Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025 ASEE
Paper ID #48182

Considering Personal Mastery as a Framework for Developing Students' Affinity for Lifelong Learning [Research]

Bailey Kathryn McOwen, Virginia Polytechnic Institute and State University

Bailey McOwen is a Ph.D. student in Engineering Education at Virginia Tech with an academic foundation in physics and industrial engineering. Her research focuses on workforce development, professional training for engineering practitioners, and engineering ethics, with an emphasis on how emerging technologies can enhance continued education. Through her research, service, and academic work, she aims to bridge engineering education and industry needs to support ethical, lifelong learning across diverse engineering pathways.

Arsalan Ashraf, Virginia Polytechnic Institute and State University

Arsalan Ashraf is a Ph.D. student in the Department of Engineering Education at Virginia Tech. His research interests include AI ethics, ethics and social responsibility, and lifelong learning. He has broad experience in academia and industry, which motivates him to do research on these vibrant areas. He is a first-generation student from a small village in Punjab, Pakistan. He completed his B.S. in Aviation Management from Lahore in 2017 and then worked in the aviation industry. After gaining experience, he changed his career path and entered academia as a lecturer at The University of Faisalabad in 2022. He joined Virginia Tech in the fall of 2024.

Emad Ali, Virginia Polytechnic Institute and State University

Emad Ali is a Ph.D. student in the Department of Engineering Education at Virginia Tech. His research focuses on the integration of artificial intelligence in engineering education with particular emphasis on its ethical implications. He holds a master's degree in Electrical Engineering with specialization in Embedded Systems, from the Information Technology University (ITU Lahore), as well as a Bachelor's degree in Avionics Engineering from the National University of Sciences and Technology (NUST), Islamabad. He has worked as TA of multiple undergraduate and graduate courses during his Masters in ITU and as a Lecturer in the Superior University in Lahore. He aims to contribute to the advancement of educational practices in engineering by addressing both the opportunities and challenges presented by the emerging technologies.

Dr. Dayoung Kim, Virginia Polytechnic Institute and State University

Dr. Dayoung Kim is an Assistant Professor of the Department of Engineering Education (College of Engineering) at Virginia Tech and a Director of the LABoratory for Innovative and REsponsible ENgineering workforce (LAB-IREEN). She conducts research in engineering practice and workforce development (e.g., practices and experiences of, and competencies required for, engineers in various employment settings, such as business organizations and government agencies; workforce challenges and opportunities from emerging technologies, such as Artificial Intelligence), engineering ethics (e.g., social responsibility of engineering professionals and its education), and related policy concerns. Dr. Kim's research aims to identify effective strategies to cultivate an innovative and responsible engineering workforce through educational initiatives and science & technology policy. She received her Ph.D. in Engineering Education at Purdue University (2022) and received her B.S. and M.S. in Chemical Engineering at Yonsei University (2017) and Purdue University (2021) respectively. She was the 2022 Christine Mirzayan Science & Technology Policy Graduate Fellow of the National Academies of Sciences, Engineering, and Medicine and received the 2022 College of Engineering Outstanding Graduate Student Research Award from Purdue University. She was also a Bilsland Fellow of the College of Engineering at Purdue University when she was a Ph.D. student.

Considering Personal Mastery as a Framework for Developing Students' Affinity for Lifelong Learning

Introduction

The United States desperately needs to expand its engineering workforce to maintain momentum on innovation, competitiveness, and economic growth. Engineering is key to technological progress, infrastructure creation, and national security. However, literature suggests there is an emerging gap — demand for engineers exceeding supply. A recent government science and engineering indicator report [1] shows that although the U.S. still leads in R&D, its share of the global STEM workforce is shrinking because of growing international competition, particularly from Asia.

Within industry, there is a need to develop engineering leadership who can facilitate the innovation and competitiveness necessary to improve the United States' competitiveness abroad [2]. Concepts such as leadership in learning organizations and its role in industrial innovation and competitiveness are discussed by Peter Senge [3]. Senge claims that, when organizations are in competition with one another, a competitive advantage is necessary to set them apart. Any competitive advantage is temporary unless the organization supports its employees' lifelong learning pursuits. This is because the cumulative passion, skills, and competencies of its employees makes up the organization's capabilities. One concept Senge notes as being necessary within an organization to achieve this is employees with a personal mastery mindset; this is an individual's commitment to lifelong learning, self-awareness, and achieving personal goals by aligning their values, vision for the future, and actions.

If industry is aiming to utilize the cumulative power of the engineers working within it, first fostering engineers with an affinity for lifelong learning would be helpful as they will become the engineering leaders who support lifelong learning in industry. The ability to perpetually develop expertise as an engineer has been emphasized both by industry and engineering education research due to the increasing rate of technical development [4]. Various pathways to developing lifelong learning, as the skill is now called, have been explored with one of the most notable being the appeal to affinity. Those with an affinity for lifelong learning develop practices and engage in experiences that further expose and engage them in learning opportunities [4]. This suggests that fostering environments that can encourage the development of individual engineers' affinity for lifelong learning would be beneficial.

Despite this, to the authors' best knowledge, no frameworks of developing affinity for lifelong learning in engineering students seem to have been created; rather, the focus has been on developing frameworks to teach the various competencies encompassed in lifelong learning [5], [6]. In fact, the limited research available on engineering students' affinity for lifelong learning are limited to those that explore engineers' membership of affinity groups [4] and the diminishing interest of engineering alumni in continuing lifelong learning practices [7]. This theory paper aims to understand how Senge's [3] concept of personal mastery may be used as one such framework to develop an affinity for lifelong learning.

Using literature and causal loop diagrams to create visual representations of lifelong learning and personal mastery as dynamic systems, an exploration of how the main tenets of lifelong learning may be facilitated by personal mastery will be performed. The two causal loop diagrams aim to represent and analyze the cyclical cause-and-effect relationships within the lifelong learning and personal mastery systems. Comparing the two causal loops can reveal how they may be related through similarities in structure, behaviors, or feedback loops. Ultimately, this paper aims to understand whether these concepts are related enough to warrant further exploration into the use of personal mastery as a framework for developing lifelong learning.

Literature Review

Learning Organizations

As technology emerges and industries shift to adapt to it at an increasing pace, learning has become the "currency of survival" [8, p. 1]. Peter Senge's [3] concept of learning organizations, "where people continually expand their capacity to create the results, they truly desire […] and where people are continually learning how to learn together," [8, p. 3] is a direct response to the learning currency. The aim of Senge's learning organizations is to achieve dynamics that improve a company's competitive advantage; this looks like facilitating the advancement of employees' skills and capabilities, encouraging innovation and adaption, and generally creating a more resilient employee base.

The five disciplines, developmental paths individuals follow to acquire skills or competencies, necessary for a company to become a learning organization include personal mastery, mental models, shared vision, team learning, and systems thinking. Broadly, personal mastery is the commitment to self-improvement and personal growth encouraged by the company. Mental models are our assumptions of how the world works which limit us to "familiar ways of working and acting" [8, p.163]. As a discipline, Senge encourages a culture of managing mental models; "surfacing, testing, and improving our internal pictures of how the world works" [8, p.163]. Shared vision has been characterized as an exceedingly compelling idea that brings employees together as a collective. Team learning is the active combat of energy wasted by an unaligned team; it is the "process of aligning and developing the capacity of a team to create the results its members truly desire" [8, p. 218]. Finally, what Senge emphasizes as the most impactful discipline, systems thinking is facilitating an understanding in employees of how different parts of the system they are within are interrelated and influence one another.

The implementation of all five disciplines culminates in an organization that will excel in the future due to their ability to engage their employees' commitment and capacity to learn at all levels in an organization [3]. While there is no order in which these disciplines need to be implemented, they are interrelated. Personal mastery has been regarded as the heart of learning organizations due to its impact on an individual's ability to grow, align with shared goals, and contribute to the collective organizational culture [3], [9].

Personal Mastery

As a discipline, personal mastery is concerned with personal growth and development; it is the continuous pursuit of self-improvement and the alignment of personal values, vision, and actions, and acknowledgement of current reality [3]. Senge refers to this as *creative tension* which is the balance between maintaining one's vision and their current reality. It is an ongoing process comprised of identifying one's deepest aspirations, engaging in behaviors that align with those goals, and committing to truth and lifelong learning. The essence of personal mastery can be described through a quote attributed to Aristotle: "Excellence is an art won by training and habituation." Personal mastery is about cultivating habits and disciplines that lead to ongoing excellence.

One should desire to understand themselves and the world and promote a mindset of continuous improvement, and they should feel passionate about their growth, discovery of knowledge, and self-improvement. Pirozzi [9] expands on personal mastery and notes, while personal mastery is focused on growth in terms of both competencies/skills and spiritual growth, it is truly pushing individuals towards proficiency. This can be seen in its application of answering the questions "what is important" and "what is real" in practical situations such as communicating with one's team, managing stakeholder relationships, and navigating projects.

Senge [3] offers insight into developing one's personal mastery through committing to face one's current reality; this includes creating realistic appraisals of an individual's current situation and leaning into creative tension which is the balance between one's current reality and their vision for the future. This is achieved by reflecting on one's own goals and aspirations and regarding oneself as an active participant in creating their reality.

Personal mastery has limited representation in engineering education literature. A brief review of available literature demonstrated it has been discussed in work around students' self-efficacy [10], [11], students professional skill development and self-directed learning in problem-based learning contexts [11], attitudes, self-concept, and team dynamics of students [12], and student portfolio assessments in engineering courses [13]. While these topics are all relevant in the discussion of using personal mastery as a framework for developing students, they do not touch on the relevance of personal mastery in developing engineering leaders or students' commitment to lifelong learning.

Personal mastery has been linked to general leadership development, which lends to its capacity to do so in an engineering-specific context. Personal mastery has been explored in connection with developing authentic leadership [14] and effective leadership [9], [15]. Personal mastery frameworks have been explored and found to cultivate leadership skills and one's individual leadership character [16]. Additionally, personal mastery has been explored in the context of human resource development, specifically within higher education, which is the process of an organization or university actively enhancing its members' knowledge [17]. Here, it was noted that organizational characteristics such as professional development opportunities, training, and organizational culture contribute to one's personal mastery as significantly as their individual characteristics such as personal vision, personal values, and competence.

Regarding personal mastery's requirement for a commitment to lifelong learning, Senge makes clear that those who pursue personal mastery understand they will never *arrive*. In other words, they understand their Persuit of self-improvement and knowledge is ongoing (i.e., lifelong). Additionally, they demonstrate characteristics such as feeling a sense of purpose that guides their goals, view reality as an ally, work with (rather than resist) forces of change, are inquisitive, connect with others and life while maintaining uniqueness, and understand they can influence (but not control) the larger creative processes they are part of [3], [18].

Lifelong Learning

Dunlap and Grabinger [19] define lifelong learning as intentional learning that people engage in throughout their lives for personal and professional fulfillment. According to Srebrenkoska et al. [20], lifelong learning can also be defined as the learning that is pursued throughout life, in which availability and diversity can be acquired flexibly at different times and places. Engineering education leaders have long acknowledged the importance of lifelong learning and have aimed to incorporate it through the ABET accreditation requirements for engineering programs [21], [22]. Consequently, engineering instructors across the globe have been wrestling with ways to assist their students in growing as individuals who continue to learn throughout their lives and methods to evaluate this development [22], [23], [24].

Currently, lifelong learning is most popularly developed in students through the development of various competencies and engagement in hands-on learning activities, which encourage lifelong learning [5]. The improvement of competencies, such as self-regulatory or communication skills, serves students personally and professionally and provides an opportunity for instructors to make the connection apparent to students [5], [25]. Additionally, the importance of lifelong learning is often experienced by students in project-based or learning-by-doing environments,as it reflects more closely the work students would do in industry [26].

Discussions have taken place around the role of lifelong learning skills in industry, specifically within the Fourth Industrial Revolution [27]. The World Economic Forum estimates that by 2025, 50% of all employees will need to learn new skills because of new technologies [46]. With the emergence of innovative practices, such as artificial intelligence and machine learning, and increasingly autonomous processes, educators are aiming to develop professionals who can not only meet the current needs but be prepared to adapt to the changing pace of industry [27], [28].

While not much discussion has taken place around the use of lifelong learning to develop engineering leaders, leadership has been brought up as a skill that requires continued learning [29]. More specifically, it has been noted that early-career engineers who have been educated under ABET's lifelong learning requirements, and "despite increased efforts to incorporate effective leadership training into engineering curriculum," employers claim early career engineers are not demonstrating the necessary leadership skills [30].

Comparison of Lifelong Learning and Personal Mastery

Review of Causal Loop Diagrams

Causal loop diagrams (CLDs) are visual representations of systems; specifically, they are used to represent and analyze feedback loops within a system. A feedback loop is an instance where the output of a process or action impacts itself. This could be either reinforcing where the process or action is amplified or balancing where the process or action is counteracted. CLDs are beneficial when aiming to understand how variables of a system interact with one another and in turn influence system dynamics. This can be helpful for problem solving and decision making at a systems level as the high-level view aids in considering unintended consequences, identifying root causes of issues, and comparing potential system layouts.

CLDs were chosen to represent lifelong learning and personal mastery because they are being viewed as systems. Lifelong learning is a dynamic system because it involves continuous, interactive processes where individuals adapt to changing needs, technologies, and environments by acquiring new skills. Personal mastery is a dynamic system because it integrates ongoing self-awareness, vision-setting, and reflective learning. Comparing a CLD for lifelong learning with a CLD for personal mastery can reveal how the two systems align and interact. The aim of comparing these CLDs is to gain insight into how personal mastery supports the development of an affinity for lifelong learning.

While CLDs are largely used by engineers, the concern with systems thinking and dynamics allows for application across a variety of fields. Fields such as healthcare [31], public policy [32], [33], construction and demolition [34], and engineering management [35] have applied the tool to understand how variables of any system theoretically and practically impact one another. Despite this broad application of CLDs, limited work was identified which applies the tool in engineering education research (EER), particularly concerning discussions of lifelong learning or personal mastery.

The interdisciplinary gap between the use of CLDs in systems engineering research and in EER may be influenced by varying research interests within the EER community. For instance, studies focusing on classroom interventions and teaching strategies often prioritize immediate educational contexts rather than broader system-level considerations. This could contribute to less exposure to systems research and CLDs. CLDs may be used for decision-making, policy, and system design, and they provide insight into uncertainties and an opportunity to challenging mental models toward paradigm shifts [36], [37].

This research utilized CLDs to understand both lifelong learning and personal mastery as dynamic systems; the CLDs were created following Haraldsson's [38] instructions on systems thinking and causal loop diagrams [38, p. 40-41]. Based on Dunlap and Grabinger's [19] definition of lifelong learning as continuous personal and professional development, it can be viewed as a system that is comprised of variables which interact to promote that continuous development. These variables can include the learner themselves, the learning opportunities they have, their motivation to learn, the knowledge they have, their competencies and skills, who they can rely on to support and facilitate their learning, and the environment in which they learn [19].

Similarly, personal mastery, being the continuous pursuit of self-improvement and the alignment of personal values, vision, and actions with reality [3], can be viewed as a system of variables promoting such outcomes. These variables can include personal vision, current reality, engagement in learning, forms of motivation, resistance to learning and current reality, and the support they experience in their learning.

In creating the causal loop diagrams for lifelong learning (Figure 1) and personal mastery (Figure 2), the goal was to create a visualization of the definition offered of lifelong learning. Causal loop diagrams have no clear end point both because it is an iterative process that can always be expanded or condensed and because the act of creating a CLD often changes the initial question being asked [38]. As this paper aims to take a high-level look at the variables and fundamental interactions of each, a boundary was placed around the CLDs to prevent the representations from expanding beyond the contents of each concept's definitions and variables.

From these descriptions, some variables can be identified in both, but further comparison of CLDs for each will allow for an understanding if the variables interact with one another the same for each concept. Furthermore, the goal of this paper is to identify the most instrumental variables of each concept (meaning the variables which are used in more than one feedback loop) and determine whether either of them are suited for preparing engineers to become leaders in industry. The subsequent sections will provide CLDs for both lifelong learning and personal mastery to visually represent how each system proposes achieving their respective goals.

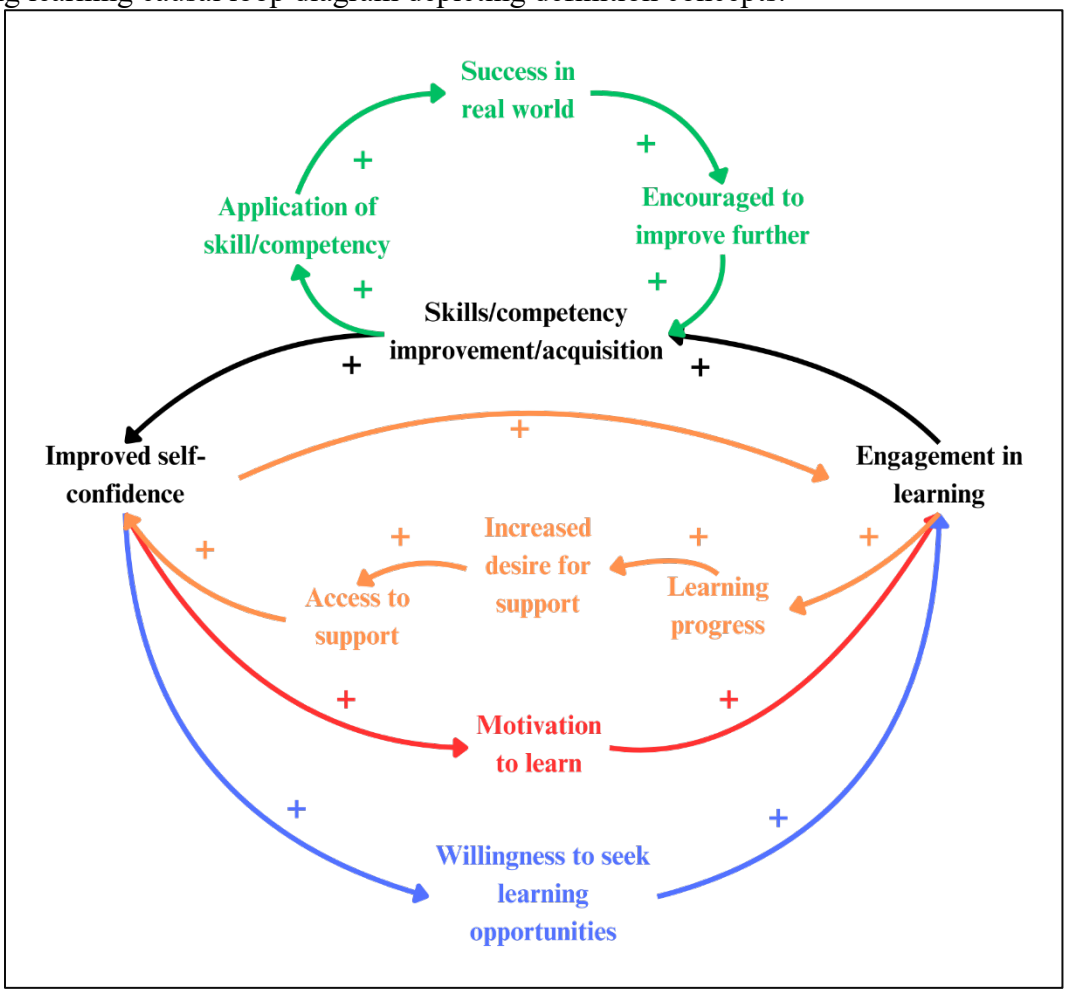
Lifelong Learning Causal Loop Diagram

The CLD for lifelong learning (Figure 1) was created around the definition of lifelong learning: continuous personal and professional development [19]. Based on Haraldsson's [38] instructions, each step for creating a causal loop diagram was addressed (Table 1). The established concepts and variables associated with this include the learner themselves, the learning opportunities they have, student motivation, the knowledge they have, their competencies and skills, who they can rely on to support and facilitate their learning, and the environment in which they learn [19]. These variables were used to assist in identifying the main actors, as seen in Table 1; for example, motivation inspired main actors such as engagement in learning and motivation to learn.

Table 1
Table summarizing Haraldsson's [38] process of creating a CLD for lifelong learning.

STEP	GUIDING PRINCIPLES [38, P. 40-41]	APPLICATION TO LIFELONG LEARNING CLD
1. DEFINE PROBLEM	What are the system boundaries?	System boundaries are around engineering students and variables defined in engineering education research.
2. ASK QUESTION	Define specifically what you want to answer in the problem.	How does learning become lifelong for students?
3.SORT MAIN ACTORS	Create a list framing established variables, so they are related to the question in order of importance; have no more than 8-10 to start.	(1) Skill/competency improvement/acquisition, (2) engagement in learning, (3) improved self-confidence, (4) motivation to learn, (5) willingness to seek learning opportunities, (6) access to support, (7) application of skill/competency, (8) learning progress, (9) success in real world, (10) encouraged to improve further, (11) increased desire for support
4. SIMPLE CLD	Draw the links between the variables you selected. Make one loop at a time and check if it is reasonable.	See Figure 1.
5. REFERENCE BEHAVIOR PATTERN	A graphical representation of the behavior of a variable over time. It is not important to draw all the variables, but the ones that explain the feedback behavior.	The variables (3) improved self-confidence, (4) motivation to learn, (5) willingness, and (8) learning progress were categorized as one that explain feedback behavior. They each increase over time.
6. TEST CLD	"Norwegian" laughing test; if you find yourself laughing, then clearly something is wrong with your assumptions.	No unreasonable assumptions were identified after 3 rounds of step 7.
7. LEARN AND REVISE	CLDs are never right the first time; it is an iterative process.	3 iterations of the CLD were created; corrections of assumptions made by justifying loops with literature.
8. CONCLUDE	When we make conclusions, we are answering our initial question. The iteration process with the CLD changed the definition of the problem and thus shifted the focus of the question.	See Figure 1. Learning becomes lifelong in students by perpetually acquiring and improving skills, engaging in learning, and building self-confidence in their competencies.

Figure 1
Lifelong learning causal loop diagram depicting definition concepts.



Four high-level feedback loops emerged from the literature on lifelong learning (Table 2). These feedback loops included professional development (green loop), motivation to learn (red loop), impact of support (orange loop), and investment in learning (blue loop). A feedback loop represents a cycle of behaviors (cause-and-effect) where the output of a system influences its own input. Each feedback loop represents a different cycle, so not every variable will be present in every loop if the variable is not relevant to the cause-and-effect relationships. Each loop identified in Figure 1 was a positive reinforcing loops, meaning the outputs amplify the action.

Table 2
Table interpreting each of the lifelong learning feedback loops.

COLOR LOOP	REINFORCING/ BALANCING	INTERPRETATION	REFERENCES
GREEN	Reinforcing	The more learners improve/acquire skills, the more they can apply them; the more they apply them, the more successful they will be in the real world; the increase in success will encourage them to continue learning to improve further.	Dunlap & Grabinger [19], Thwe & Kalman [5]
ORANGE	Reinforcing	Increased access to support improves learners' self-confidence; improved self-confidence increases their engagement in learning; the more engaged they are, the more their learning will progress; progressed learning increases their desire for support.	Thwe & Kalman [5], Chakrabarti et al. [39]; Marcynuk et al. [40]
RED	Reinforcing	The acquisition of knowledge and skills improves learners' self-confidence; this motivates students to continue learning; motivation to learn leads to engagement in learning; this leads to the acquisition of more knowledge and skills.	Dunlap & Grabinger [19], Thwe & Kalman [5]
BLUE	Reinforcing	The acquisition of knowledge and skills improves learners' self-confidence; this improves learners' interest in actively seeking out learning opportunities; the independent identification of learning opportunities leads to engagement in further learning; this leads to the acquisition of more knowledge and skills.	Dunlap & Grabinger [19], Thwe & Kalman [5], Chakrabarti et al. [39]

Some variables, causal arrows, and symbols are black; this indicates that the element is part of more than one feedback loop. This is important to highlight in the diagrams as it indicated variables and interactions that are integral to the system. Integral elements are important to know as they may require additional protection and support; if an issue were to arise in one of these areas, large portions of the system may collapse.

Additionally, if changes need to be made to the system, identifying ways to implement them in these areas would impact larger portions of the system. Finally, for the purposes of this study, identifying integral elements is important for comparison of lifelong learning to personal mastery. These integral elements allow for an essentialization of the system; this will assist in later comparisons which aim to see, at their cores, whether lifelong learning and personal mastery are compatible. If their integral elements (i.e., their essential goals) align, it suggests personal mastery may be a useful framework for developing an affinity for lifelong learning.

The lifelong learning CLD emphasizes skills/competency improvement/acquisition, engagement in learning, and improved self-confidence as the most integral elements of lifelong learning (as they are each present in three of four feedback loops). The story that emerges from this emphasis is that lifelong learning (i.e. personal and professional development) occurs when learners develop self-confidence; this is gained through engaging with learning opportunities that specifically develop skills and competencies.

Personal Mastery Causal Loop Diagram

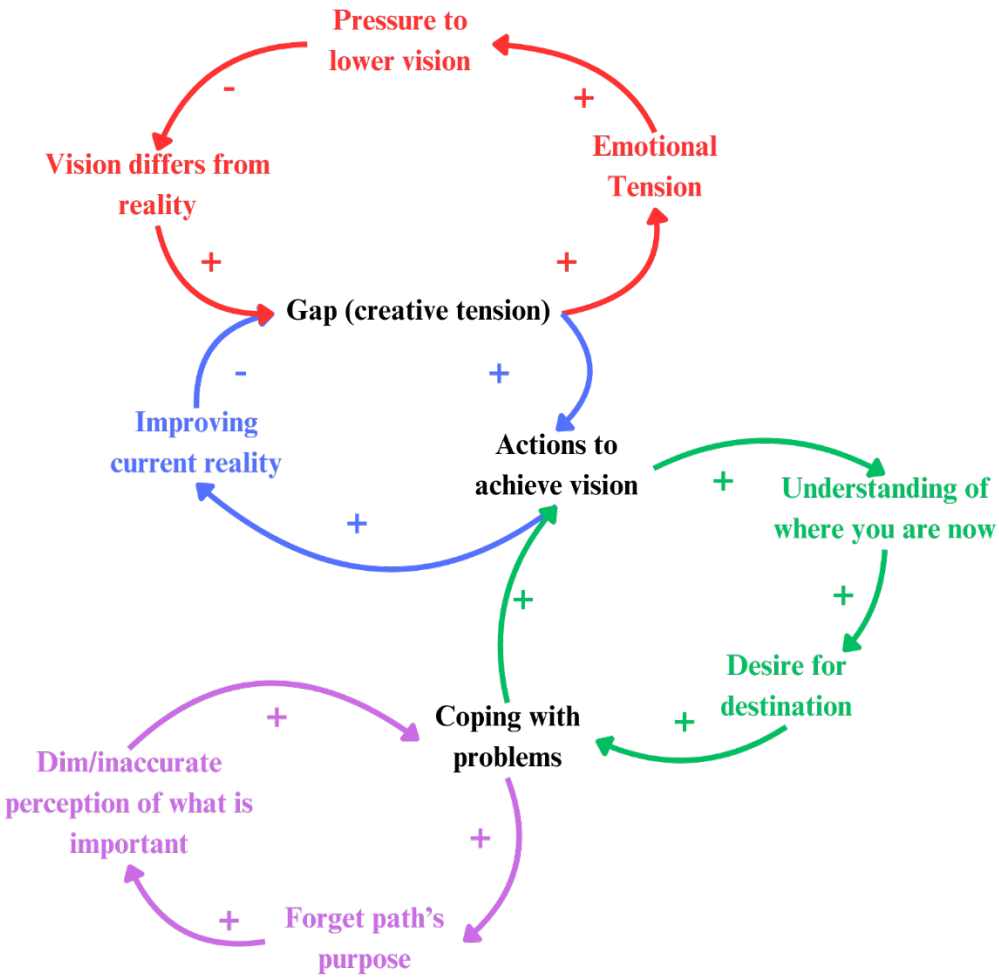
The CLD for personal mastery (Figure 2) was created around the definition of personal mastery: the continuous pursuit of self-improvement and the alignment of personal values, vision, and actions with reality [3]. Based on Haraldsson's [38] instructions, each step for creating a causal loop diagram was addressed (Table 3). The established variables associated with this include personal vision, current reality, engagement in learning, forms of motivation, resistance to learning and current reality, and the support they experience in their learning [3].

Table 3

Table summarizing Haraldsson's [38] process of creating a CLD for personal mastery.

STEP	**GUIDING PRINCIPLES [38, P. 40-41]**	**APPLICATION TO PERSONAL MASTERY CLD**
1. DEFINE PROBLEM	How does it manifest itself and what is it doing. What are the system boundaries?	System boundary is around personal mastery as presented by Senge [3].
2. ASK QUESTION	Define specifically what you want to answer in the problem.	How do the main constructs of personal mastery motivate the continuous pursuit of self-improvement and the alignment of personal values, vision, and actions with reality?
3.SORT MAIN ACTORS	Create a list of relevant variables that are related to the question and sort them in based on importance; have no more than 8-10 to start.	(1) Gap (creative tension), (2) actions to achieve vision, (3) coping with problems, (4) improving current reality, (5) understanding where you are, (6) desire for destination, (7) path's purpose, (8) perception of what is important, (9) emotional tension, (10) pressure on vision, (11) vision compared to reality.
4. SIMPLE CLD	Draw the links between the variables you selected. Make one loop at a time and check if it is reasonable.	See Figure 2.
5. REFERENCE BEHAVIOR PATTERN	A graphical representation of a variable over time. It is not important to draw all the variables, but the ones that explain the feedback behavior.	The variables (5) understanding where you are and (10) pressure on vision were categorized as one that explain feedback behavior. The former increases over time and the latter decreases over time.
6. TEST CLD	"Norwegian" laughing test; if you find yourself laughing, then clearly something is wrong with your assumptions.	No unreasonable assumptions were identified after 2 rounds of step 7.
7. LEARN AND REVISE	CLDs are never right the first time; it is an iterative process.	2 iterations of the CLD were created; corrections of assumptions made by justifying loops using Senge's [3] work.
8. CONCLUDE	When we make conclusions, we are answering our initial question. The iteration process with the CLD changed the definition of the problem and thus shifted the focus of the question.	See Figure 2. The main constructs of personal mastery motive continuous learning by encouraging continuous self-improvement by aligning personal values, goals, and actions with reality through reflection, purpose, and growth.

Figure 2
Personal mastery causal loop diagram depicting definition concepts.



The high-level CLD for personal mastery also concluded in four major feedback loops (Table 4). The four loops are personal vision (red loop), current reality (blue loop), clarity of reality (green loop), and deviation from what is important (purple loop). Two balancing loops, meaning the outputs counteract the original actions, and two positive reinforcing loops, meaning the outputs amplified the original actions, were identified.

Table 4
Table interpreting each of the personal mastery feedback loops.

COLOR LOOP	REINFORCING/ BALANCING	INTERPRETATION	REFERENCES
RED	Balancing	The disparity between one's vision for the future and their current reality can lead to frustration, unhappiness, and self-disapproval; negative emotions increase the individual's desire to lower their vision for the future to the level of their current reality; the desire leads to reestablishing more achievable goals; the vision is still different from their reality, so the gap persists.	Senge [3, p.141]
BLUE	Balancing	The disparity between one's vision for the future and their current reality leads to the individual taking steps to achieve their vision; these actions lead to raising their current reality closer to their visions for the future.	Senge [3, p.141]
GREEN	Reinforcing	One's understanding of where they currently are in the process of achieving their vision can increase their desire to reach that destination; this desire can increase their need to re-ground themselves in reality; this coping leads to actions that result in growth; growth suggests an increase in understanding current reality	Senge [3, p. 132]
PURPLE	Reinforcing	When one is stuck in a coping mentality and not taking actionable steps towards their vision, they forget the purpose of the path they are on; when they forget the purpose of action, they disfigure what they found important about their vision; when they don't have a clear vision, they need cope more to deal with the problems that occur as a result of stagnation.	Senge [3, p. 131]

Similar to the CLD for lifelong learning, the elements of this visual indicate the use of the element in more than one feedback loop. For personal mastery, three integral variables, gap (creative tension), actions to achieve vision, and coping with problems, were each used in two of the four loops. Senge [3] discusses the gap (creative tension), feedback loops, and even offers visuals which are adapted and expanded on in Figure 2 [3, p. 141]. He notes that when individuals hold a vision for the future (a goal) that differs from their current reality, this gap occurs. The two ways an individual can navigate this are the symptomatic (red loop) and the fundamental (blue loop) solutions. Often times individuals shift between these two; times when ambitious goals need to be broken down into more manageable steps are not uncommon, nor are instances where one should put their head down and power-through.

Two of the feedback loops contain two of these integral variables. Gap (creative tension) and actions to achieve vision, are within the same feedback loop (blue): the fundamental solution. The story that is suggested by this is that there may be more moments where one should be pushing through the discomfort that emerges from the disparity between one's vision and their current reality. Actions to achieve vision and coping with problems are also within the same feedback loop (green). This may suggest that, while orientation towards action is preferred, one must be sure not to fall into the trap of getting distracted by problems along the path towards their vision.

Discussion

When looking at the integral elements of both CLDs, some alignments between lifelong learning and personal mastery emerge. Whereas lifelong learning produced skills/competency acquisition/improvement, engagement in learning, and improved self-confidence, personal mastery produced gap (creative tension), actions to achieve vision, and coping with problems. Three pairs of elements align across the CLDs: (1) skills/competency acquisition/improvement and actions to achieve vision, (2) engagement in learning and gap (creative tension), and (3) improved self-confidence and coping with problems.

These alignments lend to personal mastery, serving as a framework for developing affinity for lifelong learning. Exploring the first alignment, skills/competency acquisition/improvement, and actions to achieve vision, we can see that personal mastery's promotion of taking action to achieve one's goals can take the form of lifelong learning and development of skill. To achieve a vision, you need to take action because it turns your ideas into real progress and helps you overcome challenges, grow, and stay focused on your goals. Moving on to the second alignment, engagement in learning and gap (creative tension), we can refer back to Senge's [3] understanding of creative tension as the gap between your current reality and your desired vision; this is the motivating force that drives growth and learning. Understanding that engagement in learning is an integral element of lifelong learning, personal mastery's emphasis on creative tension may be beneficial in encouraging engagement in learning. Finally, the third alignment, improved self-confidence and coping with problems, demonstrates how personal mastery encourages viewing problems not just as obstacles to be fixed but as opportunities for growth and deeper understanding. Coping with problems in personal mastery builds self-confidence, an integral element of lifelong learning, by shifting the focus from merely reacting to challenges to actively learning and growing from them. Ultimately, this approach shifts the mindset from reactive problem-solving to personal development and continuous learning.

Beyond these alignments, in terms of connection to industry and leadership, personal mastery does have a presence in industry. Literature noting that current engineering education is not producing leadership qualities in engineers [30] suggests that something must be done to meet the U.S.'s leadership needs. With many of the traditional organizations within industry transitioning to learning organizations, likely to meet the demands of the Fourth Industrial Revolution as learning is the "currency of survival" [8, p.1], lifelong learning remains the main means for continued professional development [41]. Perhaps the missing element is the use of a framework that develops an affinity for lifelong learning. From the analysis of the CLDs, personal mastery demonstrates several elements which directly align with lifelong learning. While the CLD for lifelong learning makes clear the importance of elements like skills/competency development, motivation, and support, personal mastery's CLD emphasizes the mentality that is needed for continuous development. Personal mastery may be the framework needed to develop students' affinity for lifelong learning.

In EER research, this may be beneficial for research on developing lifelong learning skills in students. Areas of lifelong learning research exploring characteristics and traits that may indicate a tendency for lifelong learning [42], the role of personality traits in acquiring lifelong learning skills [43], and assessment processes that foster the improvement of metacognition

abilities and encourage lifelong learning [44] may benefit from the knowledge of a philosophy such as personal mastery. Personal mastery is a framework that emphasizes self-awareness, intrinsic motivation, and a commitment to continuous growth. It can provide a lens for understanding how self-directed growth can shape a lifelong learning mindset and encourage learners to be active participants in their own development.

Conclusion

The CLDs for lifelong learning and personal mastery represented two systems with a similar goal: individuals should aim to continuously develop themselves and grow. Lifelong learning proposed this through variables which easily connect to interventions which literature has demonstrated as positively impacting students personal and professional development. Despite this, engineers emerge in industry lacking the passion and energy for lifelong learning and leadership skills and mentality needed to navigate the U.S. industry in an internationally competitive direction. Personal mastery, on the other hand, focuses on more abstract concepts that lend themselves towards developing a personalized positive mentality towards continuous development, but neglects to provide actionable items that can be used to develop necessary skills and competencies. It is the spirit of personal mastery and learning organizations that develop engineering leaders who encourage the collaboration and innovation needed to sharpen the U.S.'s competitive edge.

Analysis of the CLDs and the integral elements of each demonstrate alignment. The alignment across these CLDs suggest that the self-development framework of personal mastery may be helpful in encouraging an affinity for lifelong learning practices. Personal mastery fosters a mindset of curiosity, growth, and intrinsic motivation which creates an affinity for learning. This is achieved by providing an opportunity for students to find a purpose to guide and encourage their learning and allowing students to take ownership of their education. By developing students who have an affinity for lifelong learning, engineering leaders who foster innovation and adaptability within their teams are being created.

Limitations

The main limitation of this theoretical research is in the high-level nature of the CLDs. While the choice to keep them high-level was purposeful, expanding the CLDs to include the implications of a variety of actions would provide insight into other commonalities and differences between lifelong learning and personal mastery. This would be beneficial if more work was done to integrate the two and develop a framework that captures both the practicality of lifelong learning with the passion of personal mastery.

Another consideration is the developmental appropriateness of these frameworks. The motivations, challenges, and perceptions of lifelong learning differ significantly between early-career engineers and seasoned professionals. Exploring how personal mastery and lifelong learning dynamics evolve across career stages could provide tailored strategies for fostering an affinity for learning, particularly in undergraduate engineering students poised at the start of their professional journey.

Future Work

From the work presented in this paper, it seems that personal mastery is the missing spirit behind the practice of lifelong learning. Assuming that higher education and industry alike are aiming to be learning organizations, personal mastery should be used as a framework for developing an affinity for lifelong learning in students. For this reason, one area of future work would be an analysis of various institutions' statuses as learning organizations. Because of the interconnectedness of Senge's [3] learning organization disciplines, personal mastery is developed within a particular environment; one that also challenges mental models, upholds a shared vision, is committed to team learning, and that understands and discusses systems thinking. Subsequently, research pertaining to creating a framework that combines lifelong learning and personal mastery can be developed and implementing it in practice can be done.

Additionally, while this study integrates systems thinking and personal mastery to explore lifelong learning, future research could benefit from grounding these relationships within a more comprehensive theory of human development, such as Bandura's Social Cognitive Theory [45]. This framework emphasizes self-efficacy, observational learning, and reciprocal determinism, which could provide deeper insights into the cognitive and emotional factors influencing lifelong learning behaviors. Incorporating such a perspective may enhance understanding of how personal mastery interacts with both intrinsic motivations and external social influences, particularly regarding emotional drivers of behavior. This would also benefit analysis of the presented CLDs; these CLDs highlight key reinforcing and balancing dynamics, but further exploration of limiting factors related to self-efficacy and emotional resilience as outlined in Social Cognitive Theory would provide a more holistic view. Understanding barriers such as fear of failure, lack of confidence, or environmental constraints is critical to fully mapping the dynamics of personal mastery and lifelong learning systems.

References

[1] National Science Board, *The state of U.S. science and engineering 2022: Executive summary*. National Science Foundation, 2022. [Online]. Available: https://ncses.nsf.gov/pubs/nsb20221/executive-summary

[2] M. M. Bühler, T. Jelinek, and K. Nübel, "Training and preparing tomorrow's workforce for the fourth industrial revolution," *Education Sciences*, vol. 12, no. 11, p. 782, 2022.

[3] P. M. Senge, *The fifth discipline: The art and practice of the learning organization*. Broadway Business, 2006.

[4] A. Johri, "Lifelong and lifewide learning for the perpetual development of expertise in engineering," *European Journal of Engineering Education*, vol. 47, no. 1, pp. 70–84, 2022. [Online]. Available: https://doi.org/10.1080/03043797.2021.1944064

[5] W. P. Thwe and A. Kalman, "Lifelong learning in the educational setting: A systematic literature review," *The Asia-Pacific Education Researcher*, vol. 33, no. 2, pp. 407–417, 2024.

[6] L. Van den Broeck, U. Beagon, S. Craps, K. Coppens, J. Hanssens, and G. Langie, "Learn to learn for life–how can faculty staff support the development of students' lifelong learning competencies? A systematic literature review," *European Journal of Engineering Education*, vol. 49, no. 6, pp. 1488–1508, 2024.

[7] N. Dawe, *Student Development of Lifelong Learning Orientations Within and Beyond Undergraduate Engineering Programs* (Doctoral dissertation, University of Toronto (Canada)), 2024.

[8] P. M. Senge, "The Fifth Discipline," *Measuring Business Excellence*, vol. 1, no. 3, pp. 46–51, 1997. [Online]. Available: https://doi.org/10.1108/eb025496

[9] M. Pirozzi, "Basic skills and behaviors: Personal mastery, leadership, teaming, and ethics," *PM World Journal*, vol. IX, pp. 1–9, 2020.

[10] X. Y. Chen, E. L. Usher, M. Roeder, A. R. Johnson, M. S. Kennedy, and N. A. Mamaril, "Mastery, models, messengers, and mixed emotions: Examining the development of engineering self-efficacy by gender," *Journal of Engineering Education*, vol. 112, no. 1, pp. 64–89, 2023.

[11] B. Johnson, R. Ulseth, C. Smith, and D. Fox, "The impacts of project-based learning on self-directed learning and professional skill attainment: A comparison of project-based learning to traditional engineering education," in *2015 IEEE Frontiers in Education Conference (FIE)*, pp. 1–5, 2015.

[12] D. Ifenthaler, Z. Siddique, and F. Mistree, "Designing for open innovation: Change of attitudes, self-concept, and team dynamics in engineering education," in *Emerging Technologies for STEAM Education: Full STEAM Ahead*, pp. 201–215, 2015.

[13] D. Cress and B. J. McCullough-Cress, "Reflective assessment: Portfolios in engineering courses," in *Proceedings Frontiers in Education 1995 25th Annual Conference. Engineering Education for the 21st Century*, vol. 2, pp. 4c1–7, 1995.

[14] S. Dhiman, "Personal mastery and authentic leadership," *Organization Development Journal*, vol. 29, no. 2, p. 69, 2011.

[15] S. Dhiman, "Personal mastery: Our quest for self-actualization, meaning, and highest purpose," *Interbeing*, vol. 1, no. 1, 2007.

[16] L. Arsy *et al.*, "Personal mastery: Build your leadership character to be a great leader," *Inovasi Lokal*, vol. 2, no. 1, pp. 15–20, 2024.

[17] H. T. Bui, A. Ituma, and E. Antonacopoulou, "Antecedents and outcomes of personal mastery: Cross-country evidence in higher education," *The International Journal of Human Resource Management*, vol. 24, no. 1, pp. 167–194, 2013.
[18] P. Kang, "Personal mastery from The Fifth Discipline," 2018. [Online]. Available: https://www.peterkang.com/personal-mastery-from-the-fifth-discipline/. [Accessed: Nov. 20, 2024].
[19] J. C. Dunlap and S. Grabinger, "Preparing students for lifelong learning: A review of instructional features and teaching methodologies," *Performance Improvement Quarterly*, vol. 16, no. 2, pp. 6–25, 2003.
[20] V. Srebrenkoska, S. Mitrev, T. Atanasova-Pacemska, and I. Karov, "Lifelong learning for creativity and innovation," 2014.
[21] D. Briedis, "Developing effective assessment of student professional outcomes," *International Journal of Engineering Education*, vol. 18, no. 2, pp. 208–216, 2002.
[22] N. J. Mouros, "Defining, teaching and assessing lifelong learning skills," in *33rd Annual Frontiers in Education, 2003. FIE 2003.*, vol. 1, pp. T3B–14, 2003.
[23] L. J. Shuman, M. Besterfield-Sacre, and J. McGourty, "The ABET 'professional skills'—Can they be taught? Can they be assessed?," *Journal of Engineering Education*, vol. 94, no. 1, pp. 41–55, 2005.
[24] D. Riley and L. Claris, "Developing and assessing students' capacity for lifelong learning," *Pedagogies*, vol. 3, pp. 1–11, 2008.
[25] C. Martínez-Mediano and S. M. Lord, "Lifelong learning program for engineering students," in *Proceedings of the 2012 IEEE Global Engineering Education Conference (EDUCON)*, pp. 1–6, 2012.
[26] K. Y. Kapusuz and S. Can, "A survey on lifelong learning and project-based learning among engineering students," *Procedia - Social and Behavioral Sciences*, vol. 116, pp. 4187–4192, 2014.
[27] C. Yean, "Leadership and lifelong learning in higher education: Leading for learning in the industrial revolution 4.0 era," *International Journal of Academic Research in Progressive Education and Development*, vol. 13, no. 1, 2024.
[28] L. I. González-Pérez and M. S. Ramírez-Montoya, "Components of Education 4.0 in 21st century skills frameworks: Systematic review," *Sustainability*, vol. 14, no. 3, p. 1493, 2022.
[29] K. Froehle, L. Dickman, A. R. Phillips, H. Murzi, and M. Paretti, "Understanding lifelong learning and skills development: Lessons learned from practicing civil engineers," *Journal of Civil Engineering Education*, vol. 148, no. 4, p. 04022007, 2022.
[30] T. A. Carbonetto, *Early career engineers' perspective on leadership competency development in undergraduate education*, 2024.
[31] J. F. Uleman, K. Stronks, H. Rutter, O. A. Arah, and N. H. Rod, "Mapping complex public health problems with causal loop diagrams," *International Journal of Epidemiology*, vol. 53, no. 4, p. dyae091, 2024.
[32] A. Hudani, J. Long, R. Labonté, and S. Yaya, "Where are the links? Using a causal loop diagram to assess interactions in healthcare coordination for youth experiencing homelessness in Toronto, Canada," *Health Research Policy and Systems*, vol. 22, no. 1, p. 19, 2024.
[33] S. Han, R. Yao, and E. Essah, "Developing a theoretical framework to assist policymaking for retrofitting residential buildings using system player analysis and causal loop diagrams," *Journal of Cleaner Production*, vol. 411, p. 137211, 2023.

[34] W. Ma, J. L. Hao, C. Zhang, F. Guo, and L. Di Sarno, "System dynamics-life cycle assessment causal loop model for evaluating the carbon emissions of building refurbishment construction and demolition waste," *Waste and Biomass Valorization*, vol. 13, no. 9, pp. 4099–4113, 2022.
[35] G. Haghighat and N. Hosseinichimeh, "Why organizations fail to reflect on experiences: Insights from a causal loop diagram of reflection on experience," *IEEE Engineering Management Review*, vol. 49, no. 1, pp. 81–96, 2020.
[36] A. Acero and M. C. Ramírez Cajiao, "Analyzing sustainable practices in engineering projects: A systemic approach," *Sustainability*, vol. 15, no. 7, p. 6022, 2023.
[37] C. Olaya, "System dynamics: Engineering roots of model validation," *System Dynamics: Theory and Applications*, pp. 109–117, 2020.
[38] H. V. Haraldsson, *Introduction to system thinking and causal loop diagrams*, pp. 3–4, Lund, Sweden: Department of Chemical Engineering, Lund University, 2004.
[39] S. Chakrabarti, P. Caratozzolo, B. Norgaard, and E. Sjoer, "Preparing engineers for lifelong learning in the era of industry 4.0," in *2021 World Engineering Education Forum/Global Engineering Deans Council (WEEF/GEDC)*, pp. 518–523, 2021.
[40] K. Marcynuk, A. Parker, and N. Godavari, "Engineering undergraduates and their self-reported confidence and proficiency levels in lifelong learning (A12)," in *Proceedings of the Canadian Engineering Education Association (CEEA)*, 2020.
[41] G. Guest, "Lifelong learning for engineers: A global perspective," *European Journal of Engineering Education*, vol. 31, no. 3, pp. 273–281, 2006.
[42] D. M. Bath and C. D. Smith, "The relationship between epistemological beliefs and the propensity for lifelong learning," *Studies in Continuing Education*, vol. 31, no. 2, pp. 173–189, 2009.
[43] L. Grokholskyi, V. Ia. Kaida, N. V. Albul, S. V. Ryzhkov, E., and S. Ye. Trehub, "Cognitive and metacognitive aspects of the development of lifelong learning competencies in law students," *International Journal of Cognitive Research in Science, Engineering and Education*, vol. 8, no. 2, pp. 1–14, 2020. [Online]. Available: https://doi.org/10.5937/IJCRSEE2002001G
[44] K. Matsumoto-Royo, M. S. Ramírez-Montoya, and L. D. Glasserman-Morales, "Lifelong learning and metacognition in the assessment of pre-service teachers in practice-based teacher education," in *Frontiers in Education*, vol. 7, p. 879238, 2022, Frontiers Media SA.
[45] A. Bandura, "Social cognitive theory: An agentic perspective," *Annu. Rev. Psychol.*, vol. 52, no. 1, pp. 1–26, 2001.
[46] L. Li, “Reskilling and upskilling the future-ready workforce for Industry 4.0 and beyond,” *Inf. Syst. Front.*, vol. 26, no. 5, pp. 1697–1712, 2024.