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Define “Learning Engineering” with the TRAP Framework

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Define "Learning Engineering" with the TRAP Framework

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Abstract

While the term "learning engineering" was first coined by Herbert [1]; it is becoming more salient recently. But there is not a commonly shared understanding of learning engineering as a professional or an academic field. Thus, we explored a range of resources, including scholarly publications and discussions, websites and initiatives of selected professional organizations, resources from related USA government and agencies, recent job posts and learning engineering degree programs to find relevant rhetoric, descriptions, curricula, task forces and other resources on learning engineering. Based on a critical synthesis of the above-mentioned materials, we argue that learning engineering is an emerging interdisciplinary field, which is timely needed and is yet to be defined.

Further, we propose a framework named TRAP to define learning engineering from four perspectives: Theoretical foundations, Research impacts, Analytical methods, and Practical applications, followed by discussions on related fields and the impacts of learning engineering. We envision that learning engineering will leverage learning technology for rapid waves of global upskilling and reskilling at scale in the coming years. This paper is an important initial step leading towards a comprehensive, universal understanding of learning engineering as a professional field. The TRAP definition also provides fundamental guidelines to further develop the core competences of learning engineering, which will lead to more rigorous programs in higher education. Moving forward, learning engineering as an academic field also requires research and explorations on how to assess student learning and programs success.

Keywords: Learning engineering; Data science; Emerging; Interdisciplinary; Learning technology

The Emergence of "Learning Engineering"

While Herbert A. Simon used the term "learning engineering" initially in 1967 [1]; it is just becoming more salient recently through various venues. For example, the AI Institute for Adult Learning and Online Education, a USA National Science Foundation (NSF) funded project, uses "learning engineering" to refer to the iterative design approach that brings engineering to education [2]. At the Northwestern University in the USA learning engineers are hired to "foster deep partnerships with faculty, engage not only in transforming on-ground classes to online ones, but also in consulting on broader program design and evaluation, long-term technology initiatives, and faculty development" [3]. Similarly, the Massachusetts Institute of Technology (MIT) has learning engineers on the open learning initiative team. Recently, Carnegie Mellon University has also posted an opening for a learning engineer in the Human-Computer Interaction Institute to assist faculty with technology integration in online or blended courses to achieve improved learning outcomes through continuous data analysis [4].

While learning engineers seem to emerge as a new job title, as indicated above, there is barely a universal understanding of what learning engineering is or what learning engineers do in the professional world. Thus, we explore a range of resources, including scholarly publications and discussions, websites of selected professional organizations, learning engineering degree programs, and recent job posts, to find relevant rhetoric, descriptions, curricula, taskforces, and other resources on learning engineering. Based on a critical synthesis of the above-mentioned materials, we argue that learning engineering is an emerging interdisciplinary field, which is timely needed and is yet to be defined.

Scholarly Rhetoric

Scholars have discussed learning engineering from different perspectives. For example, Baker and Yacef [5] emphasize the methods, including learning analytics and educational data mining, together with design-based research to optimize learning. While Dede and colleagues [6] stress the use of evidence-based strategies to iteratively design and re-design learner experiences. The Learning Agency highlights the important applications of computer science and describes learning engineering as "the use of computer science to pursue rapid experimentation and continuous improvement with the goal of improving student outcomes" [7]. More specifically, Baker [8] also highlights that the goal of learning engineering is to make improvements during its active implementations.

Recent scholarly publications further highlight the interdisciplinary nature of learning engineering. In the "High-Leverage Opportunities for Learning Engineering" report, Baker [9] articulates that, "Learning engineering combines scientific knowledge and theory on learning, and applies a rigorous combination of theory, data, and analysis to develop and improve educational systems and methodologies to produce enduring, high-quality learning" (P. 3). More specifically, they identify the following closely related fields to learning engineering: education, learning design, computer science, data science, behavioral science, and cognitive psychology [9]. Likewise, Anindya Roy notes its deep roots in learning science, educational technology, and data science [10]. Despite the scholarly discussions, there is a lack of shared understanding of what learning engineering entails, nor do we know enough about how to prepare people for learning engineering research and development.

Related Professional Organizations

While it is virtually impossible to identify all professional organizations related to learning engineering, especially considering its interdisciplinary roots [5,6,9,10] we select the following organizations for review and explorations: (1) the Association for the Advanced of Computing in Education (AACE); (2) the Association for Educational Communications and Technology (AECT); (3) the International Society of the Learning Sciences (ISLS); (4) the Society for Learning Analytics Research (SoLAR); (5) International Educational Data Mining Society (IEDMS); (6) IEEE IC Industry Consortium on Learning Engineering (ICICLE), and (7) Futures Forum on Learning (FFoL). We use "learning engineering" and "learning engineer" as keywords to search for any relevant literature, initiatives, or task forces in February 2022. The following summarizes our search results and findings.

The Association for the Advancement of Computing in Education (AACE)

AACE is an international organization that aims to advance information technology in education and the research and development of e-Learning [11]. It has a strong tradition of serving interdisciplinary professionals through conferences, publications, awards, and a career center. Our multiple rounds of search on the AACE website do not yield any results of "learning engineering" or "learning engineer."

The Association for Educational Communications and Technology (AECT)

AECT members include educators, learning technologists, instructional designers, and researchers with a shared goal to improve teaching and learning (AECT, 2022) [12]. AECT has created five standards for Professional Education Programs, including content knowledge, content pedagogy, learning environments, professional knowledge and skills, and research. However, it does not specifically identify the knowledge or skills required to leverage dynamic, large-scaled data to enhance teaching and learning. Searches on AECT and its divisions' websites yield no results of "learning engineering" or "learning engineer."

The International Society of the Learning Sciences (ISLS)

ISLS is an international organization devoted to empirical studies on learning [13]. Learning science research traditionally focuses on the psychological and theoretical foundations of learning and the design of learning environments. It is considered a closely related field of learning engineering [10]. However, the ISLS does not mention "learning engineering" or "learning engineer" on its website.

The Society for Learning Analytics Research (SoLAR)

SoLAR is "an inter-disciplinary network of leading international researchers who are exploring the role and impact of analytics on teaching, learning, training and development." (SoLAR, 2022) [14]. Learning analytics has become increasingly important in the past decade. As a relatively new organization established in 2011, SoLAR provides a platform for scholars from different disciplines. But its website does not post any rhetoric on learning engineering.

International Educational Data Mining Society (IEDMS)

Educational data mining (EDM) is another closely related field with the application of data mining, statistics, and machine learning to information generated from educational settings [15]. The EDM community members are primarily from psychology and learning science. While it is deemed as a closely related field [5,10] our search on the IEDMS website does not yield any results concerning "learning engineering" or "learning engineer."

IEEE IC Industry Consortium on Learning Engineering (ICICLE)

The IEEE IC Industry Consortium on Learning Engineering (ICICLE) specifically focuses on learning engineering since its establishment in 2017. ICICLE is a "professional organization committed to the development of Learning Engineering as a profession and as an academic [15]." ICICLE is part of the IEEE Standards Association's (IEEE-SA) Industry Connections (IC) program. Its original goals are to deliver "(1) a set of technical resources for Learning Engineers; (2) a Conference on Learning Engineering; (3) a white paper defining Learning Engineering" [16]. Currently, the organization has four special interest groups (i.e., Design for Learning, Curriculum and Competencies, Tools, and Learning Engineering as a Profession) and three market interest groups (i.e., Higher Education, Corporate, and K12).

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Kessler [17] and the IEEE ICICLE Design SIG define learning engineering as “a process and practice that applies the learning sciences, using human-centered and engineering design methodologies, and [Iterative] data-informed decision making to support learners and their learning.” It starts with a learning problem, which is complex and requires making appropriate decisions through multiple levels of the context system. Then, learning engineers need to understand the problem context, such as learners, contexts, and available resources. Next, a team should be formed to solve the problem. The team could design and develop a solution along with instrumentation with multiple rounds of iterations. Then, they could implement the solution, gather data via instrumentation, analyze data, and use the results to provide feedback on the learning engineering process. It is an iterative process [18].

Futures Forum on Learning (FFoL)

Besides the organizations mentioned above, Futures Forum on Learning is part of Schmidt Futures’ larger initiative to enhance the learning engineering field, which “aims to improve education by leveraging computing and data to dramatically increase the effectiveness of learning science as a discipline” [19]. It has organized Learning Engineering Tools Competition since 2020. It aims to provide support to new tools that could improve learning and advance the field of learning engineering. In addition, Kumar Garg, director at Schmidt Futures, stresses the three key elements of learning engineering (i.e., data collection, data analysis, and iterations of design of the educational tool or system) to improve learning [20].

The search results clearly indicate that these major professional organizations in related fields (e.g., educational technology, learning science, educational data mining, and learning analytics) have yet to adopt the term “learning engineering.” And there is not a commonly accepted definition of learning engineering across fields.

Graduate Degree Programs in the USA

Even though learning engineering as a profession or an academic discipline has yet to be defined, a few higher educational institutions have already started offering graduate degree programs to prepare learning engineering professionals. The varied program curricula provide another lens to examine how higher education is operationalizing the academic definition of learning engineering. Thus, in the following, we review the curricula in two universities offering such programs in the USA: Boston College and Carnegie Mellon University.

Boston College

Boston College (BC) offers a one-year, 30-credits Master of Arts program in Learning Engineering. The curriculum highlights “the hands-on design experience, interdisciplinary knowledge, and technical savvy” and prepares students for the following careers as learning engineers, learning experience designers, instructional designers, curriculum developers, or educational technology consultants [21]. The program curriculum integrates four areas, (1) learning theories and cognitive sciences, (2) learner-centered design, (3) design considerations to promote justice, diversity, and equity, and (4) leadership required for successful innovations and teamwork. Accordingly, the program faculty is from disciplines like psychology, learning sciences, education, evaluation, and educational leadership.

Consistent with the program curriculum and faculty composition, Boston College defines learning engineering as “the systematic application of principles and methods from the learning sciences to support and improve our understanding of learners and learning processes. The discipline leverages human-centered design principles to iteratively develop and improve products and services that empower learners—often using technology” [21].

Carnegie Mellon University (CMU)

With the influence of Simon’s learning engineering concept [1], Carnegie Mellon University has established a Master of Educational Technology and Applied Learning Science (METALS) program. The METALS program requires core courses such as “e-learning design principles,” “educational goals, instruction and assessment,” “tools for online learning,” “interaction design overview,” and “METALS project,” and five electives. A range of options are available from three distinctive areas, (a) technology, (b) learning sciences theory & instructional design, and (c) methods & design. Students must choose a minimum of three elective courses from at least two of the three areas. The METAL faculty bring an array of expertise in fields like education, computer science, human-computer interaction, learning analytics, anthropology, psychology, media design, learning sciences, and computational linguistics. Most of the METAL faculty members have a background in computer science or human-computer interaction.

The executive director of CMU’s Open Learning Initiative for Online Courses, Norman Bier, considers CMU as a standard-bearer for the learning engineer profession. With various combinations of the elective courses from two or three distinct fields, METALS graduates are prepared for different careers, such as learning engineers, instructional designers, learning/user experience designers, educational evaluators, curriculum developers, project managers, educational data scientists, educational technology consultants, or and entrepreneurs. Consistent with its interdisciplinary curriculum and faculty, the METALS program website articulates that a learning engineer’s job is to “apply science of learning principles, evidence-based research, qualitative and quantitative cognitive task analysis, and data-driven methods to design, create, and improve educational resources and technologies that enable students and instructors to succeed” [22].

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Recent Learning Engineering Posts

Our searches on the website of the USA Department of Education and that of an international organization, the North Atlantic Treaty Organization (NATO), yield no results of learning engineering jobs as of February 2022. However, two learning engineer jobs are posted in early 2022 in the USA. One was posted by CMU in March 2022 [23] and the other one was from the private sector, Lockwood Hills company [24].

CMU is a leading institution in higher education; and they search for learning engineers to create and implement "technology enhanced learning" [23]. While the required degree could be from learning engineering, learning experience design, or instructional design, the required skill sets include data analysis in addition to the traditional instructional design skills (e.g., creating learning objectives and materials). Desired qualifications include skills and experiences in creating educational technology, learning analytics, and related educational research. More importantly, the post emphasizes that ideal candidates must be skillful in learning analytics and emerging learning technology.

The Lockwood Hills company "provides critical mission support services for federal civilian and military operations" [24]. Similarly, they also emphasize the skills and experiences in advanced technologies and analytical methods for the learning engineer position. For example, the learning engineer's job responsibilities include to "develop learning analytics and associated dashboards (i.e., visualizations of learning data)." More specifically, they highlight the following as desired skills, learning analytics, educational data mining, and emerging learning technology such as mixed reality [24].

Despite the drastic differences in their professional settings and target learners, the two recent posts both highlight the importance of learning analytics and emerging technology skills for successful learning engineers. This is consistent with the scholarly discourses, with heavy emphasis on the interdisciplinary nature of learning engineering.

Finding "Learning Engineering"

The term "learning engineering" was first used by Herbert A. Simon from CMU, in his 1967 article, "The Job of a College President" [1]. Back then, Simon articulated that learning engineers, through collaborations with faculty, would provide "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" (p. 77). Lately, the FFOL and the USA NSF have adopted the term "learning engineering." In higher education, some universities have hired learning engineers for imperative roles. Professional organizations, such as the SoLAR and IEDMS, also highlight the importance of leveraging large data and the computational approaches to data analysis; however, they do not specifically use the term "learning engineering." Among the professional organizations we have explored in this article, only two of them specialize in learning engineering, ICICLE and FFoL.

Given the emerging need for professionals with the capacity to leverage large-scaled data to enhance learning environments, the demands for learning engineers are increasing. However, the programs that offer learning engineering are rather limited. Our search yields only two-degree programs in learning engineering in the USA. And the two graduate programs at BC and CMU vary remarkably in their curricula, faculty areas of expertise, and students' career paths. Obviously, there is little shared understanding of learning engineering as a professional or academic field.

Researchers and practitioners have rich discussions on learning engineering. As indicated above, a variety of skills are required for learning engineers. The ICICLE states that the learning engineering team should be equipped with core knowledge in a range of fields, including instructional design, learning environment engineering, education and training professional practices, assessment, measurement, evaluation, subject matter expertise, learning sciences, data science, and software engineering.

Defining "Learning Engineering"

Based on a critical synthesis, we argue that learning engineering is an emerging interdisciplinary field that is timely needed and yet to be well defined. As consistently indicated in scholarly rhetoric, program curricula, job descriptions, and professional organizations' initiatives, the goal of learning engineering is to improve learner outcomes. Learning Engineering has a strong interdisciplinary foundation in education (e.g., educational psychology, cognitive science, assessments, evaluations, etc.), data sciences (e.g., statistics, educational data mining, learning analytics), emerging learning technologies (e.g., artificial intelligence for education, VR, AR, gamification, etc.), and human-computer interaction design (e.g., user experience design, learning experience design, etc.). The relationships between learning engineering and related fields are illustrated.

First, learning engineering has deep roots in education, as it leverages the theories and applications of educational psychology and assessments to improve learning experiences and outcomes. Second, learning engineering adopts the analytical methods in data sciences, such as learning analytics, [25-27] educational data mining, [28-30] and other emerging methods. Third, learning engineering follows the principles of human-computer interaction design to create better learning experiences or adaptive learning ecosystems. In addition, the emergent learning technologies demand more research on learning engineering, while scaling up the capacity of digital learning. Moreover, the implementation of

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innovative learning technologies in education, such as artificial intelligence (AI), virtual reality (VR), and augmented reality (AR) also generates large data, which in turn can be dynamically analyzed for constantly improved learning systems and outcomes.

Further, we propose a framework named TRAP (see Figure 2) to define learning engineering from four perspectives: (1) Theoretical foundations, (2) Research impacts, (3) Analytical methods, and (4) Practical applications (Figure 2) (hence the name, TRAP). As the TRAP definition (Figure 2) illustrates; first, the theoretical foundations of learning engineering include education, human-computer interaction, data sciences, and design. As an interdisciplinary field, learning engineering is based on the theories in education (e.g., learning theories, educational psychology, cognitive sciences, etc.), human-computer interaction (e.g., user-centered design, participatory design, etc.), data sciences (e.g., learning analytics, educational data mining, etc.), and design (e.g., learning experience design, educational multimedia design, instructional design, etc.).

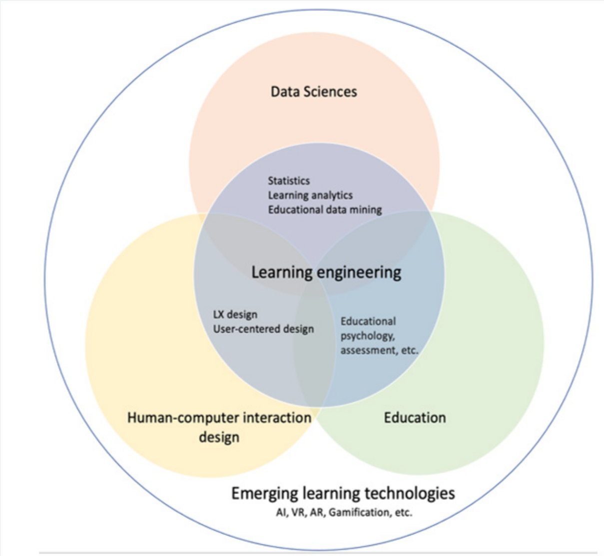

Figure 1: Learning engineering and related fields.

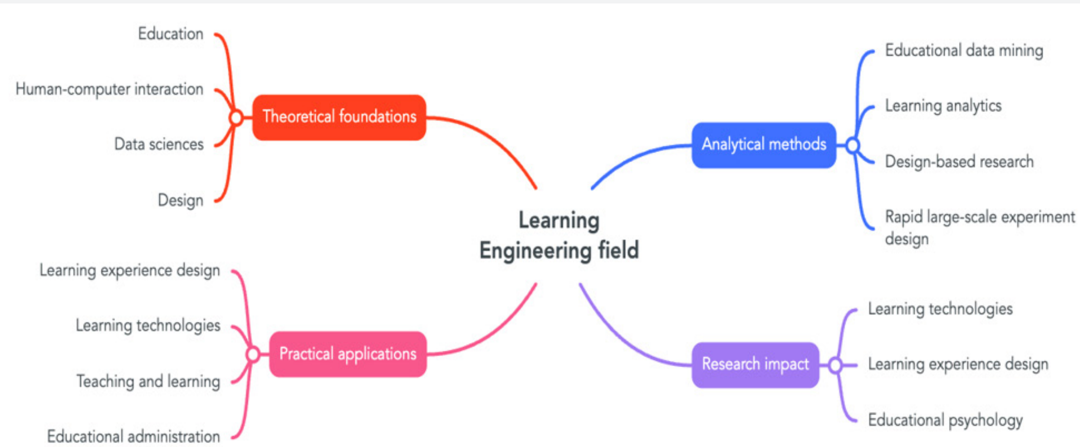

Figure 2: The TRAP Definition of "Learning Engineering".

Second, learning engineering has direct impacts on learning technologies, learning experience design, and educational psychology. The research and practice of learning engineering also apply, test, improve, and generate new theories and models to guide the design and development of learning technologies, learner experiences, and the broader learning ecosystems [6,31]. We envision that learning engineering will leverage learning technology for rapid waves of global upskilling and reskilling of the workforce at scale in the coming years.

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Third, learning engineering applies a range of analytical methods, such as educational data mining, [28-30], learning analytics [25-27], design-based research methods, and rapid large-scale experiment design. Despite some shared characteristics, educational data mining and learning analytics are distinctive in their origins, adaptions, techniques, and methods [32]. Thus, they are both identified in the TRAP definition diagram. Design-based research enables the researchers to improve both education practices and theories via iterations [33]. Meanwhile, rapid large-scale experiment design is typically used with large data and computational approaches. Applying these distinct analytical and research methods, learning engineering creates, evaluates, and improves the learning technologies and environments, as well as learner experiences and outcomes. Finally, learning engineering has a range of practical applications in learning experience design, learning technology design and development, teaching and learning, and educational administrations [6,31, 34,]. Rooted in the cross section of learning science, data science, and computer science, learning engineering provides new perspectives on educational technology and instructional design [31,35-37]. For example, the research and practice of learning engineering bridge the learning research and teaching practice [31] and improve teaching and learning through the dynamic applications of data analytics and adaptive learning ecosystems [6,34] Moreover, it could have broader impacts on the institutional, regional, national, and international levels, while empowering educators, administrators, leaders, and policymakers with data-driven decision making.

Discussion

With rapid technological development, such as AI, VR, AR, and digital games in education, large-scale data are generated every day. Not surprisingly, big data analytics is among the top technologies to be adopted by 2025 [38]. They also transform the ways of teaching, learning, and talent development, as well as e-learning, massive open online courses [39], VR for learning [40], serious games, [41,42] and AI for education [43], to name a few. The surge of innovative technologies also requires the upskilling and reskilling of the workforce across the world. Approximately ninety-seven million new jobs are expected by 2025, which requires half of the global workforce to be updated with new skills and competencies [38]. However, only 42% of employees reportedly participate in employer-supported opportunities for reskilling and upskilling [38].

Thus, it is critical to create effective resources for rapid learning and training opportunities at scale, with emergent technologies to improve the learning ecosystems. The needs for a technology-ready workforce and large-scale digital learning are calling for a new interdisciplinary field, learning engineering. More importantly, a deep and comprehensive understanding of learning engineering is crucial to guide the collaborations across disciplines. Thus, in this article, we report the explorations and synthesis of scholarly discussions, job descriptions, program curricula, websites, and other resources from researchers, professional organizations, government and agencies, and higher educational institutions in the USA [44-49]. Despite the nuances in scholars' rhetoric, they agree that learning engineering is interdisciplinary with deep roots in several fields, such as education, human-computer interaction, and data sciences as indicated in (Figure 1). With this figure, scholars and practitioners may quickly identify and select the most appropriate methods, technologies, or theoretical supports from those related fields to advance learning engineering research and practice. In addition, the TRAP definition of learning engineering illustrates its theoretical foundations, research implications, analytical methods, and practical applications.

The TRAP definition also lays out a foundation to further define learning engineering as an academic field and to guide the identification of its core competencies. For example, educational research and theories guide the practice and research of learning engineering. To bridge learning research and teaching practice, a solid knowledge base in educational psychology, learning sciences, assessments, and evaluations is essential. Human-computer interaction design also plays an imperative role in learning engineering, including user experience design, human-centered design and more. In addition, expertise in data science and design is critical in learning engineering. The analytic methods leveraged from data science (e.g., learning analytics, educational data mining), as well as design-based research and rapid large-scale experimental design, are instrumental to move the field forward with both research impacts and practical applications.

Conclusion

In the coming years, the demand for learning engineering will increase dramatically, as we address the global needs for upskilling and reskilling the workforce through rapid and adaptive learning ecosystems at scale. This paper is an important initial step leading towards a comprehensive, universal understanding of learning engineering as a professional field. According to the TRAP definition, the field of learning engineering prepares professionals and researchers with knowledge and skills in the cross section of education, data sciences, design, and technology. The TRAP definition also provides fundamental guidelines to further develop the core competences of learning engineering, which will lead to more rigorous programs in higher education, Moving forward, learning engineering as an academic field also requires research on how to assess student learning and programs success.

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