Expanding manufacturing workforce talent pool through multidisciplinary problem-focused experiential learning courses

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Abstract

Manufacturing industries increasingly require a multidisciplinary approach to design, develop, and produce products. However, the college-educated talent pool is limited because manufacturing education is typically imparted in just a few engineering disciplines. This case study highlights a project-based undergraduate course that aimed to address this challenge by engaging 44 undergraduate students from 8 different disciplines in experiential learning focused on solving advanced manufacturing problems. Specifically, it focused on solving the affordability and accessibility problems of nanoscale 3D printing by developing hardware and software tools. The class leveraged the contemporary interest in 3D printing and machine learning to attract students from various disciplines. By aligning hands-on projects with their disciplines, the course aimed to not only build relevant skills but also inspire interest in manufacturing careers. Thus, the course introduced manufacturing careers to students who might not otherwise encounter manufacturing-related projects within their academic curriculum.

Keywords: Vertically integrated projects (VIP), advanced manufacturing, nanoscale 3D printing, manufacturing education, undergraduate education.

1. Introduction

A gap exists between the needs of the future manufacturing workforce and how engineering students are currently being trained for manufacturing careers. Manufacturing industries are increasingly relying on multidisciplinary teams to tackle challenges in designing, developing, and producing products [1]. However, current undergraduate programs are often not designed to produce enough graduates or the right mix of the skills that are needed for such teams. A key factor that exacerbates this problem is that manufacturing education is typically imparted within broader disciplinary units, such as departments of mechanical or industrial engineering. In such a setting, only a subset of students from these departments learn about manufacturing careers, typically later in their academic curriculum. Consequently, the talent pool is limited both in size and skills diversity. Interdisciplinary manufacturing engineering programs can overcome these issues [2], but such programs are rare at the undergraduate level. We propose an alternate approach to tackle this problem: vertically integrated projects (VIP)-based courses that leverage discipline-specific skills to train students in solving complex multidisciplinary manufacturing problems.

The VIP program is an experiential learning framework that enables undergraduate students from various disciplines to work collaboratively on multidisciplinary hands-on projects while earning academic credit [3]. It has been formally implemented at several universities [4], and has been used to teach a variety of skills including entrepreneurship [5], software development [6], and independent research [3]. As the students in a VIP class can come from various majors and academic levels, the VIP framework can expand the manufacturing talent pool. As shown in Fig. 1, the traditional undergraduate curriculum resembles an inverted funnel that gradually narrows the talent pool for manufacturing by imparting manufacturing education to only a subset of university students. In contrast, a VIP course can draw students from a broad background and train them for manufacturing careers.

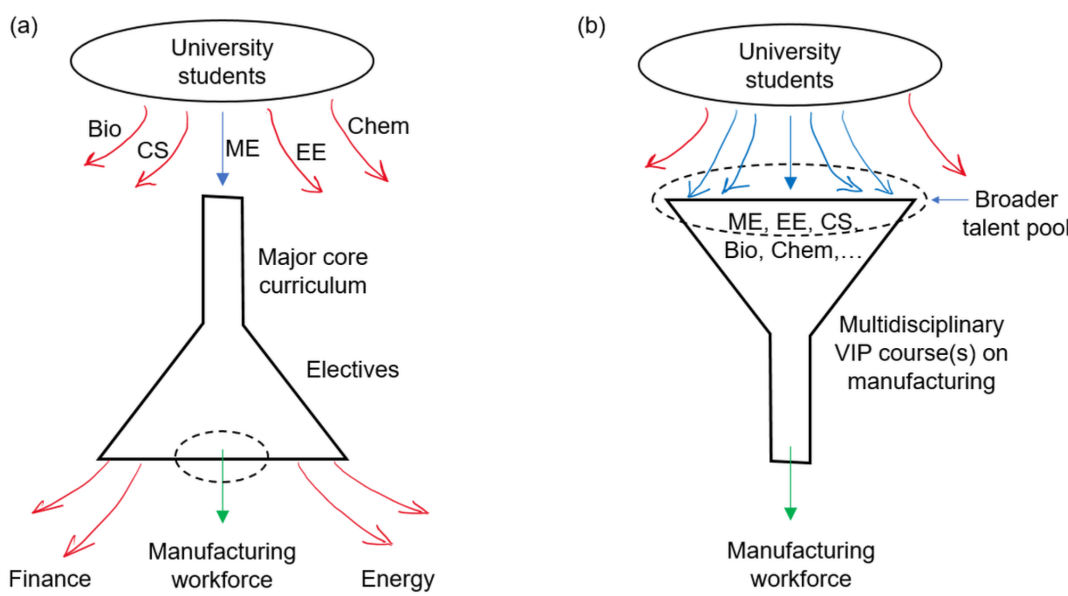

Fig. 1: Contrasting the two approaches for developing the manufacturing workforce talent pool through (a) traditional undergraduate curriculum versus (b) VIP courses.

Here, we present a review of one such VIP class that was taught for six semesters at the Georgia Institute of Technology by the author of this article. The course was titled "VIP VXK: 3D Printing on the Nanoscale" and it aimed to teach nanoscale additive manufacturing to undergraduate students through a series of design-build-test projects in a research environment. We present a summary of the course structure, the goals of the projects, the class composition, and the skills learned to demonstrate how the VIP framework can expand the manufacturing talent pool.

2. VIP class background

In our VIP class, the projects were focused on overcoming the affordability and accessibility challenges of nanoscale 3D printing, which is a highly valuable manufacturing technology for emerging applications such as advanced materials [7], optics [8], and bio-medicine [9]. Such 3D printing technologies are typically inaccessible to K-12 and college-level students due to the need for expensive equipment and specialized hands-on training. To overcome these challenges, the projects in this class were focused on: (1) generating low-cost equipment to perform nanoscale 3D printing and (2) generating computationally-efficient process simulator apps for projection two-photon lithography (P-TPL), which is a high-throughput nanoscale 3D printing technique [10, 11]. As solving these problems requires a multidisciplinary approach, students in this class could apply their own disciplinary skills while engaging with manufacturing problems that have real-world significance.

Based on the two types of projects, the class was divided into two primary teams, one responsible for hardware development whereas the other responsible for software development. Students were divided into the two teams based on their interests and expertise. The multi-semester goal of the hardware team was to build a low-cost vat photopolymerization-based nanoscale 3D printer. Specifically, the printer must cost less than \$10,000 and be capable of printing features as small as 1 μm and preferably smaller than 1 μm. Commercial printers with such fine resolution often cost more than a hundred thousand dollars. The teams repurposed low-cost optical pick-up units (OPUs) from video game consoles to build the printer. The designs were inspired by the work of Chang et al., who demonstrated nanoscale printing of polymeric features with OPU-based printers [12]. At the beginning, the multi-semester goal of the software team was to develop computationally-efficient process simulators of the P-TPL process based on machine learning (ML) models. During subsequent semesters, the goals were expanded to include the development of ML models for defect detection and the development of apps for computationally-efficient physics-based modeling of P-TPL. These projects were inspired by work performed by a graduate student researcher in the instructor's research group [13, 14], who also served as a graduate student mentor in this class.

The class was offered during the fall and spring semesters from Fall 2022 to Spring 2025 for a total of six semesters. Each semester had about 15 weeks of instruction. Second semester onwards, the specific semester-level project goals were formulated by considering the accomplishments of the previous semesters. Thus, the students could work on substantive long-term projects by taking the class for credit in multiple semesters. For example, the hardware team worked on progressively improving the resolution of printing from >100 μm to ~1 μm over multiple semesters. The specific semester-level goals of the two teams are available elsewhere [15]. Representative project accomplishments for the hardware team are summarized in Fig. 2. Each semester, several existing team members exited the team and new members joined the team. A key feature of the VIP class format is that the continuing students can serve as mentors to the new members of the team. This ensures project continuity while simultaneously providing students with opportunities to improve their leadership and mentorship skills.

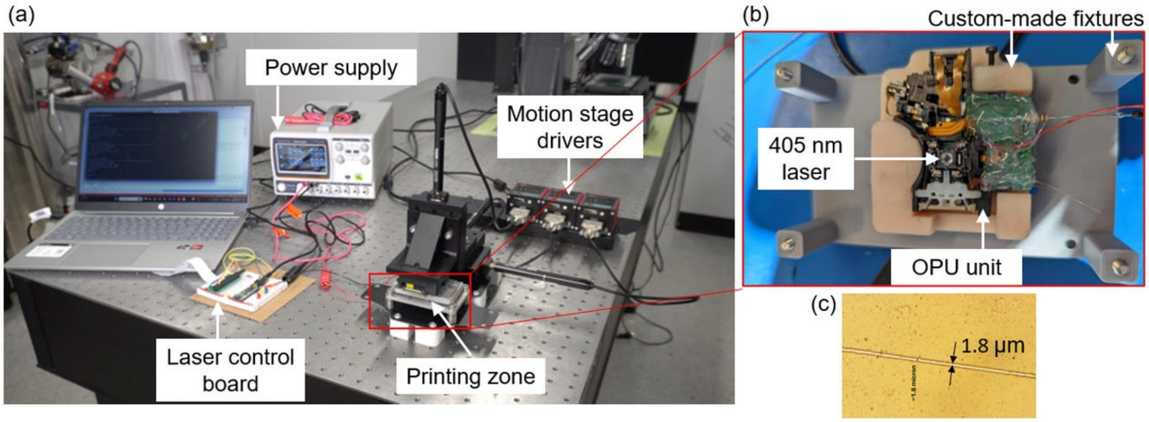

Fig. 2: 3D printer designed and built by the students of the VIP class from Fall 2022 – Spring 2025. (a) Printer with electronics, (b) details of the optical unit, (c) optical micrograph showing a benchmark microwire feature fabricated with the printer.

The grades for academic credit were assigned based on equal weightage given to these three components: personal accomplishments toward the project goals, quality of documentation, and teamwork. Formal assessments for grading included midterm and final team presentations and a peer-review assessment provided by the students on their teammates' performance. The student's grade on personal accomplishments was assigned based on their performance on the weekly progress meetings and formal class presentations, grading of their project notebooks, and peer reviews. Student's grades on documentation were assigned based on the quality of their documentation in their individual project notebooks and their entries in the project wiki, whereas their grades on teamwork were assigned based on the peer review reports and their formal team presentations.

3. Results and discussion

The class enrollment varied between 7 to 22 undergraduate students per semester and a total of 44 undergraduate students enrolled in this VIP class over six semesters. The class comprised a diverse group of students at different stages of their degree program (sophomore/junior/senior), different majors, and different skillsets. The prerequisites for joining the VIP class included familiarity with 3D printing and/or machine learning. The prerequisites were kept to a minimal to encourage students from diverse academic backgrounds to join the class. The success of the VIP class relied on this diversity of skills, given the inherently multidisciplinary nature of the projects. Student self-assessments have shown that the diverse composition of the VIP classes at Georgia Tech correlates with an improvement in students' ability to "work in a multidisciplinary team", "ability to work with individuals from diverse backgrounds", and "understanding of technology applications relevant to their field of study" [16].

In our VIP class, 27% of the enrolled students were from the sophomore year, 36% from the junior year, and 36% from the senior year. Also, 52% of the students enrolled in the class for more than one semester. Interestingly, although the instructor's academic affiliation was with mechanical engineering, the most frequent major of the enrolled students was computer science (CS). The specific composition of the class is shown in Fig. 3. In total, 66% of the students were from majors other than mechanical engineering (ME), such as electrical engineering (EE), material science and engineering (MSE), chemical and biomolecular engineering (ChBE), aerospace engineering (AE), biomedical engineering (BMED), and computational media (CM). As such, these majors have traditionally not been the home for recruiting the manufacturing workforce. We believe that the class attracted students from diverse academic backgrounds due to its focus on 3D printing and machine learning, which are two widely appealing and contemporary topics. Many students had prior experience or exposure to one of these two topics, which initially drew them to this VIP class. By enabling students to apply their skills to manufacturing-relevant projects, the class transformed their initial interest into preparation for future careers in the field.

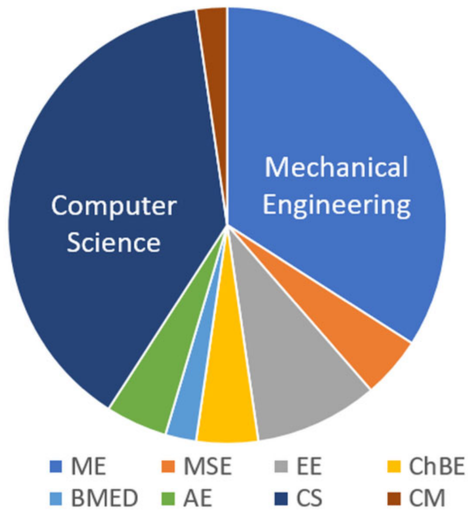

Fig. 3: Majors of students enrolled in the VIP VXK class from Fall 2022 to Spring 2025 (total 44 students).

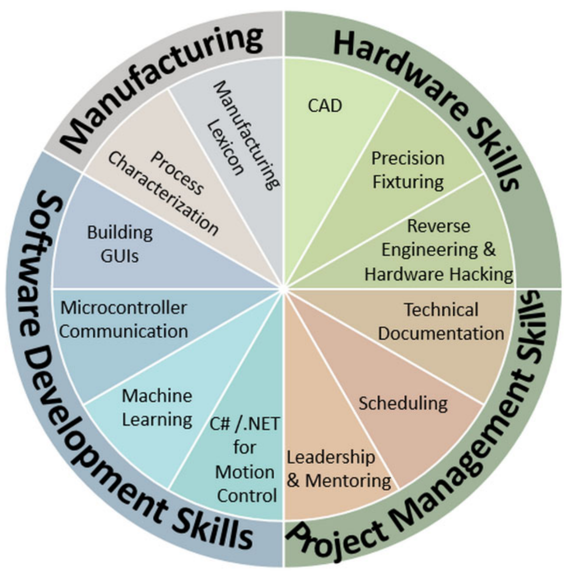

Fig. 4: Skills wheel summarizing the skills learned by students in the VIP VXK class.

As illustrated in Fig. 4, the VIP format fostered the learning of both broadly generalizable skills and specific technical topics in manufacturing. In general, the hands-on nature of the projects encouraged students to engage in design, analysis, and problem-solving in ways that are typically not found in traditional laboratory classes. In such classes, students are often provided with detailed protocols and templates, which limit their ability to think creatively or critically about the experiments that they are conducting. In contrast, the VIP format challenged students to develop their own experimental protocol, interpret their results, and iterate on their methods based on real-world constraints and observations. Additionally, students in the two project groups learned project-specific technical skills. For example, students in the hardware teams learned how to design and build manufacturing equipment, characterize manufacturing process performance, and optimize processing conditions to improve manufacturing metrics. Similarly, students in the software teams learned how to label manufacturing process datasets for machine learning, design graphical user interfaces (GUIs) for manufacturing process simulators, perform manufacturing defect detection via machine learning, and optimize computational efficiency for rapid process planning. Furthermore, while working on these projects, the students became familiar with the lexicon of manufacturing, such as gaining insights into the various ways in which process quality or throughput can be quantified. Thus, the VIP class helped students become more aware of and prepared for careers in manufacturing.

The VIP class shares some characteristics with the capstone senior design class, but the two are distinct in their focus. Capstone design courses are typically multi-semester project-based classes that help satisfy the accreditation requirements for undergraduate engineering programs [17]. Capstone classes are focused on integrating the knowledge imparted by prior classes within a particular discipline, such as mechanical engineering. In contrast, the focus of the VIP format is to assemble students from different disciplines into teams that work on solving complex problems that cannot be pigeonholed into a single discipline. Thus, VIP classes are problem-focused whereas capstone classes are discipline-focused. Due to their multidisciplinary problem-focused approach, VIP classes can train a broader set of students and effectively expand the talent pool for workforce in specific industrial sectors. For example, our VIP VXK class was focused on developing the talent pool for future nanoscale 3D printing workforce. One could envision developing other VIP classes focused on problems in semiconductor manufacturing, manufacturing of materials for extreme environments, or smart manufacturing to help alleviate the skills shortage in these areas of significant national interest.

4. Conclusions

Here, we have highlighted a VIP class that offered project-based experiential learning in advanced manufacturing to students from diverse academic backgrounds. The class was offered for six semesters and it focused on solving the affordability and accessibility problems of nanoscale 3D printing by developing hardware and software tools. The class leveraged the contemporary interest in 3D printing and machine learning to attract students from various disciplines. A total of 44 undergraduate students were trained through this class. Students represented eight different majors, with a plurality coming from computer science. A majority of the students enrolled in the class for multiple semesters, which enabled them to work on substantive long-term projects. The VIP class helped students become more aware of and prepared for careers in manufacturing by imparting both broadly generalizable project management skills and specialized technical skills. A key distinguishing feature of the VIP class format is its multidisciplinary problem-focused approach; this is in contrast to the discipline-focused approach of typical project-based capstone design courses. Thus, VIP classes offer a promising way to expand the talent pool for the manufacturing workforce.

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