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Identifying Curriculum Factors that Facilitate Lifelong Learning in Alumni Career Trajectories: Stage 3 of a Sequential Mixed-Methods Study

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1.0 Introduction

In this research paper, we present results of the third stage of a mixed-methods study that investigates the relationship between lifelong learning and undergraduate experiences for science, technology, engineering, and mathematics (STEM) alumni. Lifelong learning can be defined broadly as a graduate's "generic ability to guide their own learning throughout their lives and in the wide variety of situations they will encounter after leaving formal education" [1](p. 292). This recognizes the informal and largely self-directed nature of lifelong learning. As discussed in previous papers documenting this work ([2], [3]), it is important that undergraduate engineering programs develop effective lifelong learners given their need to take ownership of their increasingly unpredictable careers and serve the public good in a landscape of volatility, uncertainty, complexity, and ambiguity (VUCA). We focus on the concept of a lifelong learning orientation, or positive disposition towards lifelong learning in terms of motivations (intentions behind learning) and approaches (high-level learning techniques).

This study takes place at a large Canadian research institution. Our aim is to understand the long-term benefits and drawbacks of different undergraduate program models for STEM alumni lifelong learning. From this research, we can extract insights to help programs reconsider their own educational approaches towards lifelong learning outcomes. In Stage 1 of this work [2], we combined lifelong learning and college/university impact literature insights with interview findings to develop a preliminary conceptual framework (Figure 1, below) connecting individuals' pre-university characteristics [4], career trajectories [5], and undergraduate and workplace learning orientations [6] with curricular and extra-curricular experiences and perceptions [7]. The conceptual framework has guided subsequent research activities.

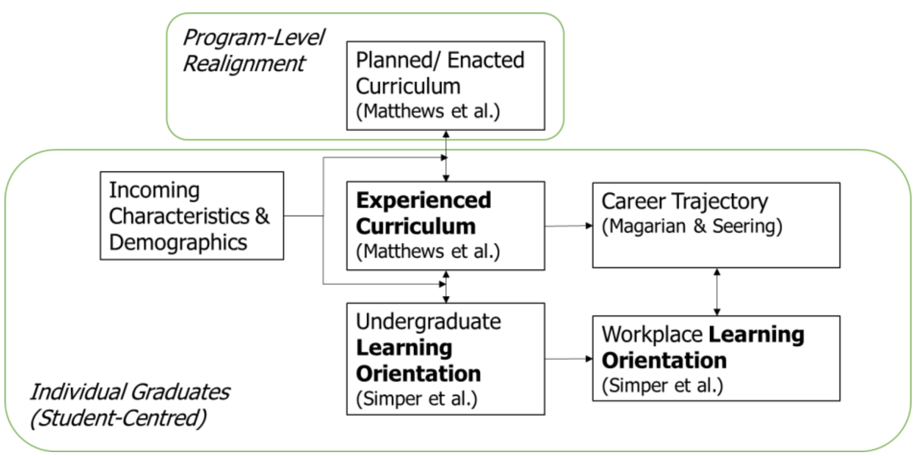

Figure 1: Conceptual Framework

In Stage 2 of this work [3], we developed and implemented an alumni survey (n = 279) grounded in the conceptual framework. The survey uncovered differences in individuals' lifelong learning motivations between the undergraduate and workplace stages (e.g. an increase in the importance of one's interest in the context or activities; a decrease in the influence of avoiding failure). We also found correlations between undergraduate and workplace learning approaches in terms of tendencies towards memorizing information, understanding through making connections, or taking more proactive approaches. At the same time, we did not find substantial differences in outcomes by program; rather, there appear to be different interactions between individuals and programs depending on prior experience, extracurricular activities, and other individual characteristics.

Stage 3 of this work builds on these findings to investigate emerging questions about the interactions between programs, individuals, and individuals' experiences outside of the undergraduate program. In this paper, we briefly summarize the background and motivation behind the work (section 2), describe the Stage 3 methods drawing from life history research and narrative inquiry to gain a richer understanding of individuals' learning journeys (section 3), present resulting learning journeys and values analysis focusing on a subset of four alumni (section 4), and discuss the implications of these results for undergraduate program design and the engineering profession more broadly (section 5).

2.0 Background and Motivation

In Canada and many other countries, future engineers must complete an accredited undergraduate program on their journey towards professional licensure [8]. Engineering programs must develop twelve graduate attributes in students, and lifelong learning is among them. The Canadian Engineering Accreditation Board graduate attribute definition for lifelong learning is one's "ability to identify and to address their own educational needs in a changing world in ways sufficient to maintain their competence and to allow them to contribute to the advancement of knowledge" [9]. In the United States, the ABET outcome for lifelong learning is "an ability to acquire and apply new knowledge as needed, using appropriate learning strategies"[10]. At the same time, alumni tracking and scholarly research shows that many engineering program graduates go on to non-engineering careers and may have different lifelong learning needs [11], [12]. Uncertainties persist regarding the most effective approaches towards achieving lifelong learning outcomes. In this literature review, we summarize existing findings regarding lifelong learning's role in graduates' careers and development.

2.1 Conceptions of Lifelong Learning

Lifelong learning orientations are the patterns of behaviour towards learning that are driven by underlying values, beliefs, attitudes, and goals [13]. However, lifelong learning's numerous other meanings can generate confusion and ambiguity for research [14] so it is important to clarify how these concepts are related.

In national and international policy, lifelong learning discussions often revolve around educational systems and their support of economic development, specifically access to formal learning or retraining for people of varying ages and abilities [15]. Tension exists between regional economic goals, which prioritize lifelong learning for a productive workforce, and more expansive perspectives that emphasize personal growth, social inclusion, and democratic engagement [16]. In addition to formal educational systems, lifelong learning extends to include continuing professional development (CPD) activities within the workplace and in accordance with engineering licensure requirements. In the context of Canadian and United States engineering program accreditation, lifelong learning graduate attribute definitions have been criticized for their implied narrow scopes [17] so it is beneficial to consider broader and potentially more impactful ways of looking at lifelong learning.

Expanding our understanding beyond formal education within institutions or professional development programs, *lifewide learning* acknowledges the diverse and interconnected spaces where learning takes place such as family life, social life, and recreational activities [16], [18], [19]. This perspective often highlights individual skills and abilities (as well as social and emotional aspects) that facilitate self-directed or informal learning in response to various experiences, ultimately supporting personal development.

Learning careers [20] focus on individuals' dispositions toward learning, how these dispositions are exhibited in social practices, and how they are influenced by social contexts. This maximalist view balances the influences of social structures with personal agency and accountability for learning. It is aligned with the cultural-historical activity theory theoretical framework [21], [22] and provides a comprehensive lens on lifelong learning in combination with the sources of the original conceptual framework guiding our work. In studying STEM alumni, it is important to look at lifelong learning through these comprehensive, holistic lenses.

2.2 Lifelong Learning and Engineering Education

Changes associated with the fourth industrial revolution necessitate future engineers to have greater career autonomy and the ability to navigate social and cultural considerations in their engineering work; this has implications for how engineering knowledge is defined, developed, and applied [23] and therefore influences what lifelong learning can and should look like for engineering education [17], [24], [25], [26]. Alumni and employer studies often suggest that engineering students have historically gained excess domain knowledge while lacking in professional, complementary, or transversal competencies including overarching lifelong learning. Having clarified what lifelong learning entails, especially from the perspective of dispositions or orientations that drive and enable lifewide learning and adaptability, we now review necessary and effective approaches towards achieving lifelong learning outcomes.

2.2.1 Lifelong Learning in Engineering Practice

In a United States study to identify gaps between engineering education and practice, Brunhaver et al. [25] interviewed early-career engineers and confirmed that engineering work is more variable, complex, and social than typical curricula suggest. After graduation, many alumni realize the importance of independent information management and cross-disciplinary communication. Learning about workplace context is crucial, as early-career engineers often struggle to connect their education to practical work. As engineers gain experience, their roles shift toward broader responsibilities, necessitating different skillsets. Despite these findings, the authors define lifelong learning narrowly as the ability to seek knowledge when gaps are recognized and do not connect their findings to an underlying need for effective lifelong learning orientations.

Lutz and Paretti [26] have highlighted similar learning challenges faced by graduates as they transition to the workplace. While engineering jobs focus on technical problems, learning occurs when graduates adapt to new contexts and align complementary skills (such as communication and project management) with their workplace. Preparing graduates to direct their lifelong learning capabilities towards technical, social, and cultural challenges is essential for successful career transitions and long-term impact.

2.2.2 Supporting Lifelong Learning Outcomes

A systematic scoping review identified 13 studies on self-regulated learning interventions in engineering education [27]. It did not uncover any clear instructional benefits for lifelong learning dimensions but rather highlighted a lack of theoretical grounding in these kinds of studies and a need for more comprehensive research [27]. Some standalone studies provide more actionable insights.

In their study on engineering education and practice, Passow & Passow [24] found that engineering work is project-based and tied to product life cycles. Lifelong learning demands remain consistent as engineers progress through their careers, but graduate attribute definitions often miss crucial aspects of what this looks like for engineering practice. The authors recommend team- and project-based educational activities to foster lifelong learning orientations. It will be important to attend to alumni reflections on these types of learning activities and any connections to their lifelong learning orientations.

Ford et al. [28] investigated the effects of capstone design project experiences on lifelong learning during workplace transitions. They examined alumni from four institutions, focusing on their initial three months at work. Challenges often related to self-directed learning, which was less emphasized in undergrad programs, as well as interpersonal interactions with colleagues from different educational and personal backgrounds. While capstone experiences didn't fully prepare individuals, they partially replicated workplace aspects in their demands for a lifelong learning orientation. There may be different outcomes for alumni from engineering programs who participate in capstone design projects when compared to alumni from sciences programs who typically do not.

In contrast to these positive outcomes associated with project-based learning experiences emphasizing design and teamwork, Strong et al. [29] came to different conclusions from their investigation into engineering graduate students' perceptions of their recent undergraduate courses. In this research, participants reported that their most impactful courses were discipline-specific non-design courses with instructor-centered approaches. This suggests a disconnect between planned, enacted, and experienced elements of curriculum and lifelong learning outcomes [7]. More research is needed to understand how or why current and recent students' perceptions of the effectiveness of their programs and courses sometimes contradict purported best practices, and the implications for lifelong learning motivations and strategies.

Marra et al. [30] also explored how the nature of an undergraduate engineering program impacted alumni lifelong learning, focusing on the program's emphasis on metacognition and reflection often facilitated through team projects. The researchers interviewed 15 recent graduates (3-4 years post-graduation) in the United States. Graduates reported that their undergraduate training, and consequential familiarity with project-based work and comfort tackling uncertainty or unfamiliar tasks, enabled self-directed learning for workplace responsibilities. For 6/15 alumni, metacognition played a role beyond engineering problem-solving as it was applied in the service of social and cultural considerations of engineering work. The study provides promising evidence that metacognitive skill development, taught through student-defined open-ended projects and reflective activities, can have benefits for lifelong learning orientations. Building on this research to investigate different program structures, and to consider local idiosyncrasies, will elicit a more comprehensive understanding of how programs can promote desirable lifelong learning outcomes for alumni.

Seevaratnam et al. [31] make the argument that incorporating design thinking attributes into higher education can enhance lifelong learning orientations. The design thinking approach is closely tied to engineering design, and may be more compatible than other high impact practices (HIPs) which are typically associated with beneficial lifelong learning outcomes in humanities and social sciences or liberal arts contexts [32] but only used to a limited extent in engineering education [33].

In the Canadian context, we performed a review of lifelong learning instruction and found that in the available documentation, there is little evidence that necessary lifelong learning orientations are considered during program-level curriculum development or renewal; rather, it appears instructors will independently implement evidence-based approaches to achieving lifelong learning outcomes for a given course [34]. One exception to this is a study of third- and fourth-year students in a Canadian engineering program to understand their lifelong learning aptitudes [35]. While fourth-year students demonstrated a reflective quality and recognized the larger importance of lifelong learning, third-year students focused more on learning skills relevant to their formal education [35]. This implies a change in orientation that could be associated with an additional year of program experience, general personal development, or the implications of their upcoming graduation. It indicates that individuals' lifelong learning orientations can evolve in response to curricular experiences as well as broader contextual factors and life stages.

A Canadian undergraduate engineering program evaluation [36] that investigated the development of dispositions or attitudes towards lifelong learning highlighted the need for greater intentionality in course design and other program-wide adjustments to ensure these outcomes. The authors generated rich findings through interviews, surveys, and document analyses considering stakeholders including faculty, students, and alumni; they acknowledged the high resource demands of their approach but deemed it necessary for meaningful evaluation of the lifelong learning graduate attribute. This study reaffirms the benefits of a mixed-methods approach to studying alumni lifelong learning and highlights some program features to look out for in alumni recollections of their undergraduate experience in our programs.

2.3 Implications for Engineering Education Research

The literature reviewed suggests that programs in Canada are often addressing a limited definition of lifelong learning that might not fully support student competency after graduation. Institutions may also be failing to consider how an educational program as an integrated whole may impact the lifelong learning competency of students. Various stakeholder perspectives consistently show that professional competencies, including lifelong learning orientations, are integral to the personal development of engineering program graduates and the future impacts of the engineering profession. In contrast to these realities, most engineering programs continue to perpetuate a narrow focus on engineering knowledge that minimizes the interconnections between technology and society [37], [38] and devalues essential skillsets and mindsets [39]. If engineering programs can develop effective lifelong learning orientations, future engineers might be better prepared to confront anticipated and unanticipated sociotechnical challenges while regaining power and autonomy over their career trajectories. Accordingly, there is a need for more research that characterizes the gap between undergraduate program experiences and their impacts on lifelong learning throughout careers. Additionally, the impacts of undergraduate programs for lifelong learning orientations are not well-understood in the broader engineering education literature. Investigating the in-depth learning journeys of STEM alumni from different programs may provide new information towards addressing these shortcomings.

3.0 Methods

In the prior stages of our study, we expected to find measurable differences in lifelong learning orientations for alumni of different undergraduate streams of science and engineering. We only found minor differences between different program alumni groups for a single dimension of outcome motivation (achieving workplace success), and thus hypothesize that interactions between individuals and programs are highly dependent on prior experience, extracurricular activities, or other individual factors.

In this Stage 3 of the mixed methods study, we performed learning journey interviews with twelve engineering and physics alumni to build on the preliminary conceptual framework developed from Stage 1 and to better understand some individual experiences behind the survey results from Stage 2. We intend to mix all these data further in the near future.

3.1 Background on Mixed Methods Designs for Lifelong Learning Research

To investigate alumni outcomes, researchers commonly implement surveys to capture aggregate data or use qualitative methods (including interviews, focus groups, and life history research) to dig into individual experiences. Mixed methods research is the deliberate collection and interweaved analysis of multiple streams of data [40]; it is well-suited to the investigation of program impact [41] especially for nebulous constructs like lifelong learning orientations. For effective mixed methods research, it is important to go beyond separate analyses of separate data sources; for example, by investigating an emergent theme using a different data stream, by quantifying qualitative data or otherwise converting data types, and by using one stream to identify cases for further exploration [41].

Life span perspectives such as life history research are relevant to alumni lifelong learning because they recognize timing and sequence in life experiences, including education and employment, and their impacts on an individual's development [42]. Life history research can incorporate tools to support retrospective reporting. In education and survey methodology, researchers have used calendars and time diaries as cues to activate autobiographical memory to improve the completeness and accuracy of reports [43]. Calendars are helpful for contextualizing distant events, while time diaries provide more detail of recent activities. One researcher employed an interview mapping protocol that asked participants to draw out and discuss connections between their current writing activities and their undergraduate education in rhetoric and composition [44]. Taking these types of approaches that expand beyond verbal recall can help participants share more complete and accurate information.

Our present research aims to understand people's experiences and make meaningful connections between life events; narrative methodology is often used for this purpose [45]. In narrative interviewing, the interviewer imposes minimal structure while carefully eliciting narrations from informants, who give detailed information that is relevant from their perspectives [46]. Experience-centered narrative research focuses on general phenomena or things that have happened to the narrator rather than a specific shared event [47]; for example, informants could be asked to give a narrative of their unique experience during the transition from university to work. Influenced by cultural historical theory (Vygotsky) and activity theory (Engeström), Daiute [48], [49] recognizes the social, dynamic nature of narratives to inform data collection and analysis methods. According to these theories, it is important to consider the interdependence inherent in the broader context of experience and narration. This perspective aligns with this research as our survey reinforced the complexity of individual experiences of lifelong learning.

In narrative research, the researcher needs to make plausible interpretations within the bounds of the narrative(s) because they capture complex experiences that are not aligned with hypothesis testing paradigms [50]. To bring forward meaningful evidence in interview approaches involving homogenous groups, 12 participants are typically sufficient for thematic saturation [51] in the sense that any additional participant data will bring negligible further insight [52]. When performing interpretative analyses within narrative approaches, saturation is unlikely to occur due to the level of detail offered by each unique case [53]. Critiques of the saturation concept recommend researchers instead make judgements based on conceptual depth [53] or information power [54], [55]. We have not sought thematic saturation; our pragmatic approach prioritized informative depth of dialogue across 12 heterogenous participants.

Narratives are often explored through paradigmatic analysis (drawing from constant comparison or grounded theory) to find themes across narratives, or narrative analysis of individual narratives to capture individuals' development trajectories [45]. Journey maps can be used for data collection or interpretation and analysis [56]. Emphasizing the dynamic aspect of narratives, effective analysis approaches include values analysis, plot analysis, significance analysis, and character and time mapping [48], [49], [57]. Values analysis is applicable to contexts of individual change (such as learning, development, and workplace practices) when researchers aim to uncover participants' values, attitudes, or beliefs surrounding these experiences [48], [57]. As discussed below, we implemented a combination of narrative smoothing, journey mapping, and values analysis to make sense of the dense interview information and address the Stage 3 research questions.

3.2 Stage 3 Research Approach

Building on the prior work in our mixed methods study, in this stage we investigated *How recent alumni with beneficial lifelong learning orientations value the undergraduate curricular experience and lifelong learning outcomes in connection to their career trajectories*. The Stage 3 narrative interviews were designed to address the following research questions within the larger study:

RQ3a What connections do alumni make between their undergraduate program experiences and later lifelong learning orientations?

RQ3b How do prior experiences and incoming learning orientations influence experiences of undergraduate program curricula and subsequent lifelong learning outcomes?

RQ3c How did alumni navigate any values tensions related to learning during their undergraduate program or after graduation?

RQ3d What is the importance of one's lifelong learning orientation in crossing disciplinary boundaries, changing mindsets/worldviews, and developing broader professional competencies?

3.2.1 Sampling and Data Collection

Interviewee selection was done through purposive sampling of Stage 2 survey participants to identify recent graduates (3-10 years after convocation) with high lifelong learning orientation scores (high interest, low failure avoidance, transfer strategies that prioritize understanding) and/or more extensive career transitions. We expected that people who had graduated within the past 3-10 years would have experienced curricula that are pertinent to the present, while having enough further experience beyond the undergraduate program to inform their retrospective accounts. The intent was to learn from extreme cases [41] that will likely offer greater reflective insight [58]. Within this shortlist, we attempted to diversify participants based on engineering or science major, gender, sexual orientation, race, and disability status. The interviews followed life history narrative methods inspired by learning career studies [20], [59], [60] and were designed as 60-90 minute virtual video interviews eliciting narratives of individuals' experiences with learning throughout their careers.

The lead author performed all twelve interviews. The starting narration question was "Can you tell me about your education and career journey up to this point in time, and as you share your journey, can you highlight events and experiences that have been important for your learning along the way." According to narrative interview practices, the interviewer did not prepare specific follow-up questions but attended to the informant's initial account and then prompted the informant to expand on certain experiences and ideas expressed. Given the study's research questions, these experiences and ideas included:

- connections between career learning experiences and undergraduate education
- changes in outcome motivations and transfer strategies
- experiences of changing mindsets, different ways of knowing, reflection and reflexivity
- the role of learning during major career transitions or within multidisciplinary settings
- unlearning strategies or orientations developed/reinforced by undergraduate experiences
- different learning contexts (e.g. individual, group/organizational, formal/informal)

3.2.2. Data Analysis

Having transcribed and cleaned the recordings, we performed pilot analyses and our data coding strategy evolved from two planned cycles of analysis to a more eclectic combination [57]. For reference, the planned first cycle would provisional codes tied to the Stage 1 conceptual framework and Stage 2 survey variables. For the second cycle, we intended to implement hypothesis and causation coding strategies to consider relationships between these variables. This approach was not productive due to the complex nature of participants' narratives [58], [61]; breaking the information down into components decontextualized details and severed the connections participants made in their narratives. Hypothesis and causation coding generated numerous permutations of possible relationships between the constructs we were exploring.

Ultimately, we 1) created journey maps aligned with the life stages of the conceptual framework (pre-undergraduate, undergraduate, post-undergraduate) to serve as visual summaries of the individual narratives, 2) used narrative restructuring [62] guided by the journey maps to create a cohesive chronology while maintaining participant voice, and 3) applied dynamic narrative analysis methods (primarily values analysis) [48] to account for the complexity of the narratives. Values analysis is a suitable technique for understanding participants' and other stakeholders' attitudes towards learning (an indication of lifelong learning orientation) as well as the importance or value of the undergraduate experience for lifelong learning. Because we were influenced by dynamic narrative research, it was important to seek narrative expressions from other stakeholders and look across all sources as in a dynamic conversation.

The values analysis process involved several iterative steps drawing from Daite [48] and Saldana [57]:

1. Identification of additional sources of narrative expressions from influential stakeholders (national accreditation bodies, undergraduate programs) and selection for four alumni narratives for initial analysis.
2. Review of narrative interview transcripts and stakeholder policy documents to identify value judgements (principles, norms, beliefs, ideologies, goals – explicit or implicit) about lifelong learning in connection to undergraduate education and/or careers.
3. Paraphrasing of implicit value judgements into explicit values statements.
4. Comparison and matching of values within and across narratives.
5. Memoing (direct responses to research questions) to synthesize each alum's narrative.
6. Comparison and matching of values across narratives and memos to finalize values statements and categorize as major or minor for each stakeholder.

The lead author performed the values analysis supported by methodological integrity check-ins [63] with the second author. This process provided a second interpretation of excerpts of the narrative expressions and also motivated the inclusion of program-level documents as sources of narrative expression. The second and third authors audited the work by providing feedback on the documentation; this encouraged further interrogation of the journey maps, values statements, and findings elicited from the data. ASEE Educational Research and Methods Division reviewers also audited the draft paper and prompted a better distinction between major and minor values, among other reconsiderations. The results follow.

4.0 Results

The narrative approach to interviewing allowed participants to share and elaborate on relevant details that a traditional semi-structured interview might not have elicited. Most informants chose to begin their narratives of lifelong learning at high school or even elementary school; this reinforces the fact that the undergraduate curriculum is just one part of someone's learning career and may or may not serve as an inflection point for lifelong learning orientations. As they got deeper into their narratives, participants appeared to uncover or clarify meaning in the connections between their undergraduate experiences and their workplace learning experiences. This results section presents the journey map summaries and values analysis for a subset of four participants as discussed below. Names are pseudonyms and we use generalizations where needed to maintain participants' anonymity.

4.1 Participant Journeys

Table 1 summarizes personal, educational, and career characteristics of the four selected participants. We choose to focus on these participants in our initial analyses for this paper because each alum completed a different undergraduate program, did not pursue doctoral degrees, and now works in the public or private sector; their learning journeys capture a variety of STEM education programs and provide insights for lifelong learning in non-academic career trajectories.

Table 1: Education and Career Summaries of Four Participants

Person	**Undergraduate Education Program**	**Further Education**	**Current Organization**	**Engineering Proximity** [4]
Jasmyn (Woman of colour)	Applied Science & Engineering: Industrial Engineering	Master of Engineering	Public Sector	Engineering; No P.Eng
Lou (Man)	Arts & Sciences: Physics	Master of Science	Private Sector	Engineering-Adjacent; No P.Eng
Marlana (Woman)	Applied Science & Engineering: Mechanical Engineering	Master of Applied Science	Private Sector	Other Engineering; P.Eng Planned

Ty (Queer man)	Applied Science & Engineering: Engineering Science	N/A	Public Sector	Engineering-Adjacent; P.Eng

Demographic information was captured from the Stage 2 survey; during the interview, Ty briefly discussed part of his experience coming out as queer as an undergraduate engineering student while the other three other participants discussed their parents'/caregivers' professional backgrounds but no other aspects of their demographic backgrounds or positionalities. In Canada, a Master of Engineering degree is a course-based professional degree while the Master of Applied Science and Master of Science are research-focused degrees. The Engineering Proximity of someone's current role was determined as part of the Stage 2 survey. The typology distinguishes between workplace roles based on one's level of influence on design form and function with four role categories: Engineering (design instantiating or governing), Engineering-Adjacent (design moderating), Other Engineering (apply engineering-related skills and knowledge), and Non-Engineering [5]. P.Eng is the protected designation of a Professional Engineer in Canada and is another way to evaluate an alum's ties to the profession from a regulatory perspective.

The following figures illustrate the participant's journeys. These journey maps were created by the first author using language from the participants' narrative interviews. The horizontal line denotes a chronological timeline broken into several stages including pre- high school, high school, undergraduate, and subsequent roles or further education after the undergraduate degree (post). The annotations highlight events and experiences that were particularly salient for the individual's learning as reported during the interview as well as keywords they used to characterize their learning motivations and/or approaches. The vertical axis differentiates between non-formal or informal learning experiences, formal learning experiences such as courses and continuing professional development (CPD) activities, learning tendencies, and contextual information about education/career interests, choices, and roles. This categorization was done for readability when digitizing the original hand illustrated journey maps.

4.1.1 Jasmyn

Jasmyn is a woman of colour who completed an undergraduate program in Industrial Engineering and went on to work in the public sector continuing at the organization where she did a co-op/internship. While her responsibilities align with the typology's engineering role (design instantiating or governing), she does not have a P.Eng designation likely because she works in a non-traditional space designing information systems. Part-way through her career, Jasmyn completed a professional Master of Engineering Degree. Jasmyn's interest in a breadth of subject areas beyond her disciplinary courses during her undergraduate education continued in her workplace roles and graduate education, where she has been able to carve out opportunities that satiate these interests. The challenges Jasmyn faced as a dreamer and synthesizer constrained by rigid program and course structures parallel the tensions she identified between innovation and operational goals in the workplace. Jasmyn's journey map is illustrated in Figure 2.

Non-formal/ informal learning	Design-build competitions		Additional language		Non-competitive design club (play), reading			YouTube, Ted Talks, podcasts, reading; Asking colleagues questions of appropriate specificity		
Formal learning	Deeper into subjects; liked math, science, arts		Courses: design, human factors, biomechanics, information systems, Capstone Sought breadth, "dabbled," faced institutional hurdles					CPD e.g. risk mgmt	Masters: data analytics + innovation	CPD
Learner tendencies	Dreamer Reader Play	Melding of subjects	Interest, difficulty prioritizing & synthesizing content, examples/applications sometimes "loveless"			Document writing too rigid	Integrate artistic side, understand other disciplines	Apply skills, deliver results; create space for interests	Need for credential, need to enjoy learning experience	Strategy, leadership, help users; tension: innovation-operations
Career context		Wanted: application to real world, breadth → industrial engineering				→ Public sector, information systems (continued part-time then hired full-time)				
	Pre-HS	**HS**	**UG Y1**	**UG Y2**	**UG Y3**	**Co-op**	**UG Y4**	**Post**		
			2011					2016		2023

Figure 2: Journey Map – Jasmyn (Industrial Engineering)

4.1.2 Lou

Lou is a man who started an undergraduate program in engineering then quickly switched majors to Physics and Philosophy. Lou went on to complete a research-based Master of Science and works in the private sector in an engineering-adjacent (design moderating) role. Lou develops financial software tools, so does not require engineering training or licensure to influence these products. Lou demonstrated a consistent perspective on problem solving as looking at a situation from multiple perspectives and oscillating between the abstract and specific. Lou expressed a bold ideal of pursuing interests over grades. He continues this as an 'outsider' in the workplace who aspires to understand systems and approaches down to first principles and uses learning strengths to authentically teach and lead others. Lou's journey map is illustrated in Figure 3.

Non-formal/ informal learning	Sciencey family	Music on the side				TAing	Expanding toolkit: programming languages, data analytics. Learning with team – input and feedback.	
Formal learning		Courses: Math, physics, philosophy, electives; same topics from different angles			Senior thesis	Lab courses	Rotational placements (4 x 6mo) Seminars, workshops Light leadership training	
Learner tendencies	Loved sciences, music	Challenging courses out of interest, transcripts don't matter			Good at learning, not always easy		Learning over time, growing, teaching, leading by example	
Career context	Wanted: understand the universe → Engineering Physics; wanted more autonomy → Physics and Philosophy		Summer jobs at financial institution		Wanted: interesting courses & research → research-based Masters		Considered PhD → Private sector, finance (individual contributor progressed to management)	
	Pre-HS/HS	**UG Y1**	**UG Y2**	**UG Y3**	**UG Y4**	**Post 1**	**Post 2**	
		2009					2016	2023

Figure 3: Journey Map - Lou (Physics)

4.1.3 Marlana

Marlana is a woman who completed an undergraduate program in Mechanical Engineering and went on to do a research-based Master of Applied Science. Marlana then did a brief internship and now works in the private sector. Her responsibilities (as reported in the survey) align with the “other engineering” category (apply engineering-related skills and knowledge) and she plans to apply for licensure as a professional engineer. Marlana expressed an overarching purpose in obtaining knowledge and skills to serve her biomedical career goals. She was self-motivated to seek extracurricular and career opportunities to fill perceived gaps in her abilities and become more well-rounded; she expressed consistent appreciation for technical, interdisciplinary, and social competencies. Marlana’s journey map is illustrated in Figure 4.

	Pre-HS	HS	UG Y1	UG Y2	UG Y3	Co-op	UG Y4	Post 1	Post 2	Post 3
Non-formal/ informal learning	Academic parent – aware of research and teaching activities	Math teacher connection to current engineering student	Campus events advertised in email newsletters (e.g. research talks), design teams, non-engineering summer jobs (e.g. call centre), research internship abroad, additional language, student governance					TA, journal articles; wanted more guidance & interaction	Learn on the job, well-prepared	
Formal learning	Knowledge and abilities in math, science		Courses: high level math, science, programming, engineering (didn’t really understand how material could be applied or connected Y1 & Y2)			Industry work environment	Limited biotech options → few courses met knowledge needs			CPD, leadership
Learner tendencies	Education serves med school goal		Interested, did the course work, explored options		More fully engaged in specialized, applied courses with clear connections			Self-directed, building broader skillset (e.g. programming, 3D modelling)		
Career context	Always aspired to be a doctor until high school hospital internship.		Try mech eng, might switch out	Seeking confirmation that mech eng. was the right choice		Biomedical with manu. process focus	Torn between research and industry	Research-based masters	Overseas, design engineer intern	“Career began”
			2015					2020		2023

Figure 4: Journey Map – Marlana (Mechanical Engineering)

4.1.4 Ty

Ty is a queer man who completed an undergraduate program in Engineering Science and went on to work in the public sector. Ty's responsibilities align with the career typology's engineering-adjacent role (design moderating) and he is licensed as a professional engineer (P.Eng). Ty highlighted the centrality of critical thinking in his day-to-day work, which was generally developed in first-year design courses and enhanced during specialisation courses. Ty was "never one to memorize" and continues to take a first principles approach to understanding and solving problems. Ty's journey map is illustrated in Figure 5.

	Pre-HS	**HS**	**UG Y1**	**UG Y2**	**UG Y3**	**Co-op**	**UG Y4**	**Post**	
Non-formal/ informal learning		Customer service part-time work → no time for extracurriculars		Applying critical thinking to life decisions, volunteer, queer community groups		Observing, shadowing		Guidance from seniors, self-directed review of papers, manuals	Mentoring others, managing large & long-term projects, picking people's brains
Formal learning			First principles. Design course: anticipate TA questions → critical thinking	First principles. Design course: real team project, failure reflection	Systems, estimation (sniff test), how things work but limited industry awareness		Capstone, thesis, grad-level courses	CPD courses & seminars (sporadic)	
Learner tendencies	Broad interest in sciences and math, high grades		There to learn, get experience; workload/difficulty shock, let go of marks as defining characteristic			Put foundation pieces together, Y3-4 = fondest years		Continuum of getting better; use critical thinking, fundamentals/ first principles, communication	
Career context		Attracted to breadth touching on everything, depth → EngSci			Energy systems, public utilities			Public sector: analyst → engineer → manager (project mgmt., planning, delegating); "been all around"	
			2010					2015	2023

Figure 5: Journey Map – Ty (Engineering Science)

4.1.5 Journey Map Discussion

The journey maps provide an overview of the recollections that participants authored in response to the narrative interview starting prompt and elaborations: “tell me about your education and career journey up to this point in time, and as you share your journey, can you highlight events and experiences that have been important for your learning along the way.” The most notable common experience across participants is that they each entered their undergraduate degree immediately after high school. They also all took on leadership or mentorship roles relatively early in their careers; this indicates that the extreme case sampling approach did select for ‘learning leaders’ [64]. Salient events and experiences as well as self-described learning orientations appear to differ. In the next section, we present the results of our values analysis to understand the similarities and differences in participants’ lifelong experiences and valuing of learning and put these in dynamic conversation with other stakeholder perspectives.

4.2 Values Analysis

As discussed in the literature review, lifelong learning orientations involve affective and social aspects of learning in addition to cognitive skills and knowledge. Practicing lifelong learning effectively in unstructured or informal environments usually requires an individual to value learning for its own sake [34]. To examine meanings of lifelong learning from this perspective, we used values analysis [48] to consider the interacting perspectives of the four interview participants as well as program planners and accreditation stakeholders with greater power. Values analysis involves 1) reading between the lines of stakeholder expressions to produce a list of principles, norms, beliefs, ideologies, and goals expressed, and 2) analysing the negotiation of values between stakeholders in terms of echoed, contested, and contradicted values [48].

Table 2 presents the stakeholders considered, the sources of their expressions on lifelong learning, and the major values we identified in our analysis. Major values “organize an entire narrative and, as such, are enacted or expressed relatively extensively” [48](p. 85). The tabulated major values are the researcher’s paraphrased interpretations of stakeholders’ and participants’ narratives. In contrast to major values, a minor value is acknowledged or implied with less frequency or intensity (for example, Jasmyn briefly expressed the value of information-seeking in the service of risk-aversion; this was not as prevalent throughout her narrative as her curiosity and creativity). Dynamic analysis of values echoed, contradicted, and omitted by different stakeholders is presented after the listing of individual major values.

<u>Table 2: Summary of Values Expressed by Stakeholders</u>

<table>
<tr><th>Stakeholder</th><th>Stakeholder expression</th><th>Major values (principles, norms, beliefs, ideologies, goals [54])</th></tr>
<tr><td rowspan="2">Engineering profession – national level: ABET</td><td>Student outcome 7 (see below)</td><td>Engineers need new knowledge.
Knowledge is acquired and applied.
Some learning strategies may not be appropriate.</td></tr>
<tr><td colspan="2">“An ability to acquire and apply new knowledge as needed, using appropriate learning strategies” [10].</td></tr>
</table>

Stakeholder	**Stakeholder expression**	**Major values (**principles, norms, beliefs, ideologies, goals [54]**)**
Engineering profession – national level: Canadian Engineering Accreditation Board	Lifelong learning graduate attribute (see below)	There are different levels of lifelong learning ability. Educational needs are first identified and then addressed. Educational needs arise due to changes in the world. Engineers need to maintain their competence. Engineers may advance knowledge.
	A graduate's "ability to identify and to address their own educational needs in a changing world in ways sufficient to maintain their competence and to allow them to contribute to the advancement of knowledge" [9].	
Institutional STEM department: Engineering Science (EngSci)	Degree Level Expectations [65]	The undergraduate program encourages global citizens and leaders who are integrative problem solvers conscious of the impacts of technology. A comprehensive, accelerated foundation emphasizing first principles followed by specialization and a research thesis develops a critical understanding of engineering, science, and engineering science. Knowledge is acquired, applied, sought, and created with awareness of uncertainties, ambiguities, limitations, boundaries, and disciplinary differences.
Institutional STEM department: Mechanical & Industrial Engineering (MIE)	Degree Level Expectations [65]	The undergraduate program inspires leading practitioners able to solve society's pressing problems. Fundamental courses including substantial design experiences followed by specialization and capstone integration ensures mastery of the appropriate body of knowledge for disciplinary practice. Knowledge is acquired and applied with awareness of uncertainties, ambiguities, and limitations.
Institutional STEM department: Physics	Degree Level Expectations [65]	The undergraduate program inspires global citizens and leaders who are connective lifelong learners. Knowledge is acquired, investigated, and extended through inquiry with an awareness of personal and disciplinary limits. Broad knowledge of arts, global cultures, the social world, etc. is needed to develop an appreciation for different ways of thinking, understanding, inquiring, and analysing.
Individuals from core group: STEM alumni	Learning journey narrative - Jasmyn	Lifelong learners are curious and make creative connections. Being a lifelong learner can result in information overload. The curriculum should be more flexible to student interests.
	Learning journey narrative - Lou	There is inherent value in understanding the world and the universe. Learning involves layering on a more accurate understanding or a new lens. Teaching and leading others through learning is important and rewarding.

Stakeholder	**Stakeholder expression**	**Major values (**principles, norms, beliefs, ideologies, goals [54]**)**
	Learning journey narrative - Marlana	It is important to build capability towards career goals by seeking varied experiences. Engineering is the duality of the "technical" and "social" outlooks. The curriculum should be more connective and multidisciplinary.
	Learning journey narrative - Ty	Critical thinking to appraise information ("sniff test") is essential. Engineering work extensively involves justifying your decisions. A first principles approach enables critical thinking, logical justification, and the development of new technical expertise.
Other relevant individuals and groups (beyond scope of paper): Current students; engineering instructors; employers, colleagues, and employees of alumni; engineering clients; licensing organizations and governments; general public; future generations.		

In Table 3, we present the negotiation of the major values expressed in accreditation definitions. To make these assessments, we reviewed our dataset of major and minor values expressed by each stakeholder and determined in which cases there was a similar value expressed or implied.

As seen in Table 3, the accreditation value most consistently echoed across all stakeholders is *Engineers need new knowledge.* The major accreditation body values echoed by alumni as minor values are *Engineers need new knowledge*, *Engineers may advance knowledge*, and *There are different levels of lifelong learning ability*. The accreditation values most consistently echoed by programs are *Knowledge is acquired and applied*, *(Engineers) need new knowledge*, and *(Engineers) may advance knowledge*. The Physics program documentation is shown as having the greatest alignment with engineering accreditation values for lifelong learning because lifelong learning itself was documented as an overarching program value in the context of undergraduate science education.

Table 3: Analysis of Accreditation Values Across Stakeholders

Value	**Jasmyn**	**Lou**	**Marlana**	**Ty**	**EngSci**	**MIE**	**Physics**	**ABET**	**CEAB**
Educational needs arise due to changes in the world.	-	Minor	-	Minor	Minor	Minor	Minor	Minor	Major
Engineers need to maintain their competence.	Minor	-	-	Minor	Minor	Minor	Major*	Minor	Major
Engineers need new knowledge.	Minor	Minor	Minor	Minor	Major	Minor	Major*	Major	Minor
Knowledge is acquired and applied.	-	-	Minor	-	Major	Major	Major	Major	-
Engineers may advance knowledge.	Minor	Minor	Minor	-	Major	Minor	Major*	-	Major
Educational needs are first identified and then addressed.	Minor	-	Minor	-	Minor	Minor	Minor	Minor	Major
There are different levels of lifelong learning ability.	Minor	Minor	-	Minor	Minor	-	Major	Minor	Major
Some learning strategies may not be appropriate.	-	Minor	-	-	Minor	-	Major	Major	Minor

*Expresses a similar value in reference to scientists/non-engineers.
Major = a predominant value for the stakeholder as sampled (i.e. accounts for much of what is expressed).
Minor = some value for the stakeholder as sampled (i.e. acknowledges the value or value is implied).
None (-) = not a value for the stakeholder as sampled (i.e. does not acknowledge the value; may be contested or may not have come up in context of authored narrative).

In Table 4, we present the negotiations of major values expressed by alumni participants and identify the life stage(s) that the value was most strongly associated with according to our analysis. The values most consistently shared are *Engineering is the duality of the "technical" and "social" outlooks*, *Lifelong learners are curious and make creative connections*, *Learning involves layering on a more accurate understanding or a new lens*, and *Engineering work extensively involves justifying your decisions*. Ty echoed other participants the least, but this is most likely due to the shorter length of Ty's interview; Ty appeared to be less expressive compared to the other three alumni.

Table 4: Analysis of Major Values Across Alumni Stakeholders

Value (by Life Stage)	**Jasmyn**	**Lou**	**Marlana**	**Ty**
Lifelong learners are curious and make creative connections.	**Maj (Pre, UG, Post)**	Min (Pre, UG, Post)	Min (Pre, UG, Post)	-
Being a lifelong learner can result in information overload.	**Maj (UG)**	-	-	-
The curriculum should be more flexible to student interests.	**Maj (UG)**	-	Min (UG)	-
There is inherent value in understanding the world and the universe.	Min (Pre, UG)	**Maj (UG)**	-	Min (Pre)
Learning involves layering on a more accurate understanding or a new lens.	Min (Post)	**Maj (UG, Post)**	Min (UG, Post)	Min (Post)
Teaching and leading others through learning is important.	Min (Post)	**Maj (Post)**	-	-
It is important to build capability towards career goals by seeking varied experiences.	Min (UG, Post)	-	**Maj (Pre, UG, Post)**	-
Engineering is the duality of the "technical" and "social" outlooks.	Min (UG, Post)	Min (Post)	**Maj (UG, Post)**	Min (Post)
The curriculum should be more connective and multidisciplinary.	Min (UG)	-	**Maj (UG)**	-
Critical thinking to appraise information ("sniff test") is essential.	-	Min (Post)	Min (UG, Post)	**Maj (UG, Post)**
Engineering work extensively involves justifying your decisions.	Min (Post)	Min (Post)	Min (Post)	**Maj (UG, Post)**
A first principles approach enables critical thinking, logical justification, and the development of new technical expertise.	*Contested*	Min (Post)	*Contested*	**Maj (UG, Post)**
Major (Maj) = a predominant value for the stakeholder as sampled (i.e. accounts for much of what is expressed). Minor (Min) = some value for the stakeholder as sampled (i.e. acknowledges the value or value is implied). None (-) = not a value for the stakeholder as sampled (i.e. does not acknowledge the value; may be contested or may not have come up in context of authored narrative). Life stage: Pre-undergraduate (Pre), undergraduate (UG), after undergraduate (Post)				

5.0 Discussion

These results provide numerous insights into perspectives on lifelong learning for STEM alumni. Differences within and between stakeholders reinforce our survey findings that lifelong learning orientations are influenced by numerous factors including variation in how individuals experience their undergraduate programs.

The accreditation body values most consistently echoed by interview participants are *Engineers need new knowledge*, *Engineers may advance knowledge*, and *There are different levels of lifelong learning ability*. These were all minor expressions by alumni which suggests that graduate attribute definitions are accurate yet limited in their conceptions of lifelong learning when compared to alumni experiences, and redefinition might be beneficial for future accreditation and continuous improvement initiatives. Further analysis could clarify the connections alumni make between their undergraduate program experiences and later lifelong learning orientations. We might expect to find that these lifelong learning-oriented alumni have different perspectives on impactful courses [29] compared to the average STEM student.

The values most consistently echoed within the four participants are *Engineering is the duality of the "technical" and "social" outlooks*, *Lifelong learners are curious and make creative connections*, *Learning involves layering on a more accurate understanding or a new lens*, and *Engineering work extensively involves justifying your decisions*. These principles or beliefs indicate the importance of lifelong learning orientations for crossing disciplinary boundaries, changing mindsets, and developing "non-technical" skillsets. These tie to existing work on development domains for workplace learning (relational development, cognitive development, practical development, and emotional development) [66], [67], de Nicolas' plurality of habits of mind [68], [69], and Engestrom's expansive learning [21], [22].

Many of the major and minor alumni values identified contradict common engineering curriculum features such as inflexible curriculum, heavy workload, grade incentives, and right-wrong answers or black-and-white thinking. The learning-oriented alumni described resisting and giving in to these demands to different extents and for different reasons. They tended to find more opportunities for self-directed interest-driven learning after graduation.

The only notable conflict in how alumni made sense of their undergraduate education in connection to lifelong learning orientations was related to the teaching of theoretical or foundational knowledge. Ty's major value *A first principles approach enables critical thinking, logical justification, and the development of new technical expertise* was echoed by Lou as a minor value but contested by Jasmyn and Marlana. This comfort with foundational theoretical knowledge aligns with program structures that start with fundamentals prior to specialization as evidenced in engineering Degree Level Expectation documentation. It is the traditional deductive approach to teaching engineering [70]. In contrast, Jasmyn and Marlana valued understanding the applications of knowledge and how the material they were learning would fit into a bigger picture and serve others; they both expressed confusing and "loveless" learning experiences in foundational courses that were decontextualized or did not provide examples of applications that resonated with them. Even in this small sample, the findings align with other research (e.g. [71],

[72]) that suggests contextualization or applying content with a meaningful sense of purpose can increase motivation and interest especially for women students.

6.0 Conclusion and Next Steps

In their learning journey narratives, alumni participants tend to highlight unique pre-university experiences and learning motivations; different responses to design, math/science, and humanities/social science categories of courses in the undergraduate program with associated periods of difficulty and demotivation; and career decisions and learning experiences that are shaped and informed by these prior experiences and dispositions to different extents. These interviews provide a rich description of STEM alumni "learning journeys" and insights for the design of undergraduate programs. These will be explored further to articulate how pre-university experiences and incoming learning orientations interact with program experiences to impact long-term motivations and strategies for lifelong learning. Approaches that could investigate and answer different research questions within the same dataset include plot analysis, character mapping, and time analysis [54].

By incorporating national accreditation definitions and program policy documents into our dynamic analysis, we found interesting differences between program and alumni perspectives on degree-level skills and knowledge for lifelong learning. The extent to which program expectations are enacted by instructors [7] or otherwise represent the norms of the programs is questionable and so alternative sources such as internal documents or accreditation reports may provide a more complete representation of program stakeholders.

Given the narrative interview approach of allowing the participant to direct the discussion, the interview did not probe into how intersectional positionalities may have mattered for lifelong learning. We will explore these relationships further as we mix the Stage 2 survey and Stage 3 interview data.

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