

Work in Progress: Delivering Flexible, Relevant, and Demonstrably Effective Online Education to Working Professionals

Dr. Marsha Lovett, Carnegie Mellon University

Dr. Marsha Lovett is Vice Provost for Teaching and Learning Innovation at Carnegie Mellon University. She has published research on learning and instruction, conducted in a variety of educational settings. A theme running throughout Lovett's work is leveraging data – from past research and present course-based activities – to enhance teaching and learning. Aligned with that theme, her favorite phrase is "data-informed iterative improvement!"

Levent Burak Kara, Carnegie Mellon University

Prof. Kara works at the intersection of machine learning, engineering design, and manufacturing. At CMU, he teaches graduate and undergraduate courses in the space of AI / Machine learning, design, dynamic systems, and linear algebra.

Prof. Rachelle Palchesko, Carnegie Mellon University

Rachelle Palchesko is an Assistant Teaching Professor in the Biomedical Engineering Department at Carnegie Mellon University. She joined CMU in 2011 as a Post-Doc in Professor Adam Feinberg's lab and was promoted to Special Faculty in 2016. She began teaching courses in 2019 and was promoted to Assistant Teaching Professor in 2022. She has taught courses in topics such as biomaterials, bioprinting and biofabrication, biomechanics, and tissue engineering just to name a few. She is interested in integrating cutting edge education tools and hands on activities into her courses and teaching laboratory courses.

Zachary Mineroff, Carnegie Mellon University

As Assistant Director of Learning Engineering at CMU, Zach supports the design, development, and implementation of innovative educational technologies and learning experiences. He supervises a team of learning engineers that supports instructors through consultations, course design projects, and fellowship programs. He is a graduate of the Masters of Educational Technology and Applied Learning Science (METALS) program at CMU.

Judy Brooks, Carnegie Mellon University

Avi Chawla, Carnegie Mellon University

As a Senior Learning Engineer at CMU, Avi works with instructors and the team at Eberly to design, develop and implement courses for online programs utilizing learning science principles. His main focus of work is on developing learning experiences which align learning goals, assessments and instruction using evidence based design principles and data analysis.

Mr. Martin van Velsen, Carnegie Mellon University

Martin is a senior system's architect with experience designing large scale production and research architectures. He has worked on research projects of a wildly varied nature, some which are: neurosurgery simulations, large scale artificial intelligence architectures, virtual humans and cognitive training simulations. Martin serves as technical adviser to many leading specialists in the field of serious games, simulations, and digital entertainment. Martin has been a speaker and panel host for various entertainment technology gatherings. Most recently he took part as a panelist at the PAX East gaming convention, but he has also organized such scientific forums as a panel on Authoring Interactive Narrative at the Stanford Spring Symposium. Over the last 18 years Martin has been responsible for shepherding open-ended research projects towards viable products that can be deployed by such organizations as DARPA, Army Research Labs (ARL), Air Force Research Labs (AFRL) and the Office of Naval Research (ONR). Finally Martin is an award winning artist, published fiction author, engineer, and a researcher in the field of interactive narrative.

Work in Progress: Delivering Flexible, Relevant, and Demonstrably Effective Online Education to Working Professionals

Many professional engineers are called upon to incorporate the latest technologies and associated skills (e.g., artificial intelligence) into their work. But they have little time or opportunity to obtain such knowledge and skill at the depth required for real-world application. The challenge for continuing education providers is: How can we create learning experiences that are both rigorous enough to address working engineers' practical needs *and* flexible enough to fit into their busy lives? Furthermore, when online education is the modality, how can we create learning opportunities that are equivalent to in-person – in quality, outcomes, and experience – and that work for cutting-edge technologies requiring physical interaction (e.g., additive manufacturing)? This paper describes our approach to these questions in the context of online, graduate certificates, i.e., official, transcribed credentials composed of 2-3 courses each.

We begin by briefly summarizing the advantages of online, graduate-level certificates, especially for working professionals. The next section describes how our approach addresses the *who* and *what* of high-quality, relevant program design. Then, the main section unpacks our signature strategy – the *how* of designing targeted, engaging, and demonstrably effective learning experiences. This strategy, called “Learning Engineering,” offers a research-based, practical approach to creating effective learning experiences, avoiding common instructional design pitfalls. Finally, we discuss preliminary, work-in-progress assessment results.

1. Online, graduate-level certificates

Amidst the burgeoning array of academic credentials, graduate-level certificates (also known as “micro-masters”) have several key advantages, especially for working engineers. First, they are smaller and quicker to complete than a full Master’s degree. A graduate certificate typically includes three courses, meaning that learners – including those taking just one course a semester – can complete a certificate in one year. Second, this kind of credential is officially recognized by the institution and recorded on the transcript. This way, employers can verify the achievement and know that the named institution stands behind it. Third, some institutions (including ours) offer specific graduate certificates that can be “stacked” to earn a Master’s degree. This allows learners the flexibility to work up to a Master’s without committing to do so up front.

Given these advantages, we chose graduate-level certificates as our primary offering for working professionals, specifically for working engineers. Our graduate-level certificates are designed to be completed 100% online, with both asynchronous and synchronous (remote) time, so students get the benefit of individual learning and class interactions without having to be on campus.

2. Prioritizing high-quality and relevant program design

We prioritize program quality and relevance by (a) engaging our world-renowned faculty experts to design and teach the courses (the “who”) and (b) focusing the curriculum on cutting-edge knowledge and skills that are sought after by employers and/or hard to obtain (the “what”).

The faculty involved in our online programs are the same faculty who design and teach in our in-person, full-degree programs. They are often designing online certificate courses based on the same material they teach to residential, degree-seeking students. The main difference is, for our online programs, the faculty are not working solo to design and implement these courses. Rather, they are the subject-matter experts working with a design team that guides them through student-centered “backwards design” (so called, because it works backwards from the desired end state). Backwards design is a best practice for instructional design [1], involving these three steps:

- articulating course learning goals (i.e., learning objectives that define what students should be able to do at the end of the course) in an action-oriented, measurable way,
- creating assessments that demonstrate whether students have met these learning goals,
- developing learning activities (that include feedback) to help students complete the assessments successfully and build the skills they need to achieve the learning goals.

Moreover, the learning goals associated with each course in a given certificate are also carefully designed – both to form a coherent set and to target industry needs and applicable skills. While the details of this process are out of scope here, it is worth noting a few data sources we use: Bureau of Labor Statistics projections of job growth; National Center for Education Statistics historical trends in academic program completions (online and overall) in job-related areas of study; and interviews with employers regarding skill gaps and opportunities.

3. Defining and illustrating our signature strategy: Learning Engineering

While other institutions may utilize some of the strategies mentioned above, what sets our continuing education programs apart is how we apply “learning engineering” to design the holistic learning experience for each program. This section defines the three key elements of learning engineering and illustrates how they unfold in practice, first via more basic examples (one element at a time) and then via rich case studies (all elements together).

Learning engineering incorporates three key elements: (1) leveraging research-based principles of learning to design effective, engaging learning experiences; (2) aligning educational technologies to meet the needs of the teaching/learning context; and (3) systematically collecting learning data to guide ongoing, iterative improvement. The resulting online courses are demonstrably effective, engaging, and applicable. They are much more than video with discussion boards or “Zoom in the room;” rather, they enable students to authentically interact with the material, the instructional team, and each other. In randomized controlled trials and quasi-experimental studies on the efficacy of courses designed via learning engineering, results have been consistent: students learn more and/or more efficiently when their course was designed via learning engineering [2] - [4].

3.1 Exemplifying each element of learning engineering individually

Incorporating learning science research into instructional design. There is a robust body of learning science research on how students learn – across a variety of contexts and disciplines. Some of these research results have been distilled into principles of learning and applied to the context of instructional design [5] - [6]. At the same time, there are many educational studies that lack scientific rigor or that focus on invalid measures of learning. With learning engineering, the

focus is on using robust results with solid theoretical and empirical support. For example, in our learning engineering process, we always foreground this principle: **Students' knowledge construction is best supported via active learning with targeted feedback.** This contrasts with the tendency to think of online course design as mostly content delivery. Therefore, when subject-matter experts dive into creating lecture videos (an often necessary, if later, step), our approach prompts them to explain what skills students should be able to apply after each video. We use this information to co-design learn-by-doing (LBD) activities while opening the question: Is video (or something else) the best way to prepare students for the LBDs? We collectively answer that question based on multiple factors, heavily weighing learning science research on multimedia learning [6]. In other words, we aim to use instructional videos for specific purposes – to motivate learning via contextualized problems, to provide initial exposure to concepts, to add a personal touch from the instructor, or to walk through worked examples step by step. In contrast, traditional instructional designers tend to focus on format – keeping videos short based on preference or behavioral data rather than data on what they are (or aren't) actually learning from the videos. Continuing our example, we intersperse the videos with LBDs, providing regular conceptual comprehension checks and opportunities to practice applying new skills. (Note: LBD activities generally provide immediate feedback, tailored to the student's particular response, and they are the precursor to more complex homework exercises.)

Aligning educational technologies to meet the teaching/learning context. With learning engineering, we leverage technology judiciously in ways that focus the learner's attention on key learning objectives. This involves starting with the learning objectives and then incorporating only tool(s) that are well aligned to those objectives and can be seamlessly integrated into the learning environment, e.g., via single sign-on and in-line placement. This contrasts with a natural tendency, especially in online design, to incorporate multiple educational technologies into a course simply because they are available and might be useful. While such technology uses *might* promote learning, they are also quite likely to create *extraneous cognitive load*, which detracts from learning. That is, when students are compelled to learn and focus on multiple tools, their attention and time are taken away from the primary learning objectives. Beyond intentionally avoiding the addition of extraneous load from tools, our approach seeks tool(s) that will *reduce* load from aspects of the instructional task that are logistically required but not germane to students' learning of targeted skills and knowledge (see 3.2). As a simple example, we use our learning management system (LMS) as a single, central hub for students to access all of their coursework. We reduce potential extraneous cognitive load from the LMS by creating a consistent course layout across all courses within each certificate and by making course navigation as smooth as possible. In addition, we integrate into the LMS any outside tools or platforms that students will need to use. As much as possible, we embed external tools in-line – i.e., *on the learning pages where students need to use them* – either via native (i.e., LTI) support for the LMS or a custom bridge or wrapper.

Collecting learning data to guide iterative improvements. As instructional designers and faculty know, designing and building an online course takes considerable time. When the process is done, there is often little energy to think about data-informed revisions. Even when there is time and energy, those involved may not be well positioned to collect valid data to guide course design improvements. For example, student evaluations of teaching and students' *perceptions of learning* do not provide valid information on what they actually learned [7] - [9]. Instead, a

learning engineering approach uses valid, direct-assessment data *from students' actual performance* to guide targeted course improvements. Each LBD/assessment that produces data is mapped to the particular skill(s) or learning objective(s) it practices/assesses. Then students' performance data (e.g., percent correct on first attempt or number of hints+attempts until correct) can be disaggregated by skill (or learning objective) and analyzed across time to produce "learning curves" that quantify students' learning for each skill according to a power function [10] - [12]. If a module addressed 10 skills, and the activities were mapped to those skills, the analysis would show which skills had the "flattest" curve (i.e., showing least improvement). Such results can help target strategic adjustments rather than arbitrarily deciding whether/where to revise aspects of the online instruction.

3.2 Case studies to illustrate our full approach in action

Now that the three elements of learning engineering have been discussed separately, we present two case studies, in two different engineering disciplines, to illustrate our full approach in action.

3D Bioprinting and Biofabrication Certificate. In this online, graduate-level certificate program, students learn to modify an off-the-shelf 3D printer so that it is capable of 3D-bioprinting, i.e., additive manufacturing of biomaterials. (We enable this hands-on component by shipping students some of the supplies needed and providing a shopping list for others.) Students also complete a project proposing a novel application of 3D bioprinting – from selecting a material, modifying it to suit their biomedical application, testing it, and preparing for FDA approval. Note that the program's learning outcomes and activities highlight authentic tasks and real-world, practical applications. The following features provide a snapshot of our instructional design:

- The instructor starts the course with a diagram that visualizes the course organization and flow through core concepts, disciplinary frameworks, etc. This diagram is reprised at the start of each week with a video overview of that week's topic, so students can see how upcoming material fits into the course and make relevant connections. This creates a conceptual structure or "advanced organizer" for the material that promotes learning and retention [13].
- Each week of the course includes a consistent sequence of pre-class, in-class, and post-class activities. Weekly agenda pages provide a summary of what to do in each phase with time estimates for individual tasks. Within each week, students navigate easily page by page and monitor their progress via an ever-present progress bar. This creates a natural routine, reduces cognitive load, and enables learners to allocate their time appropriately.
- Pre-class activities are designed for initial knowledge building. The focus is on low-stakes LBDs, directly embedded and interspersed with instructional text, images, and videos. Students can answer multiple times, receiving feedback tailored to each response. This prioritizes active learning and immediate feedback. As the course progresses, students read scientific articles within a tool embedded in the LMS that allows asynchronous, collaborative commenting and Q&A among the students and instructor, thereby scaffolding students' learning while allowing them flexibility in scheduling.
- Synchronous class sessions are not lecture-based; rather, the instructor prioritizes activities that leverage real-time feedback and collaboration, e.g., discussion of students' questions from pre-class work, small group activities to help students synthesize knowledge, and

preparation for upcoming project milestones. Besides Zoom, Google Docs is a familiar technology used for collaborative activities and to create class artifacts.

- Post-class activities focus on synthesis of what students are learning and application to the semester-long project. Regular milestones give feedback along the way and provide support for this authentic task. Graded quizzes and homeworks allow students practice on intermediate-size problems and help the instructor identify any knowledge gaps to address.

AI Engineering Fundamentals Certificate. In this program, students use tools of the trade as they learn to (a) apply machine learning strategies to real-world problems and (b) implement fundamental machine learning algorithms in Python. Although traditional homework exercises play a role, several other features highlight our signature approach to course design.

- A conceptual “big picture” of the course helps orient students, with diverse prior knowledge and experiences, to a shared framework that includes conceptual and practical components.
- The pre-, during-, and post-class activities are much like in the previous case, providing students with an organized structure and predictable way to navigate the course.
- Interspersed mini-Python programming activities are included in pre-class work, so students can get individual skill practice before incrementally progressing to combined-skills practice – during class and on homework assignments. In addition, we prioritized integrating the Python environment, Jupyter Notebooks, in our LMS, to focus students’ cognitive resources on learning key skills rather than navigating an external programming environment. This way students can practice their coding skills in an authentic yet focused way.
- During synchronous sessions, the instructor works through additional examples to help students develop expert thinking and processes.
- Challenge problems and other richly contextualized examples are designed so students from various engineering disciplines (mechanical, electrical, civil, biomedical, chemical, material) can see the course’s relevance for their field and directly apply course skills to their work/context. These problems provide further combined-skills practice and are designed to mimic real-world scenarios. Learners are eventually expected to ‘fly solo’ as they build software solutions with no guidance.

4. Our multifaceted assessment plan – elaborating on Learning Engineering’s third element

Because data-informed, iterative improvement is core to our approach, we consider assessment an ongoing activity. Given our online certificates are rather new, this work-in-progress paper describes our multifaceted assessment plan and presents preliminary assessment results. These assessment questions, with corresponding data sources and study designs, summarize our plan:

1. What areas or aspects of each course design can be improved to enhance student learning?
Data source: Performance data from online students’ coursework, analyzed according to a learning engineering approach (see section 3.1). The study design compares student learning across different skills to identify where improvements can have the greatest impact.
2. Are our online students achieving learning outcomes equally to our in-person students?
Data source: Equivalent high-stakes assessments (e.g., project reports scored on a rubric, exam scores, etc) from matched online and in-person courses, where the assessments are designed to assess program outcomes. Even though the online and in-person students come from different populations, our study design compares these two groups’ work to test for similar distributions of learning outcome achievement.

3. Are our online students satisfied with their learning experience and feel a sense of belonging? Data source: Student surveys and focus groups. This includes both quantitative survey data and qualitative data from open-ended survey questions and focus group discussions. Our study design compares results across time (previous to current student cohorts).

Given our approach to question 1 is discussed above, we focus here on questions 2 and 3.

Question 2. Testing how our online students are achieving learning outcomes relative to our in-person students is critical to this endeavor because our graduate-level certificates are official university credentials that learners may eventually “stack” together for a Master’s degree. So far, in 3D Bioprinting and Biofabrication, we have identified *matched assessments* (i.e., final project and a related assessment) across *matched online and in-person courses*. We collected multi-dimensional rubric ratings from the instructor and from a separately trained rater (who was masked to modality and student identity), calculated a summary score for each student’s submissions, and found that the distribution of ratings were visually similar across online vs. in-person modalities (and not statistically different according to Mann-Whitney U tests for both assessments). While this finding is encouraging, we recognize the need to replicate it across semesters, estimate power for these analyses, and compare outcomes in other courses.

Question 3. In addition to enhancing learning gains (questions 1 and 2), we want to enhance our students’ experience based on data. Although our surveys are still underway, we highlight some results – and iterative improvement steps – based on the focus group data. Across three semesters running these two online programs, focus groups were conducted about four weeks into the semester, to solicit students’ input on what was/was not working to support their learning and other suggestions for improvement. Data was collected anonymously by a member of our team (*not* the instructor), analyzed, summarized, and then discussed with the instructor. (See [14] for more on this method.) While the results indicated students had a positive learning experience, they also included constructive critique and helpful suggestions. For example, a focus group theme one semester was a request for *more* low-stakes practice (i.e., LBDs). We then worked with the instructor to make adjustments and found the issue was resolved the following semester. Over time, we expect past critiques will fade (as we address them) and new areas for improvement will surface. It is also worth noting that we use positive focus group feedback as a signal to (a) deliberately maintain practices that students find supportive and (b) find ways to translate those practices to other aspects of our designs.

5. Conclusion and Next Steps

As we continue to develop our online programs, there are still many areas open for data-informed iteration and refinement. A few areas of current focus include finding ways to (a) provide additional flexibility to busy, working professionals while still providing timely and targeted guidance and feedback, (b) add opportunities for students to (remotely) interact with physical systems they are learning about (e.g., in our Digital Twins program, just starting), and (c) make ongoing assessment work more efficient and automated so it can be further expanded and scaled as our programs and enrollments grow.

References

- [1] G. Wiggins and J. McTighe, *Understanding By Design* (2nd Expanded Edition). Assn. for Supervision & Curriculum Development, 2005.
- [2] M. Lovett, O. Meyer and C. Thille, "The Open Learning Initiative: Measuring the effectiveness of the OLI statistics course in accelerating student learning," *Journal of Interactive Media in Education*. <http://jime.open.ac.uk/2008/14>, 2008.
- [3] W. Bowen, M. Chingos K. Lack, and T. Nygren, "Interactive learning online at public universities: Evidence from randomized trials," ITHAKA Report, 2012.
- [4] O. Bälter, R. Glassey and M. Wiggberg, "Reduced Learning Time with Maintained Learning Outcomes," *Proceedings of the 52nd ACM Technical Symposium on Computer Science Education*, pp. 660-665, 2021.
- [5] M. Lovett, M. Bridges, M. DiPietro, S. Ambrose and M. Norman, *How Learning Works: 8 Research-Based Principles for Smart Teaching* (2nd Edition). San Francisco, CA: Wiley, 2023.
- [6] R. Clark, R. Mayer, *e-Learning and the Science of Instruction: Proven Guidelines for Consumers and Designers of Multimedia Learning* (5th Edition). San Francisco, CA: Wiley, 2023.
- [7] B. Uttl, C. White, D. Gonzalez, "Meta-analysis of faculty's teaching effectiveness: Student evaluation of teaching ratings and student learning are not related," *Studies in Educational Evaluation*, Vol 54, pp. 22-42, Sept 2017.
- [8] L. Deslauriers, L. McCarty, K. Miller, K. Callaghan and G. Kestin, "Measuring actual learning versus feeling of learning in response to being actively engaged in the classroom," *PNAS*, Vol 116 (39), pp. 19251-19257, September 4, 2019.
- [9] K. Wilson, M. Martinez, C. Mills, S. D'Mello, D. Smilek, E. Risko, "Instructor presence effect: Liking does not always lead to learning," *Computers & Education*, Vol 122, pp. 205-220, July 2018.
- [10] K. Koedinger, P. Carvalho, R. Liu, E. McLaughlin, "An astonishing regularity in student learning rate," *PNAS*, Vol. 120(13), e2221311120, March 20, 2023.
- [11] A. Corbett, M. Mclaughlin and K. Scarpinato, "Modeling student knowledge: Cognitive tutors in high school and college," *User Modelling and UserAdapted Interaction* Vol 10, 2-3, pp. 81--108, 2000.

- [12] B. Martin, A. Mitrovic, K. Koedinger and S. Mathan, "Evaluating and improving adaptive educational systems with learning curves," *User Modeling and User-Adapted Interaction*, Vol 21, pp. 249--283, 2011.
- [13] C. Stone, "A meta-analysis of advance organizer studies," *The Journal of Experimental Education*, Vol. 51 (4), pp. 194-199, 1983
- [14] B. Black, "Using the SGID method for a variety of purposes," *To Improve the Academy: A Journal of Educational Development*, 398, Lincoln, NB: Professional and Organizational Development Network, 1998.