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Building a Manufacturing Spine: Lessons from a Faculty Module Design Workshop

Mr. Benjamin Edward Chaback, Virginia Polytechnic Institute and State University

Benjamin (Ben) Chaback is a Ph.D. student in engineering education at Virginia Tech. He uses modeling and systems architecture to investigate undergraduate engineering education and is working towards creating sustainable systems for student success. Ben is a member of the American Society for Engineering Education, the Council on Undergraduate Research and is a facilitator for the Safe Zone Project and the Center for the Improvement of Mentored Experiences in Research. He is passionate about student success and finding ways to use research experiences to promote student growth, learning, and support.

Hannah Glisson, Virginia Polytechnic Institute and State University

Dr. Hannah E. Glisson currently serves as a Senior Analyst in Engineering Education at Virginia Tech. Hannah's research interests include broadening participation in engineering, sense of belonging among women in in engineering, undergraduate student support, and K-12 engineering outreach. She holds degrees in industrial and systems engineering (BS and MENG), higher education and student affairs (MSEd), and engineering education (PhD).

Dr. Lisa D. McNair, Virginia Polytechnic Institute and State University

Lisa D. McNair is a Professor of Engineering Education at Virginia Tech, where she also serves as Deputy Executive Director of the Institute for Creativity, Arts, and Technology (ICAT).

Ernesto Adolfo Cuesta Alvear, Virginia Polytechnic Institute and State University

Ernesto Cuesta is a PhD student in the Engineering Education Department at Virginia Polytechnic Institute and State University (Virginia Tech) in Blacksburg, VA. He holds a B.Sc. in Telecommunications Engineering and an M.S. in Project Management. Before beginning his doctoral studies, he spent eight years in the telecommunications industry, leading data-center projects and managing large-scale network deployments. As a Graduate Teaching Assistant, he supports Virginia Tech's interdisciplinary IDPro course, mentoring students through project-based learning and facilitating teamwork across engineering disciplines. His research interests center on workforce readiness and development, experiential learning environments, and interdisciplinary collaboration in engineering education.

WIP: Building a Manufacturing Spine - Lessons from a Faculty Module Design Workshop

Abstract:

This Work in Progress paper presents findings from the first semester of manufacturing module implementation at a large mid-Atlantic research university. The project aims to achieve two complimentary goals through sustained faculty engagement and collaborative curriculum design: (1) strengthen the integration of manufacturing concepts across the engineering curriculum and (2) provide a physical/concrete/hands-on context in which students can learn abstract/fundamental engineering concepts. 14 faculty and five graduate students were engaged in a three-day summer workshop focused on creating manufacturing-related modules for integration with their respective engineering classes. Participants engaged in hands-on sessions and structured dialogue around the national need for manufacturing education, explored strategies for embedding manufacturing principles into existing courses, and collaboratively developed course modules for implementation during the 2025–2026 academic year with a focus on incorporating experiential learning. This initiative is guided by a conceptual framework that combines Communities of Practice for the social learning processes as modules are collaboratively designed and Diffusion of Innovation to better map adoption of manufacturing modules and the importance of these participants as early adopters.

As of this paper, four faculty members and three graduate students from five different departments have successfully implemented their manufacturing modules, impacting over 560 students, with another five faculty members planning to implement their modules in the Spring 2026 semester. Data are being collected through student satisfaction surveys, faculty pre-module meetings, and faculty post-module reflections. This paper shares preliminary lessons learned, identified challenges and opportunities in faculty-led curriculum integration, and offers suggestions for scholars implementing similar training and development programs at their universities.

While the modules developed by these faculty incorporate manufacturing into unique disciplinary contexts, they are designed to be taught throughout the engineering curriculum across all domains to demonstrate real-world application of engineering first principles, provide a physical context for abstract concepts, to expose students to hands-on experiential learning with machines, materials, and/or data, and to provide a common unifying shared context for all engineering students across the College of Engineering with a theme in which students would have opportunities to learn emerging engineering topics and skills. It is anticipated that the findings of this study can more broadly inform faculty training and development, the incorporation of emerging manufacturing technologies into engineering curriculum, and ways to intentionally engage faculty from the summer throughout the academic year.

Introduction:

Expanding manufacturing education within engineering programs has become a national priority as the workforce continues to evolve to meet new technological, economic, and defense needs. Federal agencies and industry partners have emphasized that modern manufacturing relies on automation, artificial intelligence, machine learning, data-driven decision making, systems integration, and newly emerging manufacturing processes [1-2] to help address the US manufacturing workforce shortage [3]. These topics and the rapidly evolving technological landscape often extend beyond what is covered in traditional engineering courses, creating a need for more intentional connections between what students learn in class and how those skills apply in real-world manufacturing contexts. Engineering programs play a key role in helping students develop the technical and professional skills needed to enter this changing landscape.

At Virginia Tech, the Manufacturing Engineering Education Program is addressing this need through the development of a "Manufacturing Spine." The Manufacturing Spine is a coordinated effort to integrate manufacturing concepts and examples across the engineering curriculum rather than limiting them to specific courses or majors. By embedding these examples throughout different disciplines, the goals are to provide a common experiential learning context for learning engineering principles and to increase awareness of advanced manufacturing.

To support this effort, a multi-day workshop was created to guide faculty and graduate student participants in developing and refining curricular modules connected to the Manufacturing Spine. The workshop brought together educators from multiple engineering departments to co-create modules that could fit naturally into existing courses. Sessions were designed to encourage collaboration, reflection, and peer feedback. Participants used structured templates to align their modules with learning outcomes, identify assessment approaches, and plan materials for implementation.

The workshop design was informed by prior research on faculty development and instructional change in engineering education, particularly frameworks that emphasize coherence, content focus, active learning, collective participation, and sustained engagement [4]. Prior work highlights the importance of collaborative, relevant, and ongoing professional development structures for supporting instructional change in engineering contexts [5]. Accordingly, this workshop positioned faculty and graduate students as co-designers, engaging them in hands-on module development, peer feedback, and reflection to support adaptation of manufacturing content within their own courses and teaching contexts [6]. The goal was to promote shared ownership of the modules, ensure relevance across disciplines, and support continued collaboration around manufacturing education, experiential learning, and professional context around engineering education at Virginia Tech.

This paper describes the design and implementation of the workshop and provides an overview of how the resulting modules are being piloted during the current semester. Faculty are implementing their modules in a range of undergraduate engineering courses. The project team conducts classroom observations, post-implementation meetings, and faculty reflections to understand their experiences. Preliminary findings and lessons learned from these early implementations will help guide future module development and faculty support efforts.

This paper aims to answer the following research question:

RQ: In what ways did faculty implement an advanced manufacturing themed module in their engineering class?

Literature Review

Expanding meaningful manufacturing education across engineering curricula requires strategies that help faculty integrate real-world processes, hands-on experiences, and emerging technologies into existing courses. Advanced manufacturing has expanded rapidly, transforming industry practice and reshaping expectations for engineering graduates. Research consistently shows that when engineering courses incorporate real systems and live manufacturing data, students improve their conceptual understanding and ability to apply theory to practice [7-8]. Developing faculty capacity to design and implement such experiences is therefore essential, especially as manufacturing technologies evolve faster than faculty workloads typically allow.

Several studies highlight the importance of integrating modular, active, and data-rich manufacturing experiences throughout the curriculum. Mirkouei et al. demonstrated that scaffolded learning modules support deeper learning by enabling students to investigate manufacturing processes hands-on [9]. These modules also help overcome common barriers such as the high cost of instructional laboratories or limited access to industry facilities. Systematic reviews of additive manufacturing (AM) education further reveal broad global interest in teaching AM and Industry 4.0 concepts, alongside persistent challenges related to faculty expertise, access to equipment, and pedagogical readiness [10-12]. Together, these studies indicate a pressing need for faculty development initiatives that provide both technical immersion and structured support for curriculum design.

Communities of Practice in Engineering Faculty Development

Communities of Practice (CoP) provide a useful lens for understanding how faculty collectively learn to design and implement manufacturing modules. Wenger describes CoPs as groups of individuals who share a domain of interest, engage in joint activities, and build a shared repertoire of tools and practices [13]. In engineering education, CoPs have been used successfully to support instructional reform by facilitating cross-disciplinary dialogue, peer modeling, and collaborative curriculum development [14].

The Manufacturing Spine workshop functions as the starting point for such a community. Faculty from multiple engineering departments come together to co-design modules, discuss challenges, and exchange discipline-specific insights about manufacturing applications and for sharing ideas as to how advanced manufacturing can serve as a context for fundamental engineering concepts. Over time, this workshop-generated CoP has the potential to expand beyond academia by connecting with industry partners who represent established CoPs with deep manufacturing expertise. Such academic–industry bridges can enrich student learning through field visits, authentic datasets, industry-defined problems, and ongoing professional engagement.

Diffusion of Innovation in Faculty Adoption of Manufacturing Modules

While CoP explains how faculty learn together, Diffusion of Innovation (DoI) explains how the Manufacturing Spine initiative spreads across the College of Engineering. Rogers identifies five key innovation attributes that influence adoption: relative advantage, compatibility, complexity, trialability, and observability [15]. The structure of the summer workshop intentionally addresses each of these factors.

Shared worksheets and templates reduce complexity. Discipline-specific module customization increases compatibility. Small-scale pilots encourage trialability. Peer presentations, shared module repositories, and early-semester implementations contribute to observability, allowing faculty to see real examples of how manufacturing-based modules succeed in different classroom settings. These design choices help position the participating instructors as early adopters, whose experiences can reduce uncertainty and encourage broader adoption across departments, which is a process strongly supported by prior engineering education research [16].

Integrated Conceptual Framework

This initiative is guided by an integrated conceptual framework that combines Communities of Practice and Diffusion of Innovation. CoP explains the social learning processes that occur as faculty collaboratively design modules, develop shared tools, and co-construct a collective identity around manufacturing education. DoI explains the adoption trajectory of these modules across the college, highlighting how early adopters make the innovation more visible and less risky for future participants.

Figure 1 illustrates how CoP and DoI constructs guide the workshop design, shaping collaborative module creation, implementation, and assessment. Early adopters develop modules within the workshop, which then diffuse into the broader College of Engineering CoP. The Industry CoP represents a future partner that may contribute authentic data, field experiences, and collaborative opportunities to strengthen ongoing module development.

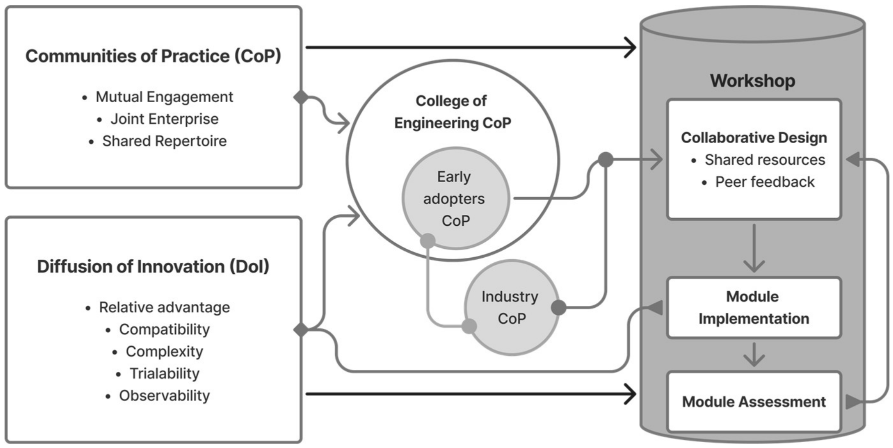

Figure 1: *Integrated CoP–DoI Framework Guiding Workshop Design, Module Implementation, and Diffusion Across the College of Engineering. Workshop Attendees Belong to the College of Engineering where the Workshop was also Hosted. Arrows Indicate Connections Between Elements of the Framework, Workshop, and Participants.*

Methodology

Pre Workshop – Recruitment:

In Summer 2025, faculty from the college of engineering were invited to participate in a three-day workshop alongside their graduate students to create a manufacturing module for their Fall 2025 and Spring 2026 classes. In total, 15 faculty and 5 graduate students attended the workshop from the disciplines shown in Table 1 below:

Table 1

Engineering disciplines represented at the workshop with faculty and graduate students

Discipline	Faculty	Graduate Students
Aerospace and Ocean Engineering	1	0
Chemical Engineering	1	1
Engineering Education	3	0
Materials Science and Engineering	2	1
Industrial and Systems Engineering	1	1
Mechanical Engineering	7	2

Day One - Foundations:

The first day centered on grounding participants in the goals of the workshop and establishing a shared understanding of what a strong manufacturing-focused module should accomplish. Facilitators opened with an overview of the Manufacturing Spine initiative and the broader need for integrating manufacturing concepts across the curriculum. This framing helped participants see how their individual course context fits into a larger institutional effort to strengthen manufacturing education.

Participants were then introduced to the module creation activity, which served as the core structure of the workshop. Using a guided worksheet, faculty identified key elements that would anchor their module design:

- **Course Details and Module Title:** Participants clarified the course in which the module would be implemented, the number of students typically enrolled, and the appropriate scope for an activity that could reasonably fit within their course structure.
- **Core Engineering Concept:** Faculty named the technical concept their module would reinforce, such as systems thinking, materials behavior, metrology, or process modeling.
- **Manufacturing Relevance:** Participants described how the concept connects to real-world manufacturing practice, industry needs, or emerging technologies. This component ensured that modules did not feel abstract but instead highlighted authentic engineering work.
- **Make it Experiential:** The workshop emphasized hands-on, active learning aligned with research on effective engineering education. Faculty brainstormed ways to incorporate lab activities, demonstrations, simulations, or real data sets.
- **Creating Great Learning Outcomes:** Participants drafted early versions of learning outcomes using action-oriented verbs and a clear sense of what knowledge and skills students should develop.

By the end of Day One, all participants had an initial module outline that defined the "what" and the "why" of their design, positioning them to shift toward assessment and logistics on Day Two. A full list of the activities for Day One is included in Appendix A.

<u>Day Two – Assessment and Materials</u>

Day Two helped participants move from conceptual design to practical implementation. Facilitators led a session on aligning learning outcomes with assessments and instructional materials, grounding this work in constructive alignment principles. Participants then expanded their module plans by developing:

- **Learning Outcomes:** Refinements of the outcomes drafted on Day One, ensuring they were measurable, aligned to course-level objectives, and appropriate for the module's scope.
- **Formative Assessment Ideas:** Participants identified checkpoints—such as clicker questions, in-class problem solving, short reflections, or peer feedback—that would help them gauge student understanding during the module.
- **Summative Assessment Ideas:** Faculty determined how they would evaluate student learning at the end of the module, including problem sets, lab reports, technical memos, design reviews, or exam questions.

- **Instructional Materials:** Participants outlined the slides, handouts, demonstrations, examples, and datasets needed to support the experiential component of their module. Many began rough drafts of these materials during the workshop.
- **Materials Inventory:** Faculty listed the specific tools, equipment, raw materials, and space requirements needed to run their module. This was especially important for modules involving additive manufacturing, machining demonstrations, or materials testing.

This day functioned as the bridge between creative brainstorming and actual course execution, helping participants identify what resources they would need and how they would measure the module's success. A full list of the activities for Day Two is presented in Appendix B.

<u>Day Three – Build, Polish, Present</u>

The final day of the workshop focused on synthesis, peer review, and preparing for implementation. Participants were asked to package their module into a brief 10-minute presentation. They were encouraged to articulate the engineering concept, describe the experiential activity, walk through the assessments, and explain how the module connected to manufacturing relevance.

Each presentation was followed by structured feedback from peers and the facilitation team. This review process helped participants identify areas for clarification, anticipate student questions, and strengthen alignment across learning outcomes, activities, and assessments. A full list of the activities for Day Three is presented in Appendix C.

A required part of each presentation was identifying the planned semester of implementation. As a result:

- 16 participants planned to implement their module in Fall 2025
- 7 participants planned a Spring 2026 implementation

<u>Post Workshop – Refine, Implement, Reflect</u>

Following the three days of the workshop, participants implemented their manufacturing module in their class. Once a month, the workshop facilitators hosted a session where participants implementing their module could join and get feedback or assistance prior to implementing their module in the classroom. Once participants completed their module implementation, a member of the workshop team met with them for half an hour to debrief how the module went and collect feedback on their experience. At the end of the semester, all participants were invited to a "lessons learned" and celebration lunch to discuss how module implementation went and how to improve the workshop for future cycles.

Results:

In Fall 2025, four faculty members who participated in the workshop implemented their modules with the assistance of three graduate students for a total of eight participants. These modules ranged from students first year to third year of undergraduate engineering coursework with approximately 560 students taking part in these modules.

<u>Bob</u>:

In September 2025, one faculty participant, Bob, implemented their manufacturing module in a junior-level mechanical engineering course with approximately 50 students. The module was integrated into an existing class session focused on dimensional tolerancing, fits, and tolerance stacks, allowing the manufacturing content to align naturally with core course concepts.

The module centered on helping students connect abstract tolerance concepts to physical parts and real manufacturing processes. Following a brief overview of the activity, students worked with components that had been fabricated in an on-campus machine shop. Using calipers, students took physical measurements of the parts and evaluated whether those measurements met specified design tolerances. Through this hands-on work, students developed an understanding of the physical meaning of a tolerance and how tolerances determine whether a part meets design requirements.

As the module progressed, students examined how the tolerances of mating parts influence fit and functional interaction, and how tolerance stacks emerge when multiple components are assembled. In the final phase, students analyzed production data, combining probability concepts with tolerance calculations to better understand variation in manufactured parts and its impact on fits and performance.

By grounding tolerance analysis in physical measurement and data-driven reasoning, the module supported students in linking theoretical calculations to manufacturing realities. The use of real parts and authentic measurement tools helped reinforce course concepts while highlighting the role of manufacturing considerations in mechanical design.

<u>Hayat and Hailey</u>:

In September 2025, one faculty participant, Hayat, implemented their manufacturing module with the assistance of a graduate student participant, Hailey. This module was delivered to a first-year general engineering class with approximately 280 students receiving the content over four sections.

The module began with a short slide show introducing the idea of manufacturing and some of the typical products that students use which have been manufactured. Students were then prompted to think a level deeper, looking at ways that manufacturing drives innovation in engineering, and the impacts of manufacturing on the local economy and labor market. Students had the opportunity to participate in think pair share opportunities looking at how current manufacturing practices could be improved, followed by a presentation by a graduate student discussing the cutting-edge research taking place in the manufacturing sector.

During the module implementation, students were kept engaged through think pair share and product review activities. The module itself lasted about 70 minutes with around half being assigned to lecture and half being assigned to activities for the students. The integration of commonly used and known products and local research connections helped students to not only better understand the manufacturing process but also see themselves as able to contribute to it.

Carlotta and Mani:

In October 2025, another faculty participant, Carlotta, implemented their manufacturing module with the help of a graduate student Mani. This module was delivered to an upper-level undergraduate materials science and engineering level class with approximately 30 students receiving the content in one section.

The module began with an overview of the labs that students would tour during the class period, delivered by the faculty participant. Students were then divided into three groups, with each group visiting one of three labs. The labs focused on various ceramic manufacturing techniques, such as additive manufacturing from powder (first lab), filament (second lab), and liquid (third lab). Each group of students participated in a 15-minute live lab demo, followed by a five-minute question and answer session for each lab. Following the completion of the three lab demos, students were asked to complete a short reflection on their experiences and relate class ceramic concepts to the lab sessions they observed.

For the module implementation, students were kept semi engaged during demos, but the large groups (approximately 10 students) were too big for many of the lab areas to properly see the steps being performed. Additionally, as the reflection was left as bonus credit for students to complete, response rates were low, with only a few students completing the assignment. The module itself lasted approximately 70 minutes and fit well into the class period.

Yoko:

Also in October 2025, another faculty participant, Yoko, implemented their manufacturing module. This module was delivered to an upper-level undergraduate aerospace engineering class with approximately 40 students receiving the content in one section.

The module began with a slide show introducing the manufacturing concepts surrounding the metal casting process, metal forging, metal 3D printing, and laser powder bed fusion. Following the slide show with some embedded videos, students were given a three-part worksheet to complete in pairs. This worksheet composed of an initial setup part, with engineering science principles being refreshed, followed by a part focusing on the heating stage of metal manufacturing, composed of a series of mathematical and conceptual questions, and concluded with a part focusing on the cooling stage of metal manufacturing, with questions composed once again of a series of mathematical and conceptual questions. The slides were approximately 20 minutes, with the students being given approximately 30 minutes to work on the worksheet.

During module implementation, students were kept engaged during the worksheet solving activity, but not as much during the initial slide show framing. It was also observed that the theoretical and applied contexts for the students were not directly related back to advanced manufacturing, and it is possible the students did not make the connection themselves. The module lasted about 50 minutes in total and fit easily into a class period, with students earning participation credit for participating in the module activities.

Andrew:

In September 2025, graduate participant Andrew implemented a manufacturing module in collaboration with faculty member Hae in a graduate-level materials science and engineering course. The module invited students to explore how manufacturing decisions influence material behavior by examining the relationships between processing conditions, microstructure, and material properties using additively manufactured parts. Approximately 15 students participated.

The module introduced students to the concept of process–structure–property (PSP) linkages through examples drawn from advanced manufacturing, including additive manufacturing, heat treatment, and forging.

In the second session, students visited a laboratory to observe additive manufacturing processes firsthand. During the lab session, students recorded processing parameters, observed variation across builds, labeled printed parts, and conducted basic materials characterization and testing, including optical microscopy and hardness testing. Working directly with the equipment allowed students to better understand how the machines operate and how processing decisions are enacted in practice.

Through these real-time observations and hands-on interactions, students were able to track variation across builds and connect differences in processing conditions to observable changes in printed parts. Seeing the manufacturing process as it unfolded helped students develop a more intuitive understanding of how processing, structure, and properties are linked, reinforcing course concepts through direct engagement with advanced manufacturing systems.

Although the module provided valuable hands-on exposure to advanced manufacturing processes, limited lab time and shared equipment meant that not all students were able to participate fully in hands-on activities. As a result, some students spent time waiting for access to machines or testing stations during the lab session.

Discussion/Conclusion:

From the five modules so far implemented by faculty members, it is clear that advanced manufacturing concepts can be integrated into the standard engineering curriculum. Many of these modules required approximately four days of faculty time to develop, with three occurring over the summer workshop and one during the semester to ensure the module was set to go and fit well within a single class period.

From the two theoretical frameworks involved in this study, Communities of Practice and Diffusion of Innovations, the module implementers are at the center. For CoP, workshop attendees leveraged the peer-to-peer network opportunities for feedback in the workshop, and for connections beyond. There are at least four American Society for Engineering Education conference papers and several industry connections which emerged. Regarding DoI, workshop attendees are recognized by interested faculty as manufacturing module experts now. Several attendees have been consulted by their colleagues for how to implement manufacturing modules in their class, and some participants have expressed interest in attending the 2026 manufacturing module workshop to be able to provide subject matter expertise to new participants.

In answering the research question, most faculty chose to implement their module within the classroom, through a combination of a multimedia presentation and student small group work. One participant did bring students to labs to gain visual experience and familiarity with different manufacturing machinery and equipment, but all faculty completed their module implementation within the duration of one normally scheduled class period.

Early evaluation of implemented modules points to two affordances and three challenges of implementing the manufacturing modules. In terms of affordances, connecting class content with real world manufacturing examples gets students excited and motivated to learn more about manufacturing. Similarly, students gain more awareness of manufacturing processes and careers through this in class incorporation.

In terms of challenges, the largest has been student bias towards manufacturing upon entering higher education. Many students reported associating manufacturing with shop floor careers and dirty, dangerous jobs. An additional challenge in terms of the students is keeping them engaged with the content, while also showing the relation between what they have learned in the class and how it relates to manufacturing. Lastly, there is a constant back and forth with the time faculty have available to spend on designing and implementing these modules.

Faculty reactions to their module have largely been positive, with many thinking of ways to collaborate with other instructors in their department to expand the students who are able to receive the content from the advanced manufacturing modules. Going forward, the collaboration between engineering education educators, manufacturing experts, and discipline specific engineering educators remains crucial for rapid development of modules which fit into a class period and have reaching impacts among the students who participate in them.

References:

[1] National Institute of Standards and Technology, 2021. [Online]. Available: https://nvlpubs.nist.gov/nistpubs/ams/NIST.AMS.100-42.pdf

[2] National Academies of Sciences, Engineering, and Medicine, "Strengthening the Talent for National Defense: Infusing Advanced Manufacturing in Engineering Education," 2022. [Online]. Available: https://www.nationalacademies.org/projects/NAE-NAE-20-02

[3] Deloitte and The Manufacturing Institute, "Manufacturing Industry Faces Unprecedented Employment Shortfall: 2.4 Million Skilled Jobs Projected to Go Unfilled," The Manufacturing Institute, Nov. 14, 2018. [Online]. Available: https://themanufacturinginstitute.org/press-releases/manufacturing-industry-faces-unprecedented-employment-shortfall-2-4-million-skilled-jobs-projected-to-go-unfilled-according-to-deloitte-and-the-manufacturing-institute/

[4] L. M. Desimone, "Improving impact studies of teachers' professional development: Toward better conceptualizations and measures," *Educational Researcher*, vol. 38, no. 3, pp. 181–199, 2009.

[5] C. Henderson, A. Beach, and N. Finkelstein, "Facilitating change in undergraduate STEM instructional practices: An analytic review of the literature," *Journal of Research in Science Teaching*, vol. 48, no. 8, pp. 952–984, 2011.

[6] M. Borrego, S. Cutler, M. Prince, C. Henderson, and J. E. Froyd, "Fidelity of implementation of research-based instructional strategies (RBIS) in engineering science courses," *Journal of Engineering Education*, vol. 102, no. 3, pp. 394–425, 2013.

[7] E. Abele, G. Chryssolouris, W. Sihn, J. Metternich, H. ElMaraghy, G. Seliger, and S. Seifermann, "Learning factories for future oriented research and education in manufacturing," *CIRP Annals*, vol. 66, no. 2, pp. 803–826, 2017.

[8] G. Chryssolouris, D. Mavrikios, and L. Rentzos, "The teaching factory: A manufacturing education paradigm," *Procedia CIRP*, vol. 57, pp. 44–48, 2016.

[9] A. Mirkouei, R. Bhinge, C. McCoy, K. R. Haapala, and D. A. Dornfeld, "A pedagogical module framework to improve scaffolded active learning in manufacturing engineering education," *Procedia Manufacturing*, vol. 5, pp. 1128–1142, 2016.

[10] P. U. Mehta and C. G. Berdanier, "A systematic review of additive manufacturing education: Toward engineering education research in AM," in *Proc. 2019 ASEE Annual Conference & Exposition*, Tampa, FL, USA, Jun. 2019.

[11] B. Motyl and S. Filippi, "Trends in engineering education for additive manufacturing in the industry 4.0 era: A systematic literature review," *International Journal on Interactive Design and Manufacturing (IJIDeM)*, vol. 15, no. 1, pp. 103–106, 2021.

[12] T. W. Simpson, C. B. Williams, and M. Hripko, "Preparing industry for additive manufacturing and its applications: Summary & recommendations from a National Science Foundation workshop," *Additive Manufacturing*, vol. 13, pp. 166–178, 2017.

[13] E. Wenger, *Communities of Practice: Learning, Meaning, and Identity*. Cambridge, UK: Cambridge University Press, 1999.

[14] A. Kezar and S. Gehrke, *Communities of Transformation and Their Work Scaling STEM Reform*. Los Angeles, CA: Pullias Center for Higher Education, 2015.

[15] E. Rogers, *Diffusion of Innovations*, 5th ed. New York, NY: Free Press, 2003.

[16] M. Borrego, J. E. Froyd, and T. S. Hall, "Diffusion of engineering education innovations: A survey of awareness and adoption rates in US engineering departments," *Journal of Engineering Education*, vol. 99, no. 3, pp. 185–207, 2010.

Appendix A:

Day One Workshop Schedule

Time	Segment	Purpose / Why We're Doing This
Day 1: Monday – Foundations		
9:00–9:35 AM	Welcome + Introductions (35)	Build community, set tone, surface energy and expectations.
9:35–9:45 AM	Workshop Goals + Agenda (10)	Help participants understand the structure and flow of the workshop. Introduce deliverables for each day.
9:45–10:15 AM	MEEP Project Overview + Defining the Manufacturing Spine (30)	Provide context for the workshop and connect it to real-world manufacturing in SWVA.
10:15–10:30 AM	Module Design Approach + Constructive Alignment (15)	Ground the workshop in module design approach; introduce constructive alignment as a framing tool.
10:30–11:00 AM	Core Concepts Brainstorm (30)	Identify key disciplinary concepts from faculty syllabi.
11:00–11:45 AM	Manufacturing Connections Activity (45)	Connect concepts to real manufacturing applications and regional needs.
11:45–12:30 PM	ISE Learning Factory Tour (45)	Ground concepts in real VT-based manufacturing spaces; inspire relevance.
12:30–1:30 PM	Lunch (60)	Time to rest, connect, and reset.
1:30–1:50 PM	Grouping + Theme Identification (20)	Spot patterns and potential shared module directions.
1:50–2:00 PM	Discussion (10)	Reflect on promising directions and collaborative energy.
2:00–2:45 PM	Experiential Learning Segment + Brainstorm (45)	Explain what experiential learning is, why it matters, and brainstorm ways to apply it.
2:45–3:15 PM	Creating Great Learning Outcomes (30)	Help participants write specific, aligned, measurable outcomes.
3:15–3:50 PM	Putting it Together (Worksheet Time) (35)	Begin assembling draft module: concept, outcome, experience.
3:40–4:00 PM	Tomorrow's Plan	Preview Day 2 and help participants mentally prepare.

Homework: Complete worksheet - DAY 1 - MODULE DEVELOPMENT

Appendix B:

Day Two Workshop Schedule

Time	Segment	Purpose / Why We're Doing This
Day 2: Tuesday – Peer Feedback + Assessment & Materials – complete DAY 2 - ASSESSMENT PLANNING WORKSHEET		
9:00–9:15 AM	Day 1 Recap + Day 2 Overview (15)	Reground participants in purpose and next steps. Share wins and questions.
9:15–10:15 AM	"Speed Sharing" Module Pitch Activity (60)	Give everyone a chance to practice articulating their module. Build confidence and gather diverse feedback.
10:15–11:00 AM	Assessment Planning (Mini-Lecture + Worksheet) (45)	Build understanding of assessment as integral to design. Introduce formative/summative types and examples.
11:00–11:15 AM	Break (15)	Recharge and reset before group work.
11:15–12:30 PM	Small Group Feedback (75)	Deepen module development through peer feedback and real-time revision. Facilitators check for alignment. Assign one facilitator to each group.
12:30–1:30 PM	Lunch (60)	Build informal community; pause to process.
1:30–2:30 PM	Materials Planning (60)	Guide participants to inventory what they'll need to teach their module (digital + physical).
2:30–3:00 PM	Share-Outs (Assessment + Materials) (30)	Participants share solutions and get inspired by each other.
3:00–3:30 PM	Game Plan for Tomorrow (30)	Help participants prioritize final tasks and feel supported.

Appendix C:

Day Three Workshop Schedule

Time	Segment	Purpose / Why We're Doing This
Day 3: Wednesday – Build, Polish, Present		
9:00–9:15 AM	Quick Recap + Goals for the Day (15)	Refocus participants on what they need to complete today.
9:15–10:45 AM	Creation Block 1 (90)	Give participants focused time to build out and polish their module, with coaching as needed.
10:45–11:00 AM	Break (15)	Rest and reset.
11:00–12:30 PM	Creation Block 2 + Feedback Stations + Start Whole Module Walkthroughs if people are ready (90)	Rotate for peer and facilitator feedback. Address final edits and unanswered questions.
12:30–1:30 PM	Lunch (60)	Recharge and connect informally.
1:30–3:00 PM	Whole Module Walkthroughs (90)	Final presentations of completed modules. Optional Zoom recording for documentation. This may take a long time. May need to divide into multiple rooms.
3:00–3:30 PM	Implementation Planning (30)	Support participants in preparing to deploy their modules. Identify timelines, resources, and pilot plans.