects have faced similar issues in maintaining breadth and depth [54].

6.0 Conclusion and Next Steps

Thematic analysis of alumni interviews revealed complex relationships between curriculum factors and lifelong learning orientations. Predominant outcomes included the ability to learn quickly and independently and confidence in these abilities attributed to the curriculum's workload, first principles teaching, and breadth rather than any explicit instruction on lifelong learning strategies or metacognition. These dimensions of lifelong learning appear to be particularly valuable for multidisciplinary work, innovation, and expanding knowledge domains for career transitions, although an engineering program's lack of broader exposure to the humanities and other ways of knowing can be limiting in this respect. As would be expected, individuals' past experiences and predispositions impacted their curricular experiences and long-term outcomes.

To explore this topic further, we planned to survey a larger population of alumni; however, there are no suitable survey instruments that span these broad and complex concepts. Thus, we have built upon the framework presented here by incorporating further theory and reviewing documentation from different engineering and science programs to develop a new alumni lifelong learning survey that meets our needs. Our next steps involve comparing responses across different curricular features that correlate with different career trajectory and lifelong learning outcomes. We will then analyse lifelong learning outcomes in relation to individual factors to understand these effects, especially predispositions towards lifelong learning that may be present prior to beginning an undergraduate engineering program.

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Appendix A: Interview Questions Analysed

Can you tell me a little about your career and educational journey since graduating from (program)?
What were the typical teaching practices you experienced in (program) and what teaching practices had the most impact on you?
We often talk about a "first principles approach" in (program). What does this mean to you?
We often talk about (program) as being "enriched" or "rigourous". What does this mean to you?
What is the value in the multi-disciplinary nature of (program)? Is there anything we should be doing to support the experience of the students as they experience this "multidisciplinarity"?
What influence did design courses have on developing your professional identity?
In what ways did you form professional/learning communities through your undergraduate experiences in (program)?
What affordances did your selected major provide? What limitations?
How did (program) prepare you for your post-graduate pursuits? Please speak to both in-class and out-of-class experiences as a (program) student.
Was there anything that you think (program) should have prepared you for, but it didn't?
Is there anything else you'd like to share about your experience in (program)?