Learning Engineering- A System Design Approach for Engineering Education

Prof. Abul K. M. Azad, Northern Illinois University

Abul K. M. Azad is a Professor in the College of Engineering and Engineering Technology at Northern Illinois University in the US. With over 40 years in academia, his research focuses on the Internet of Things, remote laboratories, mechatronic systems, mobile robotics, and educational research. Dr. Azad has published more than 140 refereed journal and conference papers and has edited five books. Dr. Azad is a member of the editorial boards for multiple professional journals and actively participates in various professional organizations, including IEEE, IET, ASEE, ISA, IAOE, and the CLAWAR Association. He has chaired numerous conferences and workshops in these fields. Additionally, he has served as a program evaluator for ABET and is involved in assessing research and development projects for funding agencies across the U.S., Europe, and Australia.

Jim Goodell, INFERable and IEEE Learning Technology Standards Committee

Jim Goodell is editor and co-author of Learning Engineering Toolkit and Chair of the IEEE Learning Technology Standards Committee. He is founder of INFERable, a Public Benefit Corporation. He was Director of Innovation at Quality Information Partners where he helps lead development of the US Department of Education sponsored Common Education Data Standards and co-facilitates the US Chamber of Commerce Foundation's T3 Innovation Network and leads Architecture and Development for the Jobs and Employment Data Exchange (JEDx). He co-led development of the Learning and Employment Record (LER) Wrapper Specification. He served as a judge for the XPRIZE Digital Learning Challenge.

Aaron Kessler Ph.D., Massachusetts Institute of Technology

Dr. Aaron Kessler is Associate Director of Learning Sciences and Teaching at MIT Open Learning. In his role within the residential education group, he is responsible for working with faculty and course teams on the development and iterative improvement of courses that use educational technologies. As part of that process, he utilizes research from the learning sciences, educational psychology, and discipline-based educational research combined with data to help inform design decisions that are situated within complex learning settings. He currently serves on the IEEE International Consortium for Innovation and Collaboration in Learning Engineering (ICICLE) Steering Committee, and co-chairs the ICICLE Design for Learning SIG.

Scotty D. Craig

Scotty D. Craig is an Assistant Professor in the Human Systems Engineering Program within the Fulton Schools of Engineering at Arizona State University. Dr. Craig received his Ph.D. in Experimental Psychology with a focus in Cognitive Psychology from the

Prof. Hamadou Saliah-Hassane ing., TELUQ University

Professor Saliah-Hassane holds a Ph.D. in Electrical and Computer Engineering from McGill University in Montreal, a Bachelor's degree and a Master of Applied Science degree from École Polytechnique de Montréal, Canada. He has retired as a full professor from TELUQ University in Montreal where he taught Computer Science and Computer Networks and Security. . His research interests include intelligent distributed systems and mobile robotics. Professor Saliah-Hassane was the Vice-President of Educational Activities and awards of IEEE Education Society (2022-2024), has chaired the Montreal IEEE Education Society Chapter (2005- 2022). He was the Past Chair of the IEEE Education Society Standards Committee (2010 - 2021) and the Past Chair of the Working Group of the joint standardization activity on "Secure and Trusted Learning Systems" (2019 -2021) sponsored by the IEEE Education Society, the IEEE Industrial Electronics Society (IES), and the IEEE Computer Society Learning Technology Standards Committee (CS/LTSC). Professor Saliah-Hassane has received many awards in recognition of his achievements, including the Latin American and Caribbean Consortium of Engineering Institutions (LACCEI) 2024

Medal of Academic Merit and the IEEE Education Society EdWin C. Jones, Jr. Meritorious Service Award (2019). And, consistent with his work in distributed embedded systems, the IEEE Standards Association's award with recognition for chairing and contributing to the development of IEEE Standard 1876™ - 2019 on "Networked Smart Learning Objects for Online Laboratories" (2019), the IEEE SA 2019 Emerging Technology Award to the IEEE SA 1876™ - 2019 Working Group.

Learning Engineering- A System Design Approach for Engineering Education

Abstract

Learning Engineering (LE) is a process that applies learning sciences, human-centered design, and data-driven decision-making to address challenges of learners and learning, including those faced by engineering education. It uses a systems engineering approach to iteratively refine learning conditions. In 2018, the Learning Technology Standards Committee (LTSC) of the IEEE Computer Society established the International Consortium for Innovation and Collaboration in Learning Engineering (ICICLE). The work of IEEE ICICLE resulted in a foundational definition of LE as a multidisciplinary practice.

This paper aims to engage engineering educators by showcasing how engineering principles can be applied to improve education through LE. It integrates a systems design approach with learning sciences, modern instrumentation, and data analytics to address key challenges in teamwork, process design, data analysis, and ethical considerations. Concluding with an initiative that develops a tool for tracking LE evidence and decisions, capturing actionable design choices in relation to channels of influence. This tool can be used to design effective, sustainable learning experiences, highlighting the potential of LE to transform practices in support of engineering education outcomes.

1. Introduction

The concept of "Education as Engineering" was first introduced by John Dewey in 1922 [1]. He argued that an established art of educational engineering does not yet exist. Dewey believed that progress in education would arise through experimentation, imagination, and courage. The true art of education will develop through reflective experimentation, rather than merely deducing from established sciences. As Dewey stated in his article:

> *"There is no question that would-be pioneers in the educational field need an extensive and severe intellectual equipment. Experimentation is something other than blindly trying one's luck or messing around in the hope that something nice will be the result."*

Given the advancements in technology and the knowledge we have accumulated, now is the ideal time to consider "engineering education" to unlock its full potential for facilitating learning.

Herbert A. Simon, Nobel Laureate, wrote an article within the Winter 1967 issue of *The Educational Record*, highlighting the responsibilities of a college president. While the article was mainly directing advice to college presidents [2], discussing the difference between the 'Teaching' and 'Learning' held an important part of the work, including the introduction of 'Learning Engineering' to create a broader learning environment. In his own words this is what he envisioned about *learning engineers*:

> *"The learning engineers would have several responsibilities. The most important is that, working in collaboration with members of the faculty whose interest they can*

> *excite,* ***they design and redesign learning experiences in particular disciplines****. Like all staff experts- operations analysis in business, for example- their long-run effectiveness to the line organization, in this instance teaching faculty.* ***Because they are experts in designing learning experiences, an important part of their skill will be directed towards devising learning experiences for the faculty****. In particular,* ***concrete demonstrations of increased learning effectiveness****, on however small a scale initially, will be the most powerful means of persuading a faculty that a professional approach to their students' learning can be an exciting and challenging part of their lives."*

He also wrote

> *"If we visited an organization responsible for designing, building, and maintaining large bridges, we would expect to find employed there a number of trained and experienced professional engineers, thoroughly educated in mechanics and the other laws of nature and that determine whether a bridge will stand or fall."*
>
> But at university *"We find no one with a professional knowledge of the laws of learning."*

While Carnegie Mellon University, where Simon worked, has advanced part of this vision, other institutions have begun taking up this call. Additions to the conversation around LE, before the creation of IEEE ICICLE community, have come in two notable forms. First, in 2016 the Online Education Policy Report at MIT where the argument is made for "expanded use of learning engineers and greater support for this emerging profession" as one potential catalyst for transforming teaching and learning in higher education [3]. Second, was the 2019 book "Learning Engineering for Online Education: Theoretical Context and Design-Based Examples" that captures the earliest state of the filed at the time [4].

As noted in that 2019 book, primary interest for LE initially came from industry professionals and defense organizations, while only a few individuals in higher education engaged with LE, despite Simon's original focus on college education. Despite the exponential advancements in computer technology, especially those technologies associated with supporting teaching and learning, the delivery of higher education programs has seen little change over the years. In most cases, except for a few initiatives by leading institutions, technology has primarily been used to support traditional teaching methods. There has been limited focus on creating a learning environment that integrates technology to enhance learning while maximizing the use of dwindling educational resources. This is especially true in engineering education, where the investment per student is much higher due to the need for specialized laboratory facilities.

This paper aims to spark an engaging discussion among engineering educators on how LE, within a systems engineering framework, has the potential to center and address many of the core challenges currently facing engineering education. It is intended for those who are already working toward a learning engineering vision and those that are new to the ideas presented. It introduces LE, a field that integrates general engineering principles with discipline-specific practices rooted in the learning sciences and utilizes human-centered design and data-driven decision-making to support learner development. The authors recognize that, for some, this approach calls for new areas of learning and significant shifts in practice that might be pursued as a series of incremental changes over the years rather than a one-time wholesale adoption. The adoption of LE must be done in a way that recognizes the learners and the learning context, including changes in organizational culture and mindsets that might be needed when leveraging learning sciences discoveries and the learning engineering process to optimize learning.

2. Current State of Knowledge and Professional Activities

In 2022, Routledge published a book, *Learning Engineering Toolkit*, edited by Goodell and Kolodner [5]. This book offers a hands-on introduction to the emerging field, blending learning sciences, instructional design, engineering design, and more to support learners. As the discipline formalizes, the book emphasizes the need for new tools to help professionals develop and refine complex, engaging learning systems. Written in an accessible style, it explores essential foundations, strategies, and challenges in creating data-driven, participatory learning experiences across various contexts and worked to address previous questions and critiques of the field.

Notable work prior to the publication of the toolkit included, Zhang and Zhu who reviewed existing knowledge on LE and tried to come up with a notion that LE is an emerging interdisciplinary field, which is timely needed and is yet to be defined at the time [6]. The authors explored various resources, including academic publications, professional organization initiatives, U.S. government materials, job postings, and LE programs, to gather relevant information. They also proposed a framework to define LE through four perspectives: Theoretical foundations, Research impacts, Analytical methods, and Practical applications. This paper can be considered as an initial step toward a comprehensive understanding of LE, guiding the development of core competencies and research on assessing student learning and program success.

Additionally, Baker and co-authors explored the potential of LE to advance both theory and practice of learning [7]. This work, the product of a virtual meeting of experts from across fields, highlighted key areas where LE could offer significant benefits and outlined steps to make these benefits a reality. Additionally, it addressed challenges hindering the adoption of LE and suggested ways to overcome them, while emphasizing the ongoing research needed for the field to reach its full potential. The article emphasized the need for better implementation engineering and broader dissemination to bridge the gap between research and practice, involving teachers, policymakers, and learning system developers. The findings suggested that LE holds great promise for improving learning experiences and outcomes, but further efforts are needed to expand its impact and connect research with real-world applications.

Finally, Cagiltay and co-authors explored the history of LE, aligning with the outlined objectives and highlights. After discussing both past and present perspectives, the authors examined key components of LE, emphasizing its challenges and potential and proposing a ten-step roadmap for advancing LE and highlighting various initiatives undertaken by universities and institutions [8]. The authors mentioned that John Dewey (in 1922) first introduced the connection between education and engineering [1]. Dewey argued that education, rooted in habits formed before the advent of the scientific method, is shaped more by the inertia of ancient traditions than by critical thinking. He believed that without innovative developments, the current state of educational science cannot advance schooling effectively.

Grounded in this history, and with extensive development done during the writing to the LE toolkit, Goodell and co-authors presented the LE as a solution to transform military learning at the pace and scale required to meet the increasing complexity of the global security landscape. The article built upon the award-winning "Learning Engineering at a Glance" poster presented at the Innovation, Instruction, and Implementation in Federal E-Learning Science & Technology Conference, a leading event in distributed learning [9]. The authors illustrated LE as a reassembling of an engineering process that is data driven and human centered and based on sciences of learning. At the end it mentioned that the LE is being applied in limited contexts within the U.S. military, such as the Army's Synthetic Training Environment (STE), which integrates live and virtual training. STE uses a multidisciplinary, iterative LE process, leveraging learning sciences, human-centered design, and data-driven decision-making to track and adaptively improve performance.

In addition to journal articles, several magazine articles have made significant contributions to promoting LE. These articles explored the background of LE, attempted to define the field, outlined the skill sets and characteristics of a learning engineer, and highlighted initiatives by various organizations collaborating to advance the development of LE [10 - 15].

Learning Engineering is growing as a field among professional societies. The International Consortium for Innovation and Collaboration in Learning Engineering (ICICLE) is the major professional organization primarily dedicated to advancing LE. In December 2017, the IEEE-SA Standards Board ICCom recommended a 24-month Industry Connections activity to define and support Learning Engineering. Sponsored by the IEEE Learning Technology Standards Committee, the initiative led to the creation of ICICLE. Less than six weeks after its formation, ICICLE already had fifty participating organizations including Boeing, Houghton Mifflin Harcourt, UL, and Allegiant; academic institutions including the Simon Initiative at Carnegie Mellon University and the Lynch School of Education at Boston College; government organizations including the Advanced Distributed Learning Initiative at the U.S. Department of Defense, and a whole host of learning ecosystem participants including ACT, EDUCAUSE, and the IEEE Education Society [16]. ICICLE currently supports a range of Special Interest Groups (SIGs) and Market Interest Groups (MIGs), which are crucial to advancing and supporting the field of LE. All SIG and MIG activities are open to the public, and we encourage broad participation from the community. However, LE has routinely been present at The Association for Educational communications and Technology (AECT) [17] and as part of the Educational Technical Group of the Human Factors and Ergonomics Society [18, 19]. Additionally, the Learning Engineering Research Network (LERN) Convening, supported by the Learning Engineering Institute at Arizona State University, is dedicated to facilitating research and data centered understanding within the LE process. These examples show the momentum of the rapidly growing field.

3. Learning Engineering as an Engineering System Design

Engineering education focuses on teaching both foundational engineering concepts, mindsets, and practices, as well as discipline-specific knowledge and skills. Some engineering principles, such as system thinking of a given problem, are applicable across various engineering fields. Many of these principles can also be adapted to enhance the learning process, including the learning of engineering itself. The work of IEEE ICICLE led to the foundational definition of LE as a multidisciplinary process and practice, which states that "*Learning Engineering is a process and practice that applies the learning sciences using human-centered design and engineering methodologies and data-informed decision making to support learners and their development.*" officially adopted in 2019 [20]. The process and practice involve general engineering principles, such as closed-loop control systems, as well as specialized concepts, including the application of learning sciences. Figure 1 represents learning as a closed loop control system.

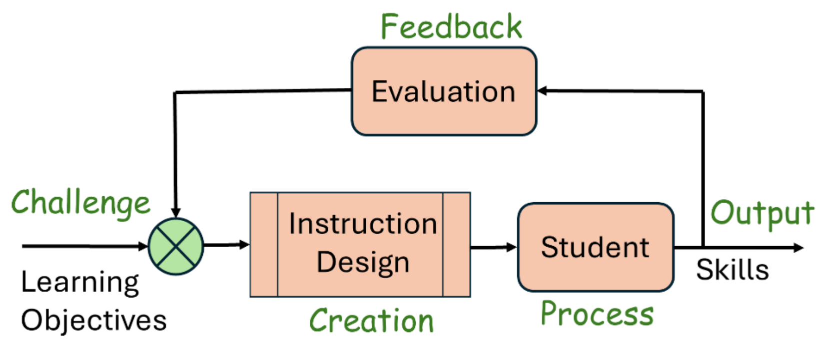

Figure 1: Learning engineering as a closed loop system.

In another definition, Bill Jerome described LE as the development, evaluation and improvement of the processes, methodologies, and educational technologies that lead to predictable, repeatable development and improvement of learning environments which leverage learning science and the affordances of technology to address instructional challenges and create conditions that enable robust learning and effective instruction. [21]

3.1 Team Formation:

Learning engineering, like other engineering disciplines, requires a combination of precision, an analytical mindset, and a deep understanding of specific knowledge frameworks. However, it is a practice that can be carried out by teams from various fields. This collaborative approach is essential because the field spans a broad range of areas, including cognitive science, technology, design, and educational theory. For the team to address challenges effectively, it is critical that they bring a diverse skill set, including expertise in data analytics, systems design, instructional strategies, and learner experience. Human learning is inherently complex, and crafting effective learning environments often requires the integration of these diverse perspectives. Moving forward, artificial intelligence agents are expected to play an increasingly important role in the LE process, supporting teams with data analysis, adaptive learning technologies, and personalized learning pathways, helping to optimize learning experiences for a wide range of learners.

In engineering education programs, it is not necessary for every instructor to be an expert in all aspects of LE, which covers a broad spectrum of domains related to how the human brain functions and processes information. While subject matter experts in the engineering field are crucial, successful LE teams require a multidisciplinary approach. This may include experts in data science, learning experience design, ergonomics, instructional design, human-centered design, and assessment. The diversity of expertise helps create well-rounded, effective learning environments. Figure 2 illustrates the possible composition of a LE team [22]. To ensure optimal outcomes, the most effective teams prioritize clear communication, shared understanding of key concepts, and alignment on terminology and processes, enabling successful collaboration and efficient problem-solving across various disciplines.

Figure 2: Possible structure of a multidisciplinary LE team [22].

We anticipate that faculty will exhibit varying levels of willingness to explore and adopt new teaching models, especially those that necessitate significant changes in their approach to instruction. However, integrating LE practices doesn't always require drastic shifts in pedagogy or andragogy. Instead, small, incremental changes to current teaching methods—guided by insights from the learning sciences and data-driven decision-making—can be implemented gradually. These adjustments, though modest, have the potential to drive substantial improvements in student engagement, learning efficiency, and overall academic outcomes, fostering a positive evolution in educational practices over time.

3.2 System Design:

Learning engineering is a practice that integrates the learning sciences with human-centered engineering design methodologies and data-driven decision-making to enhance learner development and support their progress [9]. Learning engineering is a systematic process aimed at iteratively designing, testing, refining, and enhancing learning conditions. Figure 3 provides an overview of the process, beginning with a *challenge*, followed by *investigation*, solution *creation*, and *implementation* of the solution. The sequence and specific tasks may differ depending on the nature and scope of the challenge, among other factors. However, the LE process always includes multiple iterations and relies on data to guide decision-making.

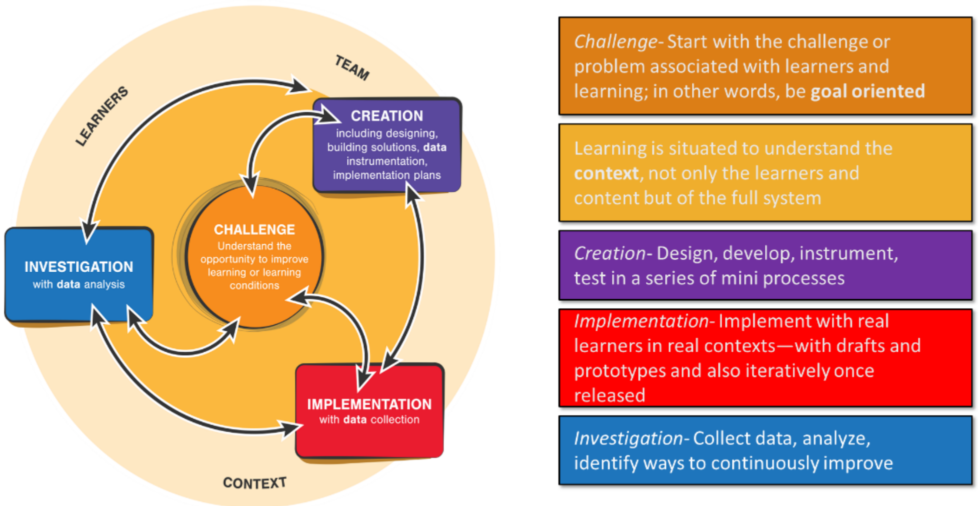

Figure 3: Possible structure of a multidisciplinary engineering team [9].

The outcomes of engaging in this process are diverse, and as such, the model is adaptable across various settings, educational levels, types of challenges, and learner groups. The process will differ depending on factors such as the challenge, learner context, team dynamics, resources, and more. The approach used by a large team may differ from that of a small team, and the process for developing a simulation may differ from that for designing a project-based learning experience.

3.3 Instrumentation and Data Analysis:

Data-backed decision making is a cornerstone of LE, as it ensures that decisions are driven by evidence rather than assumptions or intuition. This approach is vital for continuously improving learning systems and optimizing learning experiences. Data-informed decision making in LE consists of two key components: *instrumentation* and *analytics* [23]. Figure 4 illustrates the instrumentation and analysis process.

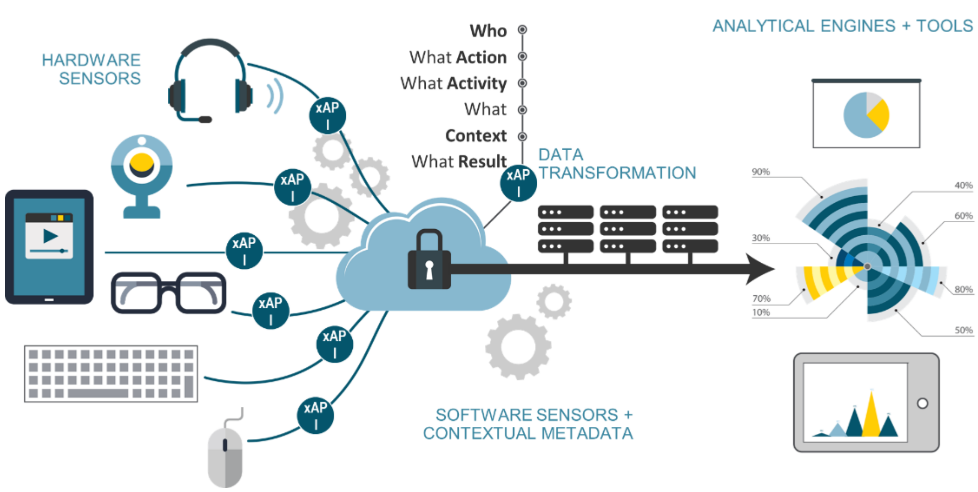

Figure 4: Instrumentation and analysis for a LE process [20].

The instrumentation part of the LE process involves designing, developing, and implementing the mechanisms for data collection that will guide the iterative improvement of the learning solution. This phase is responsible for selecting the appropriate tools, sensors, and technologies to capture relevant data from learners, their interactions with the learning system, and the environment in which learning occurs. This data might include metrics like learner engagement, performance, progress, and feedback, which are essential for fine-tuning learning designs.

Instrumentation utilizes a combination of software, hardware, and sensors to capture data in real time. Sensors may include tracking tools, wearable devices, or interactive systems that monitor various aspects of learner behavior and performance. The software then processes, stores, and organizes this raw data, creating a structured database that can be analyzed for insights. Once the data is collected through effective instrumentation, it feeds into the analytics phase, where data scientists, learning engineers, and educators analyze the information to uncover patterns and trends that can inform decisions. This cycle of data collection, analysis, and iterative improvement is integral for optimizing learning solutions, ensuring they are adaptable, effective, and aligned with the needs of the learners. By continuously refining the learning system based on data-driven insights, LE allows for ongoing enhancement of educational practices and outcomes.

Sensors are essential components that serve as interfaces between humans, computers, and environments to capture data. These sensors monitor interactions, behaviors, or conditions, providing valuable insights into how users engage with systems or experiences. In LE, data pipelines are the infrastructure—comprising both software and hardware—that enable the capture, processing, and storage of this data. Often, existing systems, such as online learning platforms, already include built-in software capable of recording learner actions. These actions, combined with context metadata, can be stored in files or databases for analysis without requiring additional hardware.

However, when existing sensors or platforms cannot fully capture the necessary data, new instrumentation or data pipelines may be required. This could involve developing new sensors or modifying existing ones to capture more specific types of learner data, such as physiological responses or real-time emotional states. Data pipelines may also need adjustments to accommodate the new data, including tagging, processing, and organizing it for analysis. Even when suitable instrumentation is available, the LE team must carefully evaluate which subset of data is relevant to the current learning challenge. They need to ensure that the data collected can be used to make informed decisions, draw meaningful conclusions, and ultimately improve the learning experience.

4. Case Studies

Researchers and educators have launched several initiatives to improve engineering education through the LE framework. LE has also been applied to develop everything from corporate training programs to learning environments for children. This section will present two case studies. The first involves the creation of an adaptive game system aimed at helping preschoolers build a solid foundation in math. The second case study focuses on the development of a learning environment for electrostatics, which allows students to interact with electrostatic representations in a virtual reality setting.

4.1 My Math Academy

Age of Learning, Inc. provides digital learning resources, including My Math Academy, an adaptive game system aimed at helping preschoolers build a strong math foundation [24]. The team behind the academy has expertise in learning sciences, curriculum development, game design, and efficacy research. The development process included three phases: exploration, iterative design, and validation. The team collaborated to explore design concepts, test prototypes, and validate designs. This case study focuses on understanding the target group and designing the game.

Exploration Phase: The exploration phase of the Math Readiness game design aimed to understand the learning needs of two- and three-year-olds, focusing on their math readiness skills and how they learn. The team used an empathy-driven design approach to explore the children's behavior, interests, and capabilities by consulting research literature and engaging directly with the children. They gathered insights from developmental psychology research to understand cognitive and motor skills and how children interact with digital games. The team also observed children playing games like Toca Life, noting how they navigated and interacted with the game world. These observations helped inform the design of an open play environment for Math Readiness, where children could freely explore and play different games. The team developed a persona named Lily, which embodied a typical child's interactions with technology and games. The persona included details about Lily's family dynamics, technology exposure, and play patterns. This persona served as a tool to predict how young children would interact with the game, considering both solo and social play experiences, and guided the game's design to engage children effectively while addressing their learning needs.

Iterative Design Phase: During the refinement phase, the team focused on improving and combining game ideas for Math Readiness. Key activities included organizing learning tasks in an interactive environment for Lily, incorporating counting, tracing numerals, recognizing patterns, and assessing understanding to determine readiness for My Math Academy. The case study focusses on the human-centered design process for iterative development of one activity in the game, *Pattern Pathway*, designed to help children recognize and complete simple patterns. The team aimed to explore how children would enjoy interacting with game elements, specifically dragging components across the screen to create patterns. This hands-on approach was designed to engage children in a fun and educational way, teaching them important math readiness skills.

a) <u>First Tests of the Game</u>- Playtesting for the *Pattern Pathway* game occurred in three rounds. In the first two rounds, children completed AB patterns, and in the third, they worked on ABC patterns. The test aimed to assess children's understanding of gameplay mechanics, the ease of learning those mechanics, and their enjoyment of the accompanying stories. The children were tasked with helping Shapey (a character in the game) cross a bridge by choosing the correct pattern block. Six children participated, and five successfully dragged a block to the bridge, showing that dragging worked well for this age group. Most children found the task enjoyable and easy to understand.

b) Second Test of the Game- The team designed an open play environment with a playground theme for children to explore learning games. Due to resource limitations, they created a paper prototype to test game instructions and visuals. Six children (ages 2 and 3) participated, but most were more interested in interacting with objects than completing patterns. Only one three-year-old completed the pattern, and the team questioned whether the activity, the background distractions, or the paper format caused the lack of focus. They speculated that a digital version could provide better engagement through immediate interaction and focused attention.

c) Third Test of the Game- The team developed a digital version of the game and tested it with six children to see if it would capture their attention more effectively. The screen design featured a brighter foreground and a less cluttered background with interactive objects related to the game. When children dragged stepping stools into place, Shapey moved to the next one. A "helping hand" modeled how to drag the stool, but most children didn't understand it without prompts. Despite some distractions, children focused more on the game than the background. Based on feedback, the team modified the game, clarifying instructions, making gameplay more forgiving, and improving visuals and animations to help children understand objectives and the narrative.

Final Testing: In the final round of play-testing with seven children, the team found that their modifications allowed children to easily interact with the game by tapping, dragging, and swiping blocks to the correct drop zones. All children successfully completed the pattern, though one needed a prompt for the last piece. The interface was simple, and children were able to identify interactive elements without being distracted by non-interactive parts of the game. The children were engaged and excited, with some giggling after completing the task and looking to their parents with pride for successfully finishing the pattern.

Preparing for final release: After validating the game, the team prepared it for release and incorporated insights from the design process into research-based guidelines for future designs. Pattern Pathways and nine other Math Readiness games are now available for young children. The team is analyzing interaction data to inform future improvements.

4.2 Electrostatic Playground:

The case study illustrates how the LE process was applied at MIT to develop the VR experience, Electrostatic Playground [25]. Figure 3 offers an overview of the process, starting with a challenge and followed by studying the learner context and creation, implementation, data evaluation and closing the loop.

Challenge- Gauss' Law in electrostatics is particularly challenging due to its three-dimensional nature, making it hard to visualize or capture in two dimensional sketches. This limits both instructors and learners in engaging with the phenomena as traditional 2D representations can often result in misconceptions. One solution, that was the focus of the Electrostatic Playground project, is to use 3D representations in a digital environment, like VR. The main challenge centered in the LE process was to encourage students to collaboratively engage with these representations to gain key insights into fundamental physics principles.

Learner Context- The learners were first-year physics students skilled in using mathematical formulas but had limited experience with visualizations of electrostatics for conceptual understanding. The project aimed to address this by having students engage with the content and peers in a VR environment. Throughout the semester, students worked on problem sets in small groups, and many chose to join the VR session with their usual partners. This familiarity with communication and problem-solving in their groups helped them adapt to the VR setting. The VR environment was designed to focus on a specific set of learning goals, ensuring students concentrate solely on those concepts without exploring other physics phenomena.

Creation- The team identified electric flux and Gauss' Law as key topics for the VR project, as they were challenging for students and involved complex 3D concepts. The team leveraged VR to encourage student collaboration while exploring field lines and Gaussian surfaces. The development process involved subject matter experts and developers working together, with user tests conducted to refine the system. Initial designs focused on allowing learners to explore freely, and data were collected through 3D recordings. Two key outcomes from these tests were the creation of short instructor-led prompts to guide students in noticing critical features and the adjustment of the VR system to capture learner perspectives.

Implementation- The first implementation involved twenty-three first-year physics students engaging with the system as part of their coursework, aimed at reinforcing their understanding of electric flux and Gauss's Law. Using the explanatory-exploratory structure, the session took place before final exams, with some students already familiar with the concepts, while others sought a deeper understanding.

Data Story- Data from learner sessions were captured through an integrated system that logged audio and participant interactions within the VR environment. This allowed for session playback from each participant's perspective. However, coding the data proved challenging, as it was difficult to track individual actions and joint attention. The VR system developers created an interface that allowed coders to view sessions from both the first-person and third-person perspectives. Using this system, a codebook was developed to track events such as attention to objects and joint attention. This process led to the identification of "aha!" moments, where participants expressed clear understanding, a key indicator of successful collaborative exploration of electrostatics principles.

Closing the Loop- Two key actions emerged from the implementation results and team discussions. First, due to the small number of learners in the first round, another implementation was necessary before drawing conclusions about effectiveness. Second, while the initial data showed a strong connection between joint object attention and "aha!" moments, the team, particularly the subject-matter experts, recognized the need for more data on content learning gains. This required additional pre- and post-assessments of electrostatics, leading to the scheduling of a second implementation for the following term to ensure data comparability.

5. Learning Engineering Evidence and Decision (LEED) Tracker

In addition to individual projects, there is an initiative aimed at developing a tool to enhance engineering education through the LE framework. This section will highlight one such initiative, which involves the creation of a tool at MIT designed to support the development of LE-driven projects.

Acknowledging the needs for LE teams to effectively conduct their work, recent efforts by Totino and Kessler [17] highlighted the development of the Learning Engineering Evidence and Decision (LEED) tracker as a way to record actionable design decisions in connection with channels of influence (i.e. learner needs, contextual limitations, and data). The three key benefits of using the LEED tracker (documenting design justifications for individuals and team members, revisiting and iterating on those decisions, and communicating across team members) emerged from authentic implementations of LEED across a number of projects run by the Residential Education Team at MIT Open Learning.

Additionally, the LEED tracker has been central in the development of the Learning Engineering Case Guide 1.0 [26], which provides a structure for reflecting on and interrogating each piece/phase of the Learning Engineering Process [27]. Together these tools were used to iteratively improve a program designed to support instructors in transforming their course materials and instructional approaches [28]. By documenting design decisions at three nested levels of the work (Program, Community, and Projects), the LE team was able to make sense of interconnected aspects of the challenges and resulting data that informed the next round of LE work to occur. Leveraging these tools and LE representations ensured that each level of the program was improved from one year to the next with clear justification for actions based on previous decisions and authentic data captured as part of each previous implementation of the program.

6. Conclusions

This paper explores Learning Engineering, an interdisciplinary field that combines learning sciences, engineering, design sciences, and data-driven approaches to improve educational outcomes. Significant contributions come from research, professional organizations like ICICLE, and practical applications in fields such as military and higher education. LE employs a systems engineering approach, integrating learning sciences and human-centered design to optimize learning environments. This collaborative, multidisciplinary process draws on expertise in data analytics, cognitive science, and instructional design, using iterative system design, data collection, and feedback to refine learning solutions and enhance student engagement and performance. We hope this overview provides a thought-provoking invitation to engineering education professionals and educators. We hope it can lead to a productive sharing of knowledge that can strengthen both fields.

References:

[1] J. Dewey, "Education as Engineering," *New Republic*, 20 September 1922, 89–91.

[2] H. A. Simon, "Job of a college president," *Educational Record,* American Council on Education, vol. 48, no. 1, pp. 68–78, 1967.

[3] K. E. Willcox, S. Sarma, and P. Lippel, "Online Education: A Catalyst for Higher Education Reforms", *Final Report, Online Education Policy Initiative,* April 2016. https://oepi.mit.edu/files/2016/09/MIT-Online-Education-Policy-Initiative-April-2016.pdf

[4] C. Dede, J. Richards, and B. Saxberg, Learning Engineering for Online Education Theoretical Contexts and Design-Based Examples, Edited book, 2019, Taylor & Francis. https://www.routledge.com/Learning-Engineering-for-Online-Education-Theoretical-Contexts-and-Design-Based-Examples/Dede-Richards-Saxberg/p/book/9780815394426?srsltid=AfmBOop2fU9R8gl4gdiJqGQzlXKqgxddcH9dpdMkvtw3u2134YRoy1Ah

[5] J. Goodell and J. Kolodner, Eds., *Learning Engineering Toolkit: Evidence-Based Practices from the Learning Sciences, Instructional Design, and Beyond* (1st ed.). Routledge, 2022. https://doi.org/10.4324/9781003276579

[6] K. Zhang and M. Zhu, "Define Learning Engineering with the TRAP Framework," Engineering Technology, vol. 4, no. 2, pp. 1-8, 2022. DOI: 10.19080/ETOAJ.2022.03.555635

[7] R. S. Baker, U. Boser, and E. L. Snow, "Learning Engineering: A View on Where the Field Is at, Where It's Going, and the Research Needed," *Technology, Mind, and Behavior*, vol. 3. No. 1, pp. 1-23, 2022. https://doi.org/10.1037/tmb0000058

[8] K. Çağıltay, N. B. Hamutoğlu, and M. Kesim, "Learning engineering: Past, present and future," *Journal of Educational Technology & Online Learning*, vol. 6 no. 4, pp. 1170-1179, 2023.

[9] J. Goodell, A. Kessler, and S. Schatz, "Learning Engineering at a Glance, Based on the iFEST Poster (Winner of Best Poster Design)," *Journal of Military Learning*, Conference Edition, pp. 46-59, 2023.

[10] E. Wagner and J. Lis, "The Rise of Learning Engineering," *eLearn*, vol. 2018, issue 8. https://doi.org/10.1145/3265972.3242101

[11] M. Lieberman, "iDesign, Learning Engineers Inch Toward the Spotlight," September 2018. https://www.idesignedu.org/latest-news/learning-engineers-inch-toward-the-spotlight

[12] M. Grush, "Learning Engineering: Making Education More "Professional" A Q&A with Ellen Wagner," *Campus Technology*, January 14, 2019. https://campustechnology.com/articles/2019/01/14/learning-engineering-making-education-more-professional.aspx

[13] P. Hogle, "New Field of Learning Engineering Edges Toward Definition," *Learning Guild*, May 29, 2019. https://www.learningguild.com/articles/new-field-of-learning-engineering-edges-toward-definition/

[14] J. R. Young, "How 'Learning Engineering' Hopes to Speed Up Education," *EdSurge*, June 9, 2020. https://www.edsurge.com/news/2020-06-09-how-learning-engineering-hopes-to-speed-up-education

[15] M. Grush, "Learning Engineering: New Profession or Transformational Process? A Q&A with Ellen Wagner," *Campus Technology*, July 8, 2024. https://campustechnology.com/articles/2024/07/08/learning-engineering-new-profession-or-transformational-process.aspx#:~:text=Learning%20engineering%20is%20an%20emerging,can%20improve%20learning%20at%20scale.

[16] S. Blake-Plock, "Learning Engineering: Merging Science and Data to Design Powerful Learning Experiences," *Getting Smart*, January 29, 2018.

[17] L. Totino and A, Kessler, "Why did we do that?" A Systematic Approach to Tracking Decisions in the Design and Iteration of Learning Experiences. *The Journal of Applied Instructional Design*, vol. 13, no. 2, pp. 277-282, May 2024. https://doi.org/10.59668/1269.15630

[18] S. D. Craig, J. Goodell, E. Czerwinski, J. Lis, and R. D. Roscoe, "Learning Engineering Perspectives for Supporting Educational Systems," *In Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, Sage Publications, 2023, pp. 304-309. https://doi.org/10.1177/21695067231192886

[19] J. Goodell and S. D. Craig, "What Does an Emerging Intelligence Augmentation Economy Mean for HF/E? Can Learning Engineering Help?" *In Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, Sage Publications, 2022, pp. 460-464.

[20] J. Goodell, M. Jay, N. Olaniyi, and J. Rogers, "Should IEEE Establish Learning Engineering as a New Engineering Profession?" in *IEEE 2022 International Conference on Advanced Learning Technologies (ICALT)*. https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=9853721

[21 18] B. Jerome. "The need for learning engineers (and learning engineering)." *ELiterate*. https://eliterate.us/learning-engineers/ [Accessed April 23, 2025].

[22 19] J. Goodell "What is Learning Engineering," *In Learning Engineering Toolkit: Evidence-based Practices from the Learning Sciences, Instructional Design, and Beyond*, J. Goodell and J. Kolodner (Eds.), 2022, Routledge: New York and London, pp. 5-25.

[23 20] E. Czerwinski, J. Goodell, S. Ritter, R. Sottilare, K.-P. Thai, and D. Jacobs. "Learning Engineering Uses Data (Part-1) Instrumentation," in *Learning Engineering Toolkit: Evidence-Based Practices from the Learning Sciences, Instructional Design, and Beyond*, J. Goodell and J. Kolodner, (ed.). (1st ed.). Routledge, 2022, pp. 153-173.

[24] K-P Thai, S. D. Craig, J. Goodell, J. Lis, J. W. Schoenherr, and J. Kolondner, "Learning Engineering is Human Centered," *In Learning Engineering Toolkit: Evidence-based Practices from the Learning Sciences, Instructional Design, and Beyond*, J. Goodell and J. Kolodner (Eds.), 2022, Routledge: New York and London, pp. 83-123.

[25] A. Kessler, S. D. Craig, J. Goodell, D. Kurzweil, and S. W. Greenwald "Learning Engineering is a Process," *In Learning Engineering Toolkit: Evidence-based Practices from the Learning Sciences, Instructional Design, and Beyond*, J. Goodell and J. Kolodner (Eds.), 2022, Routledge: New York and London, pp. 29-45.

[26] A. Kessler, L. Totino, A. Parent, and J. Goodell, "Learning Engineering Case Guide 1.0" licensed under CC BY-NC-SA 4.0, 2024. To view a copy of this license, visit https://creativecommons.org/licenses/by-nc-sa/4.0/

[27] A. Kessler, S. Craig, J. Goodell, D. Kurzweil and S. W. Greenwald, "Learning Engineering is A Process," *In Learning Engineering Toolkit: Evidence-based Practices from the Learning Sciences, Instructional Design, and Beyond*, J. Goodell and J. Kolodner (Eds.), 2022, Routledge: New York and London.

[28] A. Kessler and L. Totino, “The Nested LEPs of a Course Innovation Program: Navigating Complexities in Design,” in *IEEE ICICLE conference 2024*, Phoenix, AZ, July 22-24, 2024.