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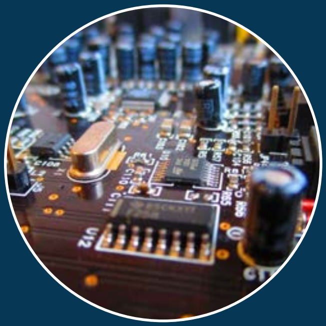

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From the **EDITOR**

Dear Engineering Technology Colleagues:

In this Spring 2024 Issue of the *Journal of Engineering Technology*®, we are excited to share four articles that could be of significant interest to the engineering technology community. In the ETD Best Presentation paper at 2024 CIEC Conference, the authors present a methodology to develop vertical integration of experiential learning curriculum for a Construction Engineering and Management Technology program. The second paper focuses on the development and evaluation of open educational resources (OER) for computer-aided design (CAD) courses. Recommendations are provided for enhancing academic effectiveness and student success through OER adoption. We also feature a condensed review paper on Cu-Al Shape Memory Alloys (SMAs). The authors give examples of research opportunities and potential use of smart materials for practical applications in engineering technology education. In the fourth paper, the authors propose a method to identify key, shared skills for efficient training resource allocation in the area of advanced manufacturing technology. This approach aims to address skill shortages while maximizing limited curriculum development resources. We hope these articles make it to your summer reading list.

In an effort to enhance dissemination, the JET editorial board is considering several options for online publication. We are also interested in creating Digital Object Identifier (DOI) for all JET papers and making them accessible online. We look forward to providing updates on the progress of this change in the summer.

Best regards,

Jyhwen Wang
Editor-in-Chief
Journal of Engineering Technology®

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COVER: Tennessee Tech engineering technology students working on projects in the lab.

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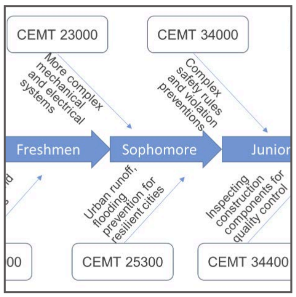

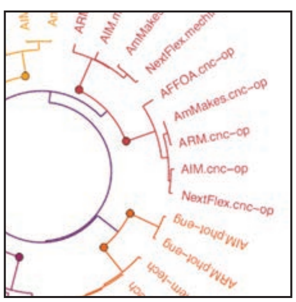

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Vertical integration of Experiential Learning in Construction Curriculum with Industry Collaboration

Afshin Zahraee, Cheng Zhang, David Pratt and Chandramouli V. Chandramouli

Abstract

This paper proposes to vertically integrate experiential learning components in courses at various levels in the Construction Engineering and Management Technology (CEMT) program at Purdue University Northwest (PNW). Specifically, this project focuses on engaging industry professionals to incorporate newly developed experiential learning (EL) components in courses at the freshman, sophomore, junior and senior levels (vertical integration). The design of these EL components will be based on the revised Kolb's theory of EL, which includes contextually rich concrete experience, critical reflective observation, contextually specific abstract conceptualization, and pragmatic active experimentation. The vertical integration of EL components can supplement classroom learning with real-world problem solving, whose outcomes include professional communication, teamwork, self-guided learning, observation, and reflection.

The PIs will develop and implement EL components in six unique courses at the CEMT program, including five regular lecture-based courses and one existing EL course. Industrial collaborators have been selected as experts and will be heavily involved in developing and implementing each of the EL components. The methodology of developing EL modules will follow a framework involving the integration of evidence-based pedagogical approaches and Kolb's theory, to be validated through this project and adopted by other institutions.

1. Introduction and Background

Teaching and learning in the fields of science, technology, engineering, and mathematics (STEM) traditionally employ conventional methods such as classroom lectures, laboratory works, and internships (not necessarily a requirement for graduation). Many students in a classroom have difficulty comprehending and relating the contents of classroom lectures to real-world applications. This project focuses on engaging industry professionals to incorporate newly developed experiential learning (EL) components in courses at the freshman, sophomore, junior and senior levels (vertical integration) in the Construction Engineering and Management Technology (CEMT) program at Purdue University Northwest (PNW). It is intended to include an integrated assessment and evaluation plan for continuous improvement.

The EL components are designed to supplement classroom learning with real-world problem solving, whose outcomes include professional communication, teamwork, self-guided learning, observation, and reflection. These components will also help students visualize a variety of field-based scenarios, including constraints and barriers to completing projects. These complexities are difficult for students to experience in a traditional classroom setting. Vertical integration of EL components throughout the program will provide an opportunity for the students to get more field interactions as well as work in groups in a field setting. In addition to EL component objectives addressed, students will develop other relevant skills, including the perspective of overlapping areas of fieldwork and research, exposure to various federal and state agencies, regulations, and codes including contemporary issues.

2. Rationale

While the construction industry is expected to grow 11% from 2020 to 2030, according to the Bureau of Labor Statistics (2020), academic institutions face several challenges preparing employees for this industry. Current CEMT students have difficulties applying the learned knowledge from the classroom to the construction site. A college degree in construction, which helps the students have a holistic view of different domains of the industry and build a comprehensive and systematic framework of all needed skills, is crucial for the student's long-term career development. However, the current construction education does not guarantee students' capability to transfer the learned concepts to practical applications.

Educators consider engaged learning in different ways. One way is actively involving students in course content. Another way is engaging a student with a direct experience of a field problem related to the subject content. Bowen defines student engagement through a variety of real-world contexts such as social, cultural, and civic nature (Bowen 2005). Young's research supports faculty including engagement when developing instructional components (2010). Young further describes a classroom environment including factors such as the ways materials are presented, learning activities used in the classroom, as well as the feedback given to the students (2020). Bowen indicated four different curricular engagement sources, namely the learning process, subject matter of study, the context, and the human condition (2005). Kolb classified "engagement with the subject matter of study" as experiential learning in which students learn by engaging themselves in the field case studies or laboratory experiences, or computer simulations (1984). This engagement stimulates student learning through an intervention based on real-world experience. Wright indicates these interventions can take place with minimal logistic constraints when applied short term (Wright 2000).

One of the leading and well-researched models for EL is Kolb's Experiential Learning Cycle (1984). The application of Kolb's Experiential Learning Theory, consisting of a four-stage cycle (experiencing, reflecting, thinking, and acting), is widely popular in many fields of study such as nursing and teaching (Kolb and Kolb 2018). Figure 1 below references Kolb's cycle, which is the basis for the experiential learning that will be offered as a result of this project. Kolb briefly defined the terms within the cycle as follows:

- Concrete Experience - This refers to a new experience or situation being encountered, such as a site visit or a situation students have not encountered. It can also represent the re-interpretation of an existing experience.
- Reflective Observation - This is a review of any inconsistencies and their importance between the experience mentioned above and any previous understanding a student had of the subject.
- Abstract Conceptualization - A reflection that gives rise to a new idea or allows the modification of an existing concept that is abstract. This essentially states that the student has learned something new from their experience.
- Active Experimentation - The learner, or student, now applies their idea to the world around them to see what happens. Essentially, the students take what they have learned and apply it to an experiment.

Research has suggested that time spent in the field helps in developing more robust mental models of construction managers (Mukherjee, Rojas, and Winn 2005). Thus, this project aims to expand extensively those practical field-based experiential learning opportunities for students throughout the program.

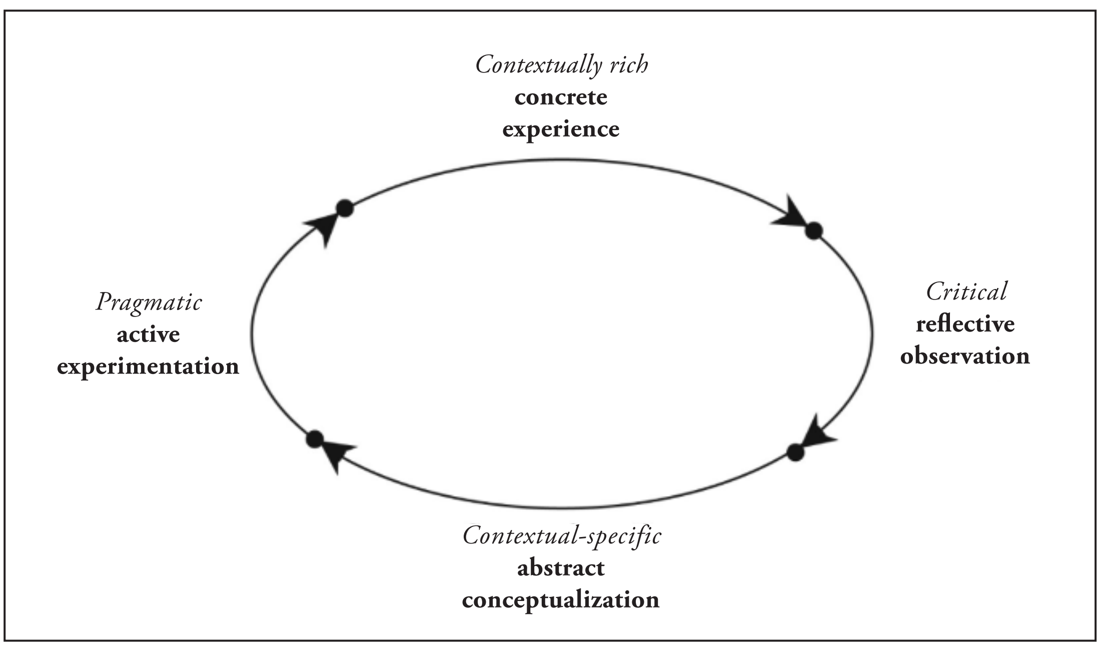

Figure 1. Modified Kolb's experiential learning cycle (Morris 2020).

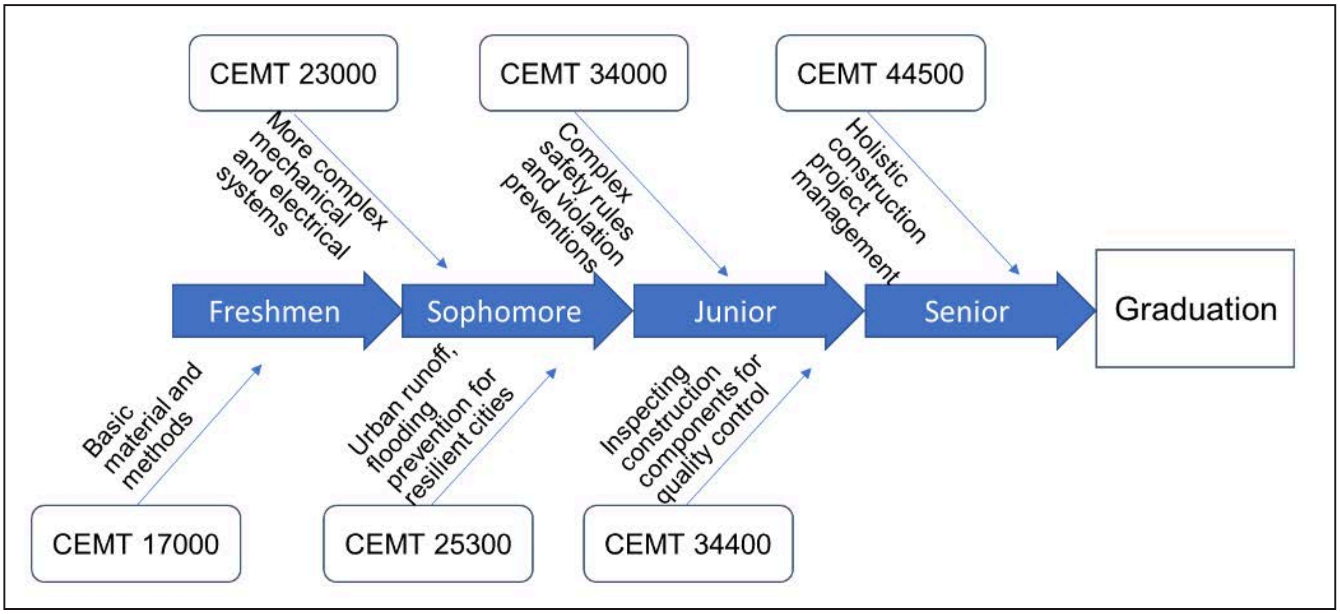

Figure 2. Fishbone cause-and-effect strategy for course selection.

Adding these EL components will provide a more holistic view of learning from a specialized knowledge into a more sophisticated and integrated form of learning (Mainemelis, Boyatzis, and Kolb 2002). The overall objective of this project is to offer students opportunities to learn in the field and to align student learning outcomes to these experiences. The project team will implement specific activities to assure the objective is met. These steps include (a) implementing and validating the proposed EL framework of short-term EL activities in regular classes for enhancing student learning, and (b) embedding EL components in Construction courses (first year through the fourth year) by engaging industry professionals in the classroom and field, and (c) examining the effectiveness of the engaged learning.

PNW currently offers experiential learning courses with EL components. Every program at PNW is required to offer a minimum of three credit hours of experiential learning. In the CEMT program, two higher-level courses are designated and currently offered as experiential learning courses. The proposed new implementation involves integrating the EL components vertically at different levels as shown in Figure 2. Five regular courses, ranging from freshman level to senior level, will be modified with EL components. One existing EL course (CEMT 34400) will also be included in this project with revision to the evaluation implementation. The instructor will work closely with construction industry professionals to implement each EL component uniquely based on the course needs.

For each course, an evaluation will be performed to assess the benefits of engaged experiential learning. Fishbone cause and effect strategy (Figure 2) will be used in this project to clearly define the focus and the direction of the project implementation to achieve student learning outcomes. Progressive learning from the first year to the final year of students' college careers will also be evaluated summatively. Based on the data collected and interviews, a review of selected courses and their EL components will be performed, and appropriate further modifications are carried out.

2.1 EL Module Framework

The theoretical foundation of this proposed pedagogical system is Kolb's experiential learning cycle (Figure 1). In this project, courses were selected at each level of the undergraduate construction program to integrate the EL component into the course contents. Most of these are common core courses in construction programs in many universities. For each course, the PIs will partner with industry professionals to identify a set of activities that will provide engaged learning including concrete experience, reflective observation, abstract conceptualization, and active experimentation. The hypothesis of the overall project is the proposed framework of EL modules will advance the students in the abilities of 1) demonstrating application of content knowledge in field settings, 2) solving complex problems using higher order thinking, 3) composing professional communication, 4) applying effective aspects of teamwork during group projects, and 5) observing and reflect effectively on field experiences.

2.2 Module Design

The design of EL modules will include the following elements. First, the instructor will work with the professional to identify an EL project topic for the specific course content. In addition, the industrial professional will provide data from state-of-the-art real-world construction projects. The instructor will then design course-specific objectives and tasks for each module in such a way that the students need to use knowledge or skills outside the scope of delivered lectures. In addition, the method to bridge the knowledge is not unique; the students can search for the needed knowledge online or connect with other industry professionals on their own behalf. The rationale for doing so is that the students are forced to develop self-directed learning and develop the ability of professional communication to bridge the knowledge gap in finishing the tasks in EL modules.

2.3 EL Module Implementation

The implementation of the EL module is oriented to reduce the workload of industrial professionals. Therefore, modules have been pre-designed to minimize the time commitment of the project industrial partners. Construction industry professionals typically have very tight schedules due to multiple projects and impending deadlines. Time commitment to the EL module has been considered and designed to not be a barrier to industry professional participation. During a typical fall or spring semester, an industry professional will engage in an EL module four times, not including time spent preparing the data used in the module. Before the semester starts, the instructor will need to have a one-hour planning meeting with the industrial professional to discuss any changes needed for the previous year's module. Specifically, the industrial professional is responsible for updating the technical details and data from construction projects that are used in the EL module according to state of the art.

3. Evaluation

The evaluation will be guided by a conceptual model based on elements of quality for evaluation approaches (American Evaluation Association 1995) that are consistent with guidance provided by the Common Guidelines for Education Research and Development (Institute of Education Sciences 2013). Ongoing, external, iterative, critical oversight will integrate the following components: implementation monitoring of programmatic and research activities; provision of timely, periodic feedback to inform the improvement of those activities; and summative reviews of the goals and quality of the work near its completion.

The evaluation data collection will include these steps: (1) document and report reviews to systematically assess the project planning and development process(es); (2) review research data collection tools and provide feedback, (3) develop and administer surveys and conduct interviews with students, the PI, Co-PI, and other pertinent project staff and research team members; and (4) develop pre- and post-question sets for different courses and implement them in proper time slots during coursework (5) compare pre and post-tests and evaluate the improvements, and (6) attend project meetings. Throughout the project, the project evaluator will compare the work-as-planned with the work-as-implemented across the grant years to determine the extent to which activities were planned and completed and expected outcomes were achieved.

4. Conclusion

The proposed project will benefit industries by cultivating a better-prepared workforce. These EL components will be developed and delivered by PNW to its Northwest Indiana and the greater Chicago area industrial partners. Development and implementation of the EL framework of this project will also help educational institutions such as PNW to have closer interaction with industry as well as with local agencies. Students will have on-site training and be more prepared to become valuable and contributing members in their field. This effort will help underperforming students to become more engaged in learning, leading to retention and a higher graduation rate. Students will benefit as they will be able to identify an area of career interest within the construction industry. The new EL initiation also brings robust field exposure in different courses beyond the selective and project-specific internship.

This method of teaching in construction can be easily adapted by other institutions to deliver their construction-related discipline by incorporating EL at each level within their program. The framework laid out in this proposal is easily transferable to other institutions and programs seeking a similar experience for students. The main effort comes in flexibility and connectivity: the flexibility to alter predominantly outdated traditional teaching methods, and connectivity to industry to introduce and assist with helpful topics and projects. This framework will appeal to younger generations and help transform the learning of construction topics more effectively. The documented results of the evaluation from this project will provide a clear guideline to easily transfer and replicate the proposed approach in other programs at other institutions.

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Measuring the Impact of Newly Developed Open Edcational Resources (OER) Materials of CAD Courses Using Mixed Method Analysis

Mohammad Moin Uddin, Keith V. Johnson and Leendert Craig

Abstract

This study describes the development of open educational resources (OER) course materials for three computer-aided design (CAD) courses and the evaluation of student and faculty perceptions after their first implementation. We used mixed-method research techniques which involved analysis of quantitative data, utilization of COUP (cost, outcomes, usage, and perception) framework and analysis of qualitative comments using thematic coding. Results suggest students find faculty developed OER materials are more useful and preferable to a traditional textbook without compromising student academic performance. Most students agreed or strongly agreed that the materials provided fair treatment, access, opportunity, and advancement for all students. Assessment of faculty data showed that faculty have positive views of OER, their accessibility, customization, and equity measures, and reported increased student engagement when using OER. Faculty also indicated challenges with OER such as time and effort required to create OER contents and the need for periodic update of dynamic courses like CAD as technology and industry needs change. Several recommendations are provided in support of OER for academic effectiveness and student success.

1. Introduction

Design is an integral part of engineering innovation. To prepare students, all Engineering/Engineering Technology (E/ET) curricula focus on engineering design and design thinking so that students can actively design, model, simulate, and analyze solutions of engineering problems. Computer-aided design (CAD) is a popular and often required course in E/ET curricula that introduces students to engineering design. A typical CAD course utilizes CAD software (e.g., AutoCAD products) and trains students in 2D drawings and 3D models with precise measurements. There is an abundance of course materials to train students in CAD. However, most of the CAD textbooks and instruction materials are expensive. A recent report shows that over the last decade the price of college textbooks has soared. Since 2006, the cost of a college textbook increased by 73%–four times the rate of inflation (Bureau of Labor Statistics 2016). Today, individual textbooks often cost over $200, sometimes as high as $400.

A report from the U.S. Public Interest Research Group has shown that 66% of students tend to skip buying or renting college course materials altogether, with 63% skipping textbook purchasing specifically because of the high cost of textbooks (Vitez and Nagle 2021). Faculty also recognize that student costs are a significant barrier to success (Seaman and Seaman 2020). Furthermore, publisher-determined content may not be current and personalized to foster student engagement in a changing technology environment (Jaggars, Rivera, and Akani 2019).

To promote textbook affordability, open educational resources (OER) have recently entered the textbook market. OERs are any type of educational materials that are in the public domain or introduced with an open publishing license (OER Commons n.d.). Note that online contents (such as YouTube) without open publishing license and digital subscriptions (such as eTextbook) are not considered as OER. Besides textbooks, OERs include resources such as course assignments, tests, lecture notes, syllabi, videos, review materials, etc. Anyone can legally copy, use, adapt, remix, and reshare such resources. Thus, opensource textbooks can be adapted to fit an instructor's version of the course, and OER can be incorporated in such adaptations. Even though in recent years the supply of open textbooks and course materials grew significantly, there is a lack of OER course materials for ET programs, especially for CAD courses. A search of keywords "Computer Aided Drafting and Design; CAD; CADD; Drafting" on OER Commons, BCcampus, Open Textbook Library and Merlot resulted in only 0, 3, 0 and 0 open-source textbooks, respectively. Besides limited availability, due to changes in CAD technologies and industry needs, most contents are outdated which significantly reduced their usability. This lack of OER CAD materials often force faculty to rely on expensive publisher textbooks and pass the cost of the textbook to the students.

East Tennessee State university (ETSU) is the home of a diverse student population. 18% of ETSU students are African American, Hispanics, Asian or other races (ETSU Fact Book n.d.). Moreover, at ETSU, 6% of students are identified as individuals with disabilities, 5% are traditionally underrepresented gender, and there are large numbers of adult learners and veterans. More than half of ETSU students, especially underrepresented students, come from low-income families. These student populations face a tremendous financial burden for their education and often have unmet financial need in terms of textbook costs and course material fees. In Fall 2019, 88% of underrepresented students had unmet financial need greater than $500. Due to the prevalence of unmet need, the Summer Bridge Plus Program provided 50 $500 book scholarships to all of the program's participants. Based on evaluations, many of the students indicated they would not have been able to afford their required textbooks if they did not receive this assistance. Based on our experience, many students go without their required textbooks each semester for financial purposes.

This article describes redesigning and teaching three E/ET CAD courses with OER materials and their impacts on student learning. The instructors who taught the courses participated in developing the OER course materials. All three OER supported courses were first taught in Spring 2023. At the end of the semester, two surveys were administered: one for students and one for the instructor, to measure student learning experience, access, usage, outcome, and instructor pedagogical impacts. We used mixed-method research techniques that involved analysis of quantitative data, utilization of COUP (cost, outcomes, usage, and perception) framework and analysis of qualitative comments. We also compared drop, withdrawal, and fail (DWF) grades. Results show use of OER course materials eliminated the cost and access barrier on the first day of the class, leveling the playing field for all students. OER CAD courses sent a positive message to the students that the professors care about them, understand their financial burden, want them to succeed in the class, stay enrolled, and graduate.

2. Existing Literatures

OER history dates to 1994, when an NSF grant led by James Spohrer resulted in the creation MERLOT to identify and provide access to mostly free, online curriculum materials for higher education (Bliss and Smith 2017). Rice University's Connecxions (now OpenStax) and MIT's OpenCourseWare project were the first two recognized OER projects, though the open education movement predates this event with roots in open source, open and distance learning, and open knowledge. David Wiley coined the term "open content" in 1998, and OER was first used at UNESCO's 2002 Forum on the Impact of Open Courseware for Higher Education in Developing Countries (Wikibooks 2021). Since early 2000, OER initiatives grew tremendously as school districts, colleges and universities, state education boards, leaders, and policy makers embraced the use of OER across the country.

Many studies demonstrated that high quality OER can lead to significant financial benefits for students and/or institutions, as well as reduce the potential of financial burden of college education (Zaback 2022; Watson, Domizi, and Clouser 2017; Fischer et al. 2015; Farrow et al. 2015). As the open-education movement has matured, literature shows OER can improve student outcomes beyond student cost savings when well planned and executed. For example, implementation of OER courses resulted in significant differences in academic performance: higher final grade and lower DFW grades (Colvard, Watson, and Park 2018; Ashford 2018); OER is more readily accessible to students, and research has shown it can lead to increased student engagement (Chang 2020) and improved student outcomes (Griffiths et al. 2020; Shenoda 2020). In terms of quality, most teachers and students perceive OERs as the same quality as traditional textbooks or in some cases, the OERs are perceived to have better quality than their standardized counterparts (Seaman and Seaman 2022). OER closes equity gaps because it provides students who cannot afford required course materials access to the resources they need (Nusbaum, Cuttler and Swindell 2020; Grimaldi et al. 2019; DeRosa and Robison 2017). Additionally, OER can improve faculty engagement, support better pedagogy, and enable more culturally relevant learning materials (Sergiadis and Smith 2022; Griggs and Jackson 2017; Ozdemir and Hendricks 2017).

Despite these benefits, there is a lack of OER textbooks and course contents for E/ET programs. A search on the eight major OER repositories (Open Textbook Library, OER Commons, Openstax, Merlot, BCcampus, LibreTexts, Teaching Commons, and SUNY) resulted in only half having engineering subjects, and E/ET textbooks and course contents account for less than 1% of all OER materials available in those repositories. The authors identified only three OER CAD textbooks available online for download; however, due to dynamic changes in CAD tools, technologies, and industry trends, most of the contents were outdated. CAD is one of the E/ET courses that requires frequently updating contents, which made it more challenging to the instructors compared to other E/ET courses. Besides availability, instructors place a great deal of value on the perceived quality of the textbook, which is, in turn, often influenced by colleague recommendations, knowledge, and experience with OER materials, and the existence of rigorous peer review (Jung, Bauer, and Heaps 2017). If an instructor perceives the existing OER contents are poor quality and outdated, for the sake of student learning, they will naturally be more inclined to use publisher textbooks, which seems to be the case for CAD courses in E/ET programs. It is true that developing OER course materials requires time and effort, but if an instructor invests the time and effort to review materials and customize them for a course learning outcome, an OER will inherently not lack in quality or content (Cozart, Horan, and Frome 2021).

Considering the above-mentioned challenges, this article investigated the effectiveness of the three newly developed OER CAD courses using mixed method analysis. E/ET faculty would benefit from the understanding and awareness of OER, the need for OER contents in E/ET programs, and the opportunities it offers toward student learning and pedagogical transformation in E/ET education. The results contribute to the body of knowledge on the understanding of the values of OER and outcomes that can be achieved relative to student success.

3. CAD Courses

The Department of Engineering, Engineering Technology and Surveying at ETSU offers four BS in Engineering Technology degrees in Biomedical, Construction, Electrical and Electronics, and Manufacturing. The Department also offers one BS in Engineering in collaboration with Tennessee Tech University (TTU). For each program, a CAD course is required. The department offers three CAD courses. ENTC 2170, Computer-Aided Drafting and Design, focuses on concepts and skills needed to sketch and create 2-D drawings and 3-D CAD models. The course is required for manufacturing, industrial, electronics and biomedical majors. ENGR 1110, Engineering Graphics, is required for the TTU-ETSU Joint Engineering program. The course focuses on training students in learning the techniques and standards of graphical communications so that design ideas can be clearly communicated and produced. ENTC 2160, Architectural CAD, is required for construction majors. The course trains students how to prepare formal drawings by providing students with basic guidelines for drafting layout, minimum design and code requirements in a knowledge-building format. The concepts and skills learned from the course allow students to prepare complete sets of working drawings for residential and light commercial construction projects.

Although objectives of the three targeted courses vary slightly, course contents, tools, and software used for these are mostly similar. The primary reason for selecting these three courses is because of the similarity of course contents. Basic drawing techniques, sketching, sections and views, dimensioning and tolerance practices, 2-D and 3-D modeling techniques are the same for the courses. Once students master these basic skills, they can apply them to create architectural, construction and mechanical drawings in their areas of specialization. Efforts to create OER for all three courses will offer synergy for the instructors and non-differentiated impact on student success. The second reason is the limited availability of open-source CAD course materials, which are mostly outdated. Lastly, these three courses accumulate one of the largest enrollments in the department. Converting these courses to OER courses will result in the largest financial benefits to the students.

4. Development of OER Materials for CAD Courses

We utilized a team-based approach to create OER materials for the CAD courses. We also involved the Office of OER Program (OERP) for guidance and support from the very beginning of this project. The team met bi-weekly over the summer and the fall semester of 2022 to identify, organize, discuss, and develop OER materials. CAD is a required course for E/ET programs all over the world. As such, abundant course contents such as textbooks, videos, and software are available. However, most of them are commercial, publisher content and expensive. In recent years, some opensource CAD course materials and videos have been created, and the authors reviewed those materials, finding that the use and applications of those open-source materials are very limited for our content and context. Therefore, we decided to create our own materials and license them by creative commons (CC BY). Since CAD contents require frequent update, we abandoned the idea of creating a textbook.

Instead, we took a modular approach. We divided the CAD courses into topics and for each topic we developed short PowerPoint presentations, handouts, and demonstration videos to facilitate periodic and easier content updates. All three faculty invested time and effort over the summer and fall of 2022 to create the OER course materials for the courses, developing a OneDrive site to post the newly created materials. The team reviewed one another's materials and provided feedback for improvement. This team-based review process helped faculty to include diverse contents that cover a broad range of applications in E/ET programs. The OERP provided constant support to ensure that the materials meet OER guidelines and creative commons licensing requirements. Once materials were finalized and licensed, the OERP posted the materials on the ETSU's Digital Commons website.

5. Methods

The main goal of this study is to measure the impact of implementing CAD OER materials using mixed method techniques. To achieve it, we requested that the OERP at ETSU to develop and administer survey instruments. The office has the resources and expertise to offer such a service.

Another reason was to avoid bias and conflict in data collection. The office developed two surveys (one for students and one for instructors) as a method to collect student and faculty experiences with the CAD OER materials. Conducting surveys was cost effective and an easy and reliable mechanism to quickly capture a large number of student and faculty perceptions. The surveys were adapted from Bliss et al. (2013) with additional questions about equity and inclusion.

5.1 Survey Instrument

The student survey had 36 questions divided into three sections. The first section focused on textbook cost and students' habits of purchasing textbooks, which provided a baseline for comparison. Section two focused on student usage of CAD OER materials, quality of materials, accessibility, diverse contents, and student perception of learning outcomes. The last section asked for demographic information. The faculty survey had 26 questions. They were focused on time and effort to develop CAD OER materials, quality, and usage of OER materials, diverse contents and factors that may help or hinder future OER implementation. ETSU's Institutional Review Board approved the study after an expedited review (IRB Number: c0223.4swd-ETSU). A copy of the surveys was added in the supporting document section.

5.2 Distribution of the Survey

Prior to distributing the student survey, the OER coordinator requested instructors to indicate the best mode to distribute the survey to their individual classes: paper survey distributed in person during class, and/or online survey forwarded by the instructors through email or course site. If the instructor chose an in-class survey, the OER Coordinator distributed the survey in our class(es) during the first three weeks of April for the spring 2023 classes. Once the survey was distributed in class, instructors could provide a link to the online survey for the students who missed class. If the instructor chose to forward the online survey, the OER coordinator provided the survey information during the first week of April for the spring 2023 courses. The survey was left open until the end of the spring semester, and several reminders were sent to students to complete the online survey. The OER coordinator distributed the faculty survey online through email during the third week of April to all the CAD instructors, with a mid-May deadline to complete it. All instructors permitted us to use their responses for research. The online surveys for students and instructors were distributed using Research Electronic Data Capture (REDCap), and a student assistant entered responses from paper surveys into REDCap.

5.3 Data Analysis

A total of 33 students (84.6%) and all three faculty (100%) completed the survey. The two incomplete student surveys were excluded from this analysis. There were few open-ended questions, and we received a small number of comments which were analyzed through qualitative content analysis using thematic coding. Anonymous quotes were chosen to illustrate specifics.

5.4 Demographic of Student and Faculty Surveys

Most of the students who completed the survey identified as White (75%), followed by Black or African American, Hispanic or Latino, and Native American or Pacific Islander (Figure 1). 77.4% of students identified as males, 19.4 % as females, and 3.2% as other genders. About one third (29%) identified as first-generation college students. The majority of students stated that they are freshman (61.3%), followed by sophomore (19.4%). Students tended to be full-time students (90.3%) and the majority worked either part-time (58.1%) or full-time (12.8%). 87.2% of respondents stated that they received some form of financial aid (e.g., loans, grants, work-study, scholarships, etc.) for their college education.

For the faculty survey, there were three total responses. Faculty had an average of 12 years of experience teaching at the college level, and all of the instructors had previously taught the courses in which they were implementing OER. All three faculty were male. One faculty member identified as White, one Black or African American, and one Asian.

6. Results

The results of this study were derived from the

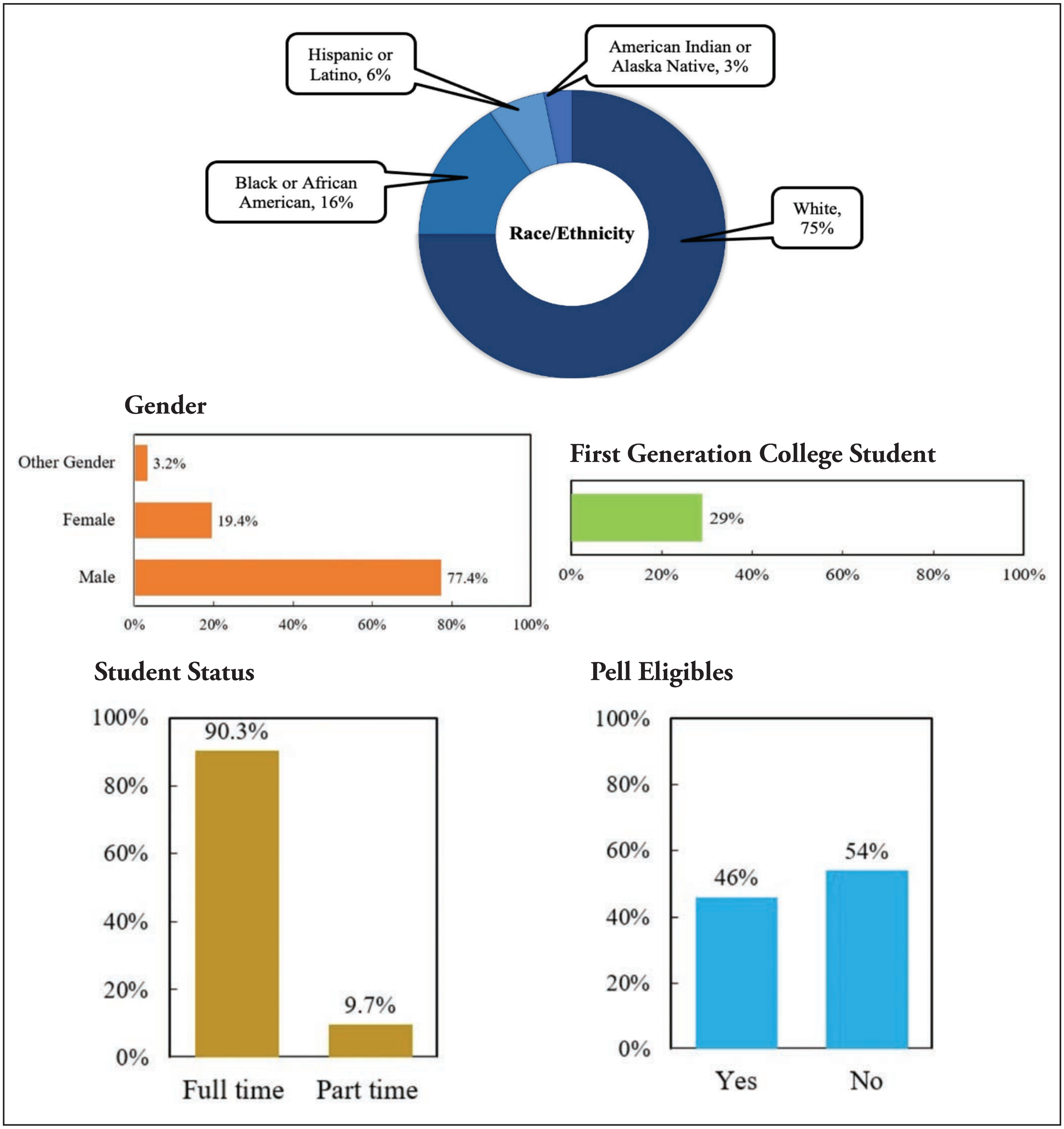

Figure 1. Student demographic information.

student and faculty surveys. Student data were analyzed using the COUP framework. Developed by the Open Education Group, COUP is a widely used framework to study the impact of OER and open pedagogy in secondary and post- secondary education (Open Education Group n.d.; Hilton III et al. 2013; Magro and Tabaei 2020; Cozart, Horan, and Frome 2021; Sergiadis and Smith 2022). For faculty surveys, we analyzed and coded faculty responses into three distinct themes: 1) course preparation, 2) diversity of content, and 3) pedagogical changes and impact. Results were summarized using descriptive statistics only. The high response rates in this study infer strong conclusions.

6.1 Cost Savings

The three OER-based CAD courses saved students an average of $71 (weighted average) in the spring of 2023 when the instructors implemented them for the first time. This is a reasonable estimate as 87% of the students mentioned they always, often, or half the time purchased the required textbook in a semester (Figure 2). Student cost savings will increase as the instructors continue to offer the OER-based CAD courses every semester. 45% of the students who rarely or never purchased the textbook mentioned that it was the high cost of the book that prevented them from purchasing it.

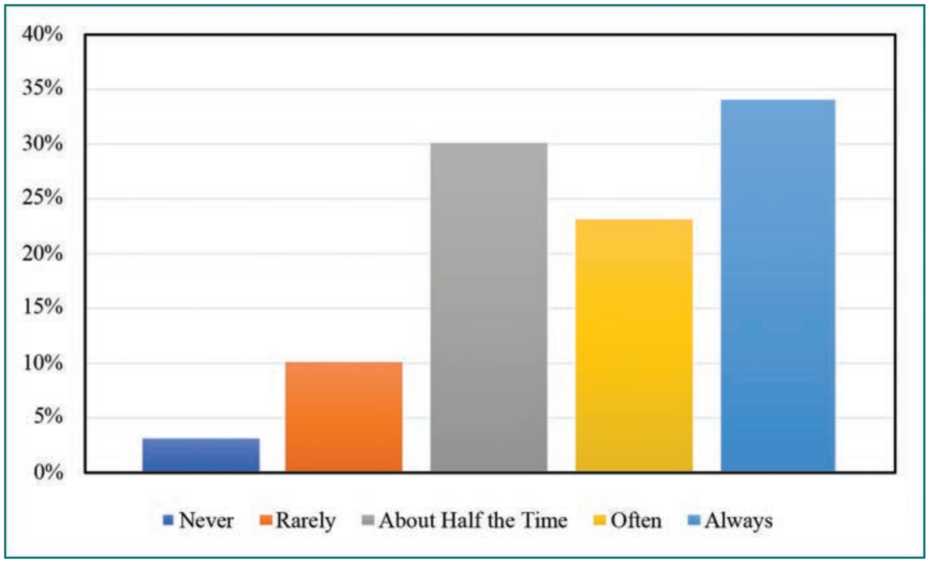

Figure 2. Students' required textbooks buying habit for the courses in a typical semester.

6.2 Outcomes

To measure student outcomes and success, we compared CAD course grades of Spring 2023 to those of Spring 2019. We divided the grades into two buckets: A to C, and drop, and DFW. As shown in Table 1, student grades A to C increased 47% and DFW rates decreased 60%. The grades aligned with the instructors' perception of student preparedness. All faculty members thought that their students were equally or more prepared.

Many factors may have contributed to student success. First, availability of the materials 24/7 made it easier for the students to check the materials and use them when doing assignments or preparing for the exam. Second, faculty members had more time during class to engage students in learning and support them. These engagement activities kept students motivated and helped them gradually build their skills and knowledge to be successful in the course. The decrease in DFW rate can be attributed to pedagogical transformations that CAD OER offered. Faculty members enjoyed more freedom in selecting course materials and could customize these materials to fit the specific needs of their students and goals of their classes. Use of free and open course materials send a positive signal to the student that the professor and the university care about them—view them as people with tight budgets, jobs, and families—and want them to succeed in the class. Increasing access and fostering a greater sense of belonging makes students want to stay enrolled and graduate.

6.3 Usage and Accessibility of the CAD Course Materials

The survey explored how often students reported using the CAD OER materials versus their reported use of course materials in general. It was found that

Table 1. Assessment of Student Success.

	Student Outcome and Success					
	Spring 2019 (Non-OER)			Spring 2023 (OER)		
	Enrollment	Grades A to C	DFW	Enrollment	Grades A to C	DFW
ENGR 1110, ENTC 2160 and ENTC 2170	44	55.75%	44.25%	39	82.05%	17.95%

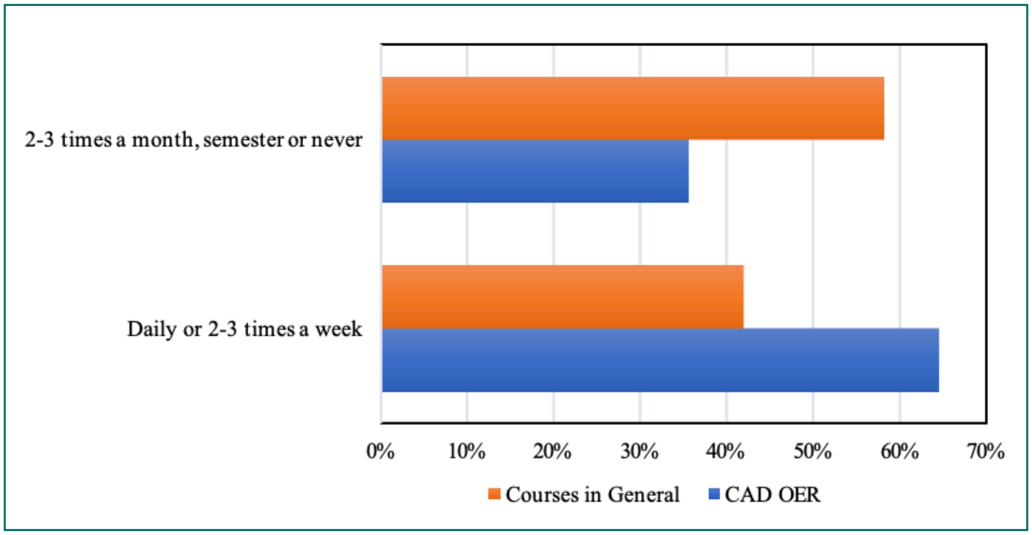

Figure 3. Comparison of student usage of CAD OER materials.

students used CAD OER materials more often than other non-OER courses (Figure 3).

In addition, more than 95% of students mentioned no accessibility issues with the course materials. Some student comments were "Material is easy to navigate and easy to access"; "The AutoCAD software is readily available for use in many computer labs, and for download to personal computers. Digital commons is also free to navigate"; "Just a quick look up on ETSU digital commons/D2L and you can find it from there." Students also mentioned several challenges: "The apps we use are difficult to learn at first but easy once you understand them"; "It was there for free, but the website was slightly confusing until I got used to it."

During the development of course materials, the faculty members evaluated them using a DEI (diversity, equity, and inclusion) lens to ensure the course represents diverse range of views, perspectives, and systems in an affirming, positive way. Providing all students with access to course materials on the first day of class served to level the academic playing field in course settings. Over 90% of students agreed or strongly agreed that the materials provided fair treatment, access, opportunity, and advancement for all students (Figure 4). Faculty members believe that it provided more engagement opportunities during class time.

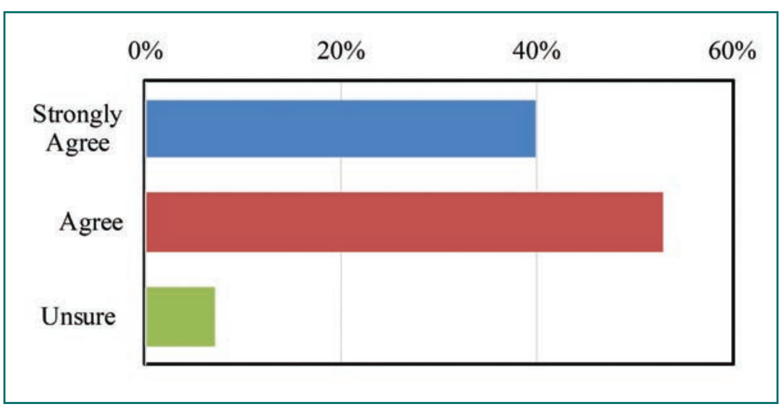

Figure 4. Student opinion of the course materials provided fair treatment, access, opportunity, and advancement for all students.

7. Student Perceptions of OER CAD Course Materials

7.1 Quality of OER Materials

Overall, students' perceptions of newly developed open and affordable CAD materials was positive. All students mentioned that the OER materials were the same as or better than the quality of the texts in their other courses (Figure 5). This finding aligns with prior studies on students' perception of OER and indicates that students find open resources as good or better than commercial textbooks (Sergiadis and Smith 2022; Colvard, Watson, and Park 2018; J. Hilton III 2020).

The students also commented on what they liked about the OER materials. It was no surprise that most students appreciated that the course materials were free. The students also mentioned that they liked the usability and/or accessibility of the materials since they were freely available through ETSU Digital Commons. Students commented that the content was high quality, specifically that they were digestible or easy to understand and learn. One student mentioned "clear, concise, easy to access materials, making it an easier learning curve." Students mentioned the benefits of the materials' medium (lecture videos and demonstration videos) other than texts. One student stated "Videos helped walk through assignments. I didn't really use the PowerPoints, but I'm sure they'd be useful for those who learn via reading." In fact, most students believed that the new CAD course materials helped them study more effectively (Figure 6)

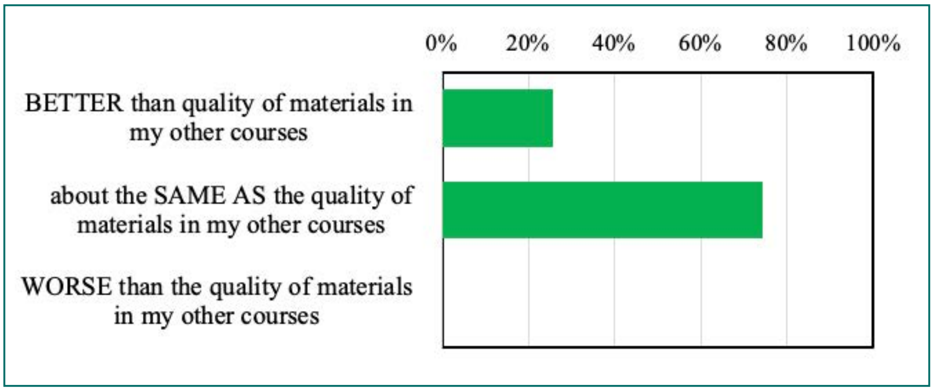

Figure 5. Quality of CAD OER materials.

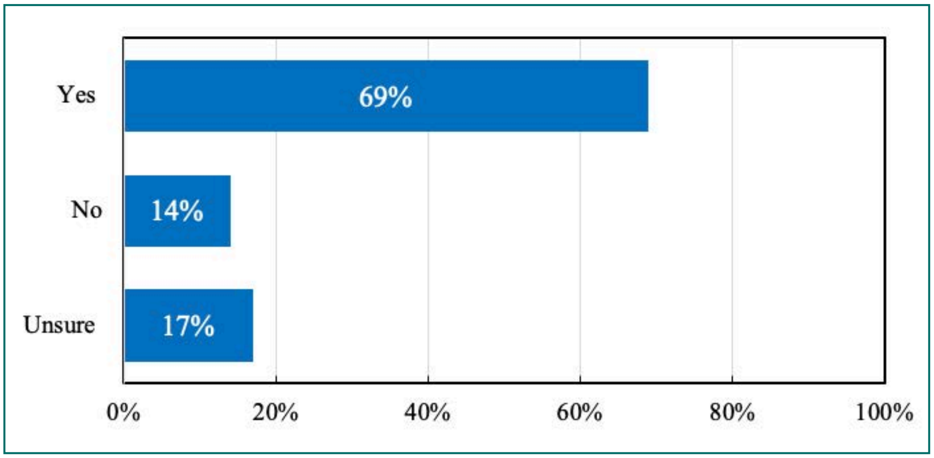

Figure 6. Student opinion of whether the materials in this course helped them to study more effectively.

7.2 Diverse/Relevant Contents

Publisher textbook contents can occur from the time the book is written to when it is published and distributed. This can be a significant issue in technical fields where technological innovation and trends change rapidly. Students are less likely to engage with materials that they find outdated and irrelevant. However, materials that are more current and personalized for a course can foster an increase in student engagement, ultimately leading to higher course grades and greater student retention (Lee, Pate, and Cozart 2015). In the survey most of the students (41%) agreed the materials in this course represented a diverse range of views, entities, and systems in an affirming, positive way (Figure 7). However, the student responses were mixed. More than 40% of students disagreed or were unsure. Few students defended their responses by

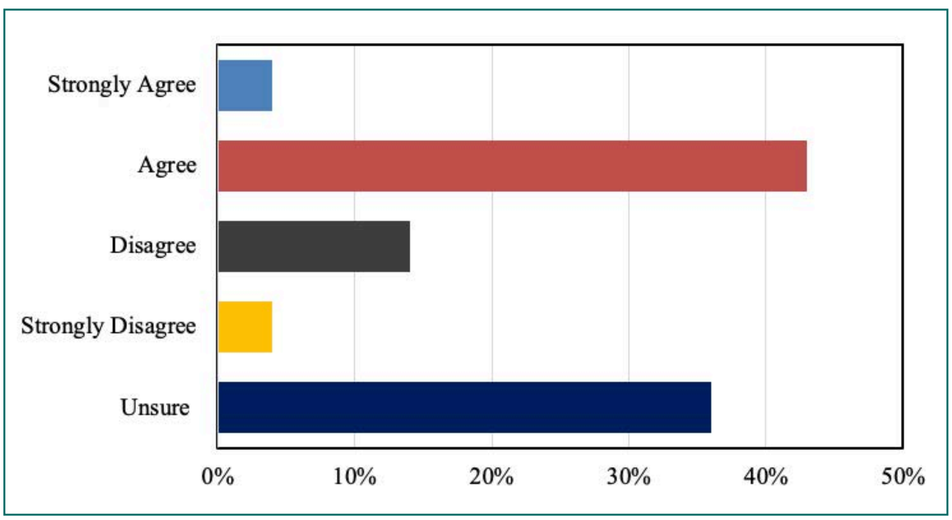

Figure 7. Student opinion of the materials in this course representing diverse range of views, identities, entities and systems in an affirming, positive way.

mentioning that CAD is technical and there can be less opportunity or need the content to be diverse and inclusive (as it may be warranted for general education and other social sciences). Students mentioned if the contents are current and represent diverse aspects within the technical fields, they are satisfied with the course contents.

7.3 Value beyond Cost

It seems the benefits of the OER course have a lasting positive impact on students, as they mentioned overwhelmingly that they were very likely to register for future courses with open and affordable materials (Figure 8). The three faculty are committed to continue using OER materials in the CAD courses as well as other courses that they teach. This indicates potential future behavioral changes that would increase the implementation and usage of open and affordable materials beyond the scope of the CAD course.

8. Impact on Faculty Teaching

8.1 Course Preparation

Two of the three faculty mentioned that they spend more time locating, selecting, customizing, making accessible, and/or creating open and affordable materials in comparison to courses that were not OER (Figure 9). All three faculty previously used publisher textbooks and copyrighted materials in their courses. Faculty mentioned their experiences teaching CAD courses for a long time was beneficial, but still they had to invest significant time and effort creating new OER materials with high quality. OER CAD courses required creating new drawings, which was also time consuming. Even though the OER approach required faculty to have more time to prepare for that particular semester, all of the faculty mentioned it was worth the time and the investment. As one faculty stated "Students seem to really liked the new OER CAD materials. It provided a more in-depth knowledge base for them to use which is more aligned with the lessons and course outcomes."

8.2 Diverse/Relevant Content

Faculty members enjoyed customization of the course materials since they were not restricted by a textbook anymore. All faculty mentioned that they choose more diverse, relevant, and/or current content based on their students' needs. Faculty believe the OER course materials provided more peer learning opportunities and students were involved with creating reusable content for the class, such as projects as examples for future students. Faculty members also believe that the OER CAD materials helped them facilitate an inclusive class environment, where all students felt supported intellectually and academically, and it created a sense of belonging in the classroom regardless of identity, learning preferences, or education.

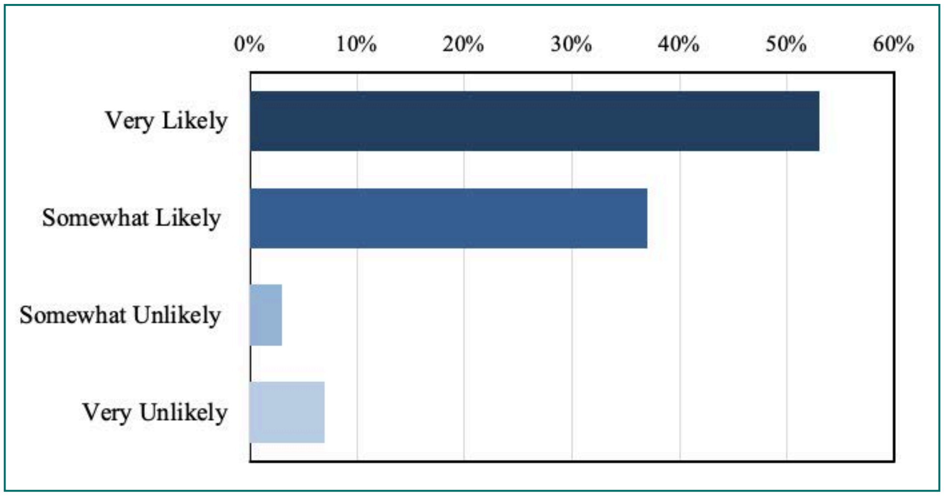

Figure 8. How likely are you to register for a future course with zero or low-cost materials?

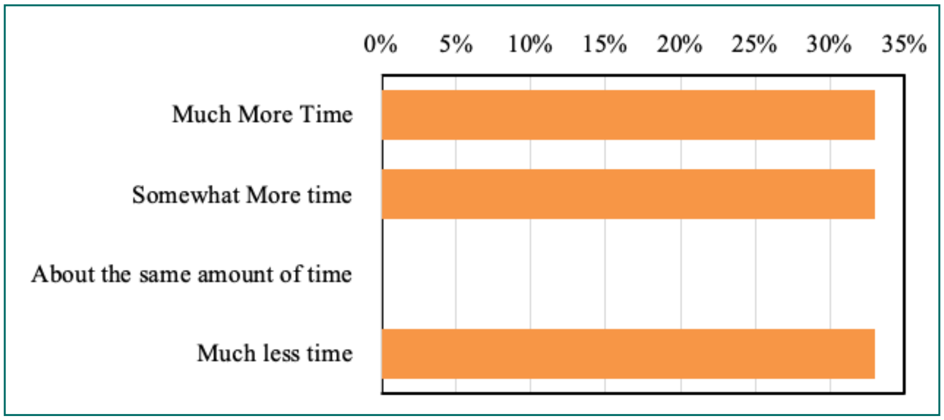

Figure 9. Faculty course development/preparation time.

8.3 Pedagogical Changes and Impact

Faculty mentioned several pedagogical changes with the new OER courses. First, they discussed the experimental nature of the open and affordable materials approach with their students 2-7 times in the semester, which is considered an inclusive teaching practice (transparency). Second, students need practice and hands-on demonstrations to master CAD skills. Having course materials online and easily accessible before the class provided the faculty more time during the class to go over more examples and support students in learning. One faculty member stated, "I spent less time lecturing, because all the materials are available online and easily accessible on multiple platforms. This lessens the need to go over the basics and allow us to spend more time on CAD practices."

Another explained,

"Once the materials are supplied to the students the only preparations needed were occasionally printing out a few handouts. The students had access to the handouts via the internet but the students learned the material more thoroughly when they had a physical copy for reference. The lessons were designed to allow the student to complete most of the work during class time, so we could start a new lesson during each class, which really helped the students stay engaged. I think the students enjoyed the class more, with less stress, and with improved capability of completing the work outside of class time when needed, resulted in the engaged students having desirable outcomes."

Thirdly, all the faculty in the comments indicated that their students were more prepared than previous semesters, which resulted in better student performance. One faculty member noted:

"Typically, several students or more a semester would end up losing points from their final grade because they could not afford the materials required to complete the assignment. That was not an issue this semester. By completion of the semester the students had become competent at the level I was hoping to get them to by the end of the semester, as evidenced by the level of work they performed on the Final exam. I often have students with previous exposure to CAD and 3-D modeling software, having had classes in them somewhere. The students with previous knowledge arrived expecting to be bored because they thought they already knew the material but left feeling they learned plenty of new techniques and the course was worth their time and effort."

And yet another suggested, "Using the OER materials allowed ALL of my students to complete every assignment compared to some of my students not completing some of the assignments because they could not afford the required materials."

Faculty also mentioned a few challenges that would prevent them using OER in future. First, the need for periodic update of the OER CAD contents: "The coursework is a moving target. The software is updated regularly, so the lessons must adapt to the changes in software, or they become outdated. As long as we can keep up with the updates, I would prefer to continue to use it." Second, textbook publishers provide support for faculty with free textbook copies, presentation materials, test banks, etc. With OER, faculty are on their own. Faculty mentioned they would need recurring support from the department and the university to sustain and enhance OER materials. Third, developing OER is a time-consuming process. Faculty mentioned without appropriate reward, recognition, and credits toward their academic goals (such as tenure and promotion), they would be cautious to expand OER in their other courses. Nonetheless, OER has the potential of delivering course content effectively online when an on-ground delivery option is not available.

9. Conclusion

This study examined the academic outcomes and perceptions of students with three newly redesigned CAD courses with OER materials, as well as the pedagogical impacts of the faculty members who taught those courses. The most obvious outcome of switching the required courses materials to OER is cost savings (an average of $71 per student in Spring 2023 semester). Findings also indicate higher passing grades and fewer DFW grades with the OER courses. Analysis of data demonstrated that students perceive OER positively when judging its quality, format, and use. Faculty also had a positive experience with OER, acknowledging that working as a team and collaboration with OERP from the very beginning were critical steps in successfully developing the CAD content and making it available to students in a structured way. To reduce the students' financial burdens and to improve the values of postsecondary education, E/ET faculty can use the findings of this study to justify continuing OER creation. With easy access of OER contents–print or online, anywhere, anytime–OER provides flexibility for faculty to easy transition of a course from in-person to online and vice versa. By developing more quality OER courses, E/ET faculty can contribute to a more equitable and accessible education for all learners.

10. Recommendations

The authors learned valuable lessons during their OER journey. We have the following recommendations for E/ET faculty, university administrators, and researchers:

1. It is true OER content development requires a large time commitment. However, benefits in terms of cost savings, student learning, retention, and graduation outweigh the time and effort. So, it is the authors' opinion that the benefits outweigh the effort in the developing OER materials, given their limited supply for E/ET programs.
2. Going through copyright laws, availability of open-source tools and technologies, different licensing methods, and publishing materials have been identified as major barriers for faculty in their OER journey. To make it easier, faculty should collaborate with OER support groups in their respective libraries when considering developing these materials. Support groups can help faculty with identifying, compiling, reviewing, copyright and licensing, and publishing OER materials so that faculty can mostly focus on just developing OER materials.
3. High enrollment and multi-section courses are good candidates for OER as they offer the largest benefits of OER implementation. Lessons learned from these courses can help faculty to expand OER to other courses. Whenever possible, a team- based approach will often benefit faculty in producing high quality OER materials.
4. When developing OER materials, faculty should consider course content and educational materials that are culturally responsive, inclusive, focused on equity and social justice to improve student engagement and their academic achievements.
5. Universities should seek to remove barriers and make it easier for faculty to create OER materials by installing adequate OER support systems. Developing an incentive structure such as monetary, recurring support for periodic update of materials, awards, recognition and credits toward tenure and promotion can encourage more faculty to increase OER productivity.

11. Limitations

This study has several limitations. The results are based on data from one semester. As courses are offered in the future with OER materials, better student and faculty perceptions can be expected. In most cases, traditional courses (with required publisher textbooks) have been offered for many years and matured. In comparison, OER courses were offered for the first time, and students and faculty may have had different experiences when comparing their OER experiences with those traditional courses. Results were analyzed based on descriptive statistics since a control group was not identified and no statistical test was conducted. Due to these nuances, future studies may benefit from several years of data from OER courses and a more qualitative approach (e.g., focus groups, interviews) to learn more about student experiences with OER CAD materials.

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Condensed Review on the Chemical Compositions and Transformation Temperatures Characterization in Cu-Al Shape Memory Alloys

Muhammad Muneeb Rasheed, Rana Atta ur Rahman, Shahid Mehmood, Ahmed Saif, Muhammad Usman and Abdul Moiz Rao

Abstract

Smart materials are classified into several types such as piezoelectric materials, shape memory alloys (SMAs), magneto strictive materials, hydrogels, electroactive polymers, and bi-component fibers. SMAs exhibit the shape memory property of returning to their original shape after removing the load, and super elastic or pseudoplastic SMAs exhibit shape recovery behavior without thermal change. Currently, there is an interest in SMAs other than nitinol, such as Fe-SMAs and Cu-SMAs, in achieving shape memory applications due to the high processing cost of nitinol, and Cu-Al SMAs are one of the potential candidates. Alloy composition, manufacturing process, and post-processing are the principal characteristics of an SMA that must be controlled to achieve the mechanical, thermal, and chemical properties, microstructure, phase stability, and their application. Several studies report the fabrication, post-processing, and characterization of Cu-Al SMAs, but there is still a need to determine the methods that control the phase transformation behavior in terms of transformation temperatures to tailor these temperatures in the desired range. It should be noted that the martensitic transformation temperatures are a fundamental design aspect of Cu-Al SMAs, and it is essential to study the behavior of these smart materials particularly for civil and mechanical engineering technology students, as these alloys are promising for several innovative applications.

1. Introduction

The property of memorizing shape makes SMAs superior to various smart materials. Due to this property, these alloys have a wide range of applications, including aerospace, pharmaceuticals, biomedical, medicine, robotics, agriculture, automotive industry, adaptive materials, mechanical, mechatronics, and civil engineering (Dasgupta 2014). Several alloys show shape memory behavior, including nitinol, Fe-SMAs, Cu-SMAs, Au-Cd SMAs, and Ni-Mn-Ga SMAs, but nitinol, Cu-SMAs, and Fe-SMAs are considered to be the most viable (Alaneme, Anaele, and Okotete 2021). Nitinol is one of the best SMAs with more applications because it exhibits super elasticity, allowing SMAs to recover their shape after the removal of deforming stress without heat. However, due to the high cost of processing nitinol, researchers are trying to develop other SMAs for more inexpensive shape memory applications that are comparable to nitinol. Fe-SMAs and Cu-SMAs are alloys under consideration that can be cheaper options than nitinol, but the properties of these alloys must be enhanced for efficient and reliable applications. Cu-SMAs also exhibit super elasticity along with brilliant ductility, low processing cost, high corrosion resistance (X. Zhang et al. 2021), long-term thermal response, high electrical conductivity, and mechanical strength. In addition, Cu-Al-Mn SMAs show brilliant characteristics that allow use in damping applications (Santosh et al. 2022).

For preparing a novel composition for a specific application, a deep knowledge of the pre-existing compositions and transformation temperatures is needed to get a better idea of properties. Martensitic transformation temperatures, Austenite start and finish temperatures (A_s *and* A_f), Martensite start and finish temperatures (M_s *and* M_f) are used for the characterization of SMAs. So composition and transformation temperatures are the principal identity properties of an SMA that determine its application for the respective field. Recently reported compositions of Cu-Al-SMAs are presented in Table 1, along with the martensitic transformation temperatures.

2. Key Features of Cu-Al SMAs

Easy fabrication, brilliant electrical and thermal conductivity, good ductility, damping properties, and improving the shape memory effect by controlling the grain size and texture make these alloys suitable for several applications. Due to the ease of fabrication, several methods are reported for the fabrication of these alloys including casting, powder metallurgy, rapid solidification, spray casting (Agrawal and Kumar 2018), additive manufacturing, and severe plastic

Table 1. Compositions and transformation temperatures of Cu-Al SMAs.

Composition (wt.%)					Transformation temperatures				References
Cu	Al	Ni	Mn	Other element(s)	A_s (^oC)	A_f (^oC)	M_s (^oC)	M_f (^oC)	
81.3	13.7	5	-	-	44	65	54	26	(Kim et al. 2019)
					129	154	124	91	
82	13.5	4	-	0.5Ti	74	117	83	40	(Tian et al. 2019)
57.53	37.78	-	4.69	-	160.95	167.83	164.19	148.77	(Karaduman et al. 2019)
78.7	13	-	7.7	0.6Cr	-55	-	-59.2	-	(Yang et al. 2019)
83.85	12.26	3.29	-	0.6Ti	224	261	226	177	(Dalvand et al. 2019)
84.36	12.34	3.30	-	0.62Ti-0.04 (Ce + La)	210	274	233	165	
					190	260	230	145	
82.22	11.76	3.22	2.78	0.02Nb	135	225	-	-	(da Silva Junior and Mazzer 2020)
					183	222	-	-	
81.34	13.96	4.7	-	-	169	237	165	115	(Agrawal and Vajpai 2020)
83	13	4	-	-	325	377	229	210	(Q. Zhang et al. 2021)
82.8	13	4	-	0.2Sm	142	181	168	139	
82.5	13	4	-	0.5Sm	151	176	174	150	
83	13	4	-	-	325	377	229	210	(X. Zhang et al. 2021)
82.8	13	4	-	0.2Nd	168	194	189	165	
82.5	13	4	-	0.5Nd	164	190	182	160	
82.76	12.49	-	-	4.75Fe	381	442	241	209	(S et al. 2022)
82	12	-	-	6Fe	346	402	224	194	
83.5	10.7	0.7	-	5.3Fe	268	350	204	152	
83.8	10.2	0.9	-	5.1Fe	288	360	213	166	
84	10.1	-	0.9	5Fe	281	351	167	147	
84.2	9.8	-	1.1	4.9Fe	273	338	164	141	
87.2	11.53	-	-	0.497Be	14.42	37.14	20.28	-3.86	(Kalinga et al. 2022)
86.7	11.98	-	-	0.55Be	-18.95	-10.40	-25.13	-27.96	
86.3	12.23	-	-	0.57Be	-22.71	-15.12	-30.12	-34.08	
71	18	-	-	11Mn	-15.75	-12.36	-21.84	-26.04	(M. W. Wu et al. 2023)
82	14	4	-	-	223	258	139	101	(Abolhasani et al. 2023)
85.8	14	-	-	0.2GN	293	332	231	178	
81.8	14	4	-	0.2GN	260	295	178	131	

deformation (Mazzer, da Silva, and Gargarella 2022). The brittleness in Cu-Al alloys can be overcome with the addition of Mn as it helps in higher ductility, allowing cold workability (Sutou et al. 2013) along with low thermal expansion, super elasticity, both one-way and two-way shape memory effect, higher recovery power, and shape memory strain with better damping capacity. Key attributes of Cu-Al-based SMAs encompass

- *Cost Efficiency:* In contrast to alternative shape memory alloys like Ni-Ti, Cu-Al-based alloys present notable cost benefits owing to the abundance of their constituent elements.
- *Elevated Transformation Temperature:* These alloys showcase relatively high transformation temperatures, rendering them suitable for elevated temperature applications (López-Ferreño et al. 2020).
- *Excellent Cold Workability:* Cu-Al-based SMAs generally exhibit favorable cold workability, enabling their formation into diverse shapes and geometries (Dasgupta 2014).

- *Super elasticity:* Certain Cu-Al-Mn-based alloys display super elasticity, allowing them to regain their original shape upon unloading after substantial deformation (Sutou et al. 2004).

Still, Cu-based SMAs present some challenges, including

- *Restricted Fatigue Life:* There can be some limitations on the durability of these alloys when shape alteration cycles are repeated, causing fatigue issues in these alloys (Dasgupta 2014).
- *Martensite Aging:* Their shape memory properties can be affected over time due to aging processes (Alaneme, Anaele, and Okotete 2021).
- *Property Tailoring:* The achievement of optimal combinations of multiple properties can be achieved through precise adjustment of composition and post-processing parameters.

3. Applications of Cu-Al SMAs

Despite the challenges, Cu-Al-based SMAs hold promise for diverse applications:

- *Medical Applications:* Due to biocompatibility, low toxicity, and anti-microbial action, Cu-Al SMAs have promising features for medical applications in optometry, medical accessories like Wagner's thermolock, medical guidewire for surgery, and biomedical implants (Dasgupta 2014).
- *Mechanical Applications:* Mechanical applications of Cu-Al SMAs include micro actuators due to quick response, safety devices, coupling, seismic dampers, and fluid connectors (Dasgupta 2014).
- *Automotive Applications:* Their shape memory properties can be utilized for smart actuators in self-deployable airbags and other automotive components (López-Ferreño et al. 2020).
- *Civil Structure Applications:* Civil structure applications of these alloys include structural health monitoring, piping, and sensual materials for safe storage (Dasgupta 2014).
- *Robotics:* Due to good thermal and electrical conductivity and thermal-based phase transformation, these alloys have applications in thermal-based sensors and regulators with better controllability than conventional sensors (Mazzer, da Silva, and Gargarella 2022).

Researchers are actively exploring novel compositions and processing techniques to enhance the properties and broaden the scope of applications for Cu-Al-based SMAs. Determination of the contributing factors for the phase transformation mechanism and controlling these factors is required for advanced applications.

4. Novel Compositions

Cu-Al SMAs are further characterized into Cu-Al-Mn, Cu-Al-Ni, and Cu-Al-Be systems (Dasgupta 2014). Several other ternary element additions to Cu-Al-SMAs are also reported, including Sn, Si, Be, Nb, V, Co, Ag, C, Ge, Ce, Fe, Cr, Zr, B, Ti, and Zn. Ternary additions for Cu-Al-Ni-SMA also include Hf, Ta, Fe, Zn, Cr, V, and Sn (Mazzer, da Silva, and Gargarella 2022). In a recently reported study by (Abolhasani et al. 2023), a graphene micro powder addition to Cu-Al SMA is performed using a powder bed fusion process. The results showed a higher shape memory effect (SME) due to rapid temperature distribution leading to a quicker recovery, so the alloy can perform at elevated temperatures without defects or losing SME. Quaternary additions of Ni and Mn to Cu-Al-Fe SMA are also reported by (Santosh et al. 2022) and the results are promising for high-temperature damping applications. These additions resulted in a slight decrease in the transformation temperature and the damping value is comparable to Ni-Ti-Cu alloys, making these quaternary alloys a promising alternative for elevated temperature damping applications. Quaternary addition of Ag and Nb to Cu-Al-Fe-SMA is reported to adversely affect the damping capacity with improved hardness (Gholami-Kermanshahi et al. 2023).

5. Educational Impact and Importance of Cu-Al SMAs

Cu-Al SMAs are one of the smart materials that have several applications in civil structures and mechanical components. The exceptional combination of attributes, such as cost effectiveness, elevated transformation temperatures, cold workability, and super elasticity, signifies the importance of these alloys among other SMAs. A fundamental understanding of fabrication, post-processing, material properties, and characterization of these alloys is essential for engineering students as it can help in interdisciplinary learning, innovation, problem-solving, real-world applications, and career opportunities. Incorporating Cu-Al-SMAs into engineering technology courses, such as materials science or metallurgy courses at the undergraduate level, can engage students in learning about advanced materials.

Taking steps like teaching theoretical concepts, material properties, characterizations, hands-on experiences, guest lectures, and research opportunities can help include these smart materials into the curriculum. Preparation of these alloys at the laboratory scale is essential for understanding the process involved in the fabrication and post-processing as it helps regarding parameter control, property tailoring, and selecting a suitable combination of mechanical and thermal properties. A glimpse at the ongoing Cu-Al SMA research at the lab is shown in Figure 1, where major steps involved in the powder metallurgy route for preparation of these alloys are illustrated. Starting from the left, ball milling, compaction, and sintering of the compacted samples are the fundamental steps involved in the powder metallurgy route.

6. Recent Developments and Outlook

Recent developments in Cu-Al SMAs include high-temperature SME in Cu-Al-x SMAs, elastocaloric effect in Cu-Al-Mn SMAs (Mazzer, da Silva, and Gargarella 2022), and enhancement of pseudo elastic behavior of Cu-Al-x (Be, Mn, and Ni) SMAs. Medina, Herrera, and Beltran (2023) reported an improvement of super elasticity limit with higher thermal treatment time along with higher grain size, and variation in the composition of Cu-Al-Be SMA is reported to deteriorate the pseudo elasticity of these alloys (Kalinga et al. 2022). In the case of Cu-Al-Mn, selective laser melting is proposed for manufacturing complex shapes with high pseudo-elasticity (M. W. Wu et al. 2023). Torsion pre-deformation is reported to enhance the temperature stability of Cu-Al-Be SMA in a wide temperature range. Enhancement of pseudo-elasticity in Cu-Al-Ni SMAs is under consideration by preparing these alloys through horizontal continuous casting to achieve strong orientation (M. Wu et al. 2022). Flat grain boundaries with large grain sizes are achieved through continuous casting to enhance the pseudo-elasticity of these SMAs.

Future interest in Cu-Al-SMAs involves both novel compositions and manufacturing methods. One of the significant novel compositions includes the Cu-Al-Fe-Mn system and expected future work is the fifth element addition using mathematical formulations via the same or different manufacturing methods adopting the technological advances in the manufacturing sector. Additive manufacturing methods, such as direct energy deposition, direct metal laser sintering, and metal binder jetting, are to be optimized to produce these alloys. Manufacturing sector advances also require the development of novel characterization techniques for a better understating of SMEs. Energy applications for these alloys using the electrocaloric effect are needed to study the phase transformation mechanisms that affect the latent transformation energy in Cu-Al SMAs.

7. Conclusion

Cu-Al SMAs show promise for applications in medical, civil structures, automotive, robotics, and elevated temperature shape memory. Investigations for novel compositions and manufacturing routes along with the development of novel characterization techniques can revive interest in these alloys. Several recent studies reported on the improvement of pseudo-elasticity of these alloys, and there is still a need to control the phase transformation to use these alloys for long-term applications without affecting the recovery performance.

Advancements in these alloys are crucial to teaching undergraduate students in mechanical, civil, and

Figure 1. A glance at preparation of shape memory alloy via powder metallurgy route in an ongoing research study in laboratory.

material science. Advanced materials courses can be designed using content from review studies like this along with case studies, guest lectures, and research studies to promote interdisciplinary learning, innovation, real-world applications, and career opportunities.

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Occupation Clustering Methodology for Training In-Demand Engineering Middle-Skilled Workers in the Advanced Manufacturing Industry

Elizabeth A. Moore, Frank R. Field and Randolph Kirchain

Abstract

The manufacturing industry faces a labor shortage and a mismatch between available and desired employee skills. This challenge is more acute for advanced manufacturing and for middle-skilled engineering workers. Despite this need, funding to develop middle-skilled training programs is severely limited. This article addresses this challenge by providing a method for identifying high-value, shared skills to maximize training resources. A novel set of methods were developed to classify advanced manufacturing industries, quantitatively characterize engineering skills gaps, and identify occupations with shared in-demand skills. These methods were applied to a dataset collected across five industries: robotics, flexible electronics, advanced fabrics and fibers, integrated photonics, and 3D/additive manufacturing. Semi-structured interviews with industry experts were performed to quantify skill importance and skill gaps. A combination of rank-biased overlap analysis and unsupervised clustering methods were used to identify occupations with shared in-demand skills. Results suggested that the eight most prevalent middle-skilled occupations could be trained effectively in four programs by sharing training resources. These training recommendations can prepare tomorrow's engineering technology workforce while maximizing scarce curriculum development resources.

1. Introduction

Manufacturing–particularly advanced manufacturing–is widely recognized as essential for economic and strategic benefits. More recently, the COVID-19 pandemic has brought into stark relief the impacts, even to public health (Hotez et al. 2021), when domestic manufacturing capacity cannot respond quickly enough to changing needs (Ardolino, Bacchetti, and Ivanov 2022). Although much of the broader discussion of the state of manufacturing in the United States focuses on the role of foreign competition and a lack of investment in new technology, another key challenge is workforce availability. While workforce shortages can be found across industries (Ozkan-Ozen and Kazancoglu 2022), they are especially prevalent in manufacturing (Schmid and Melkote 2022). One estimate suggests that 2.4 million manufacturing positions could go unfilled by 2028 (Li et al. 2021).

Despite increased automation in manufacturing, the demand for labor, particularly middle-skilled labor, is rising (Christo-Baker, Sindone, and Roper 2017). "Middle-skilled" refers to workers with training beyond a high-school diploma but less than a bachelor's degree. Engineering middle-skilled (M-S) workers are a typical class of technical, middle-skilled occupations. One aspect of the middle-skilled labor challenge that is less widely discussed is a mismatch between the skillsets of prospective employees and the skills needed by employers. In the US, 52% of jobs are middle-skilled, but only 43% of workers have the necessary skills (National Skills Coalition 2021). Highly skilled, adaptable workers are needed to avoid manufacturing bottlenecks in the US.

One solution to this challenge is to update the ecosystem for training M-S workers to ensure that it teaches in-demand skills. Unfortunately, institutions that focus on middle-skilled training often have few resources for curriculum development (Harnett 2019) and generally have weak communication channels with thought-leading firms and researchers who are changing manufacturing practices. Providing fewer, more general training programs (e.g., engineering M-S worker vs. electronics engineering M-S worker) reduces the cost of training but risks omitting specialized skills valued by industry. To address this challenge, this article presents a methodology that couples a detailed assessment of skills gaps within five emerging manufacturing engineering industries and across eight professions with a hierarchical clustering analysis to identify opportunities to group training into fewer programs. This information should allow training institutions to create or modify shared training programs that still produce graduates with highly valued skills. In this study, results show how rank-biased ordering methods and clustering algorithms are effective methods for creating clusters of occupations and industries with similar skillsets. A four skills-cluster result is demonstrated, which would require half of the training resources compared to a traditional training solution. This method can also be applied for future curriculum development for emerging industries by comparing skill gap similarities by position and industry.

1.1 Literature Review

The worker skills gap, the difference between demand for specific skill levels and supply of workers with those skills (Christo-Baker, Sindone, and Roper 2017) has been viewed as a challenge for years (Sharvari 2019). This challenge has only been exacerbated by the COVID-19 pandemic, which emphasized the importance of building dynamic national capabilities especially for domestic manufacturing(Amaral et al. 2023). In a regional analysis of Northwest Indiana, job posting analytics indicated that only 49% of the middle-skilled workforce had the required skillset (Christo-Baker, Sindone, and Roper 2017). With technological advancements, job requirements are changing (Harteis 2018), and the existing gap will only widen.

In the integrated photonics industry, research indicates that automation of production processes would reduce the need for middle-skilled operators while, conversely, product integration would increase demand for M-S workers (Combemale et al. 2022). Even if these technical changes are not expected to reduce the number of jobs, they are expected to change the portfolio of skills that are most valued, which has implications for education and training of workers (Nof et al. 2013).

Although often overlooked, middle-skilled training is a vital part of economic development. Community colleges have historically played a large role in providing the necessary training for high school graduates or adult job training. However, these programs are facing critical issues including declines in state funding, student retention and completion, and non-competitive faculty salaries (Grover and Miller 2019).Employers have also raised the concern that there is a skills mismatch between what is needed versus what is taught on campus (Arthur-Mensah 2020). Consequently, community colleges have had to prioritize programs under these resource constraints. The programs that are prioritized are those that have high student demand and sources of external funding (e.g., direct local industry support). As a result of these pressures, community colleges have to think strategically about where to apply their limited resources.

Several solutions have been discussed to improve worker readiness even when training resources are limited. These include public-private partnerships (Christo-Baker, Sindone, and Roper 2017), apprenticeship programs (Arthur-Mensah 2020), and redesign of existing curriculum (Moraes et al. 2022). Cluster analysis of related occupations has been proposed as a method to inform various aspects of technical workforce strategy in the face of technological change (Goldberg 1931). Occupation clusters are groups of occupations that have related skills, knowledge, training, and wage levels. Clustering methods have been applied to identify related-firms to support economic and workforce development efforts in a region (Markusen 2007), isolate career pathways to support job mobility and bolster interest in technical careers (Geel, Mure, and Backes-Gellner 2010), and highlight geographic areas where existing occupational clusters can support industrial expansion (Chrisinger, Fowler, and Kleit 2012). Regarding curricular design, the use of clustering methods dates back to at least 1971, when Goldberg (1931) used logical heuristics to identify skills common to a cluster of electrical and electronic occupations. Kettenring et al. provide the earliest application of statistical clustering to identify common skills and training gaps for a single occupation, the dial administrator (1976). Recently, more advanced data mining and clustering methods have been applied to answer similar questions for data science curricula (Fortino et al. 2019).

Most existing applications of clustering methods to workforce questions utilize abstract representations of skills (e.g., repair, robotics) (Chrisinger, Fowler, and Kleit 2012). While this allows studies to consider a wide range of occupations (e.g., from a mechanic to a taxi driver), it is not useful to inform curricular decisions. Studies that have applied higher-resolution task information have focused on training for individual occupations. No previous study has applied statistical clustering methods to explore curricular design across a range of occupations.

This study applies a modern rank-biased clustering method to a novel dataset based on high-resolution descriptions of worker tasks and interviews of over 120 industrial experts in five emerging manufacturing sectors. The rank-biased method identifies high-priority skills shared across these industries based on both existence and importance. Several clustering methods are applied to identify optimal training groupings. This information reveals how to allocate limited training resources to best serve industrial needs.

2. Methods

2.1 Workforce Needs Characterization

The characterization of workforce needs in advanced manufacturing is not straightforward. The emergence of new technologies can lead to new structures for knowledge coordination across formerly well-defined occupational boundaries. Further complications include the fact that labor databases often do not define or track occupations in these emerging fields, and companies supplying data to these databases span industry classes and therefore are imperfectly characterized. Therefore, we develop and apply a new research method because traditional sources of information about labor needs are not well suited to answering these questions within advanced manufacturing.

The most widely consulted source of data on the US labor market is the Occupational Information Network (O*NET) database maintained by the Bureau of Labor Statistics (BLS) (U.S. Department of Labor 2020). That database contains information about workforce needs broken down into about 1,000 occupation types across more than 100 industrial sectors. Although this serves as an invaluable source of information for workforce questions, there are at least two challenges when applying it to examine needs within advanced manufacturing. First, despite the scope and detail of the O*NET database, it is difficult to isolate the needs of emerging industries within those data. It will always be the case that advanced manufacturing sectors such as photonics or robotics will operate at the interfaces of traditional sectors and, as such, will not be simply mapped using conventional industrial classification systems. Secondly, there will always be concern that government databases are not updated frequently enough to capture rapidly evolving industries.

For this study, we identify firms within five advanced manufacturing industries and characterize workforce gaps through semi-structured interviews, interviews with a flexible set of predetermined questions, with firms along the supply chain. Informed consent was obtained from all interview participants. New England was chosen as the focal region for this study (72% of the firms were New England-based) because it is a diverse manufacturing ecosystem and hosts a large number of advanced manufacturing companies. In the case where a sufficient number of firms within the region were not available for interviews, participants outside of the region were included in the study. The five industries were chosen based on their affiliation with US manufacturing institutes: The Advanced Robotics for Manufacturing (ARM) Institute (robotics), the NextFlex Institute (flexible electronics), Advanced Functional Fabrics of America (AFFOA) Institute (advanced fabrics and fibers),the American Institute for Manufacturing (AIM) Integrated Photonics (integrated photonics),

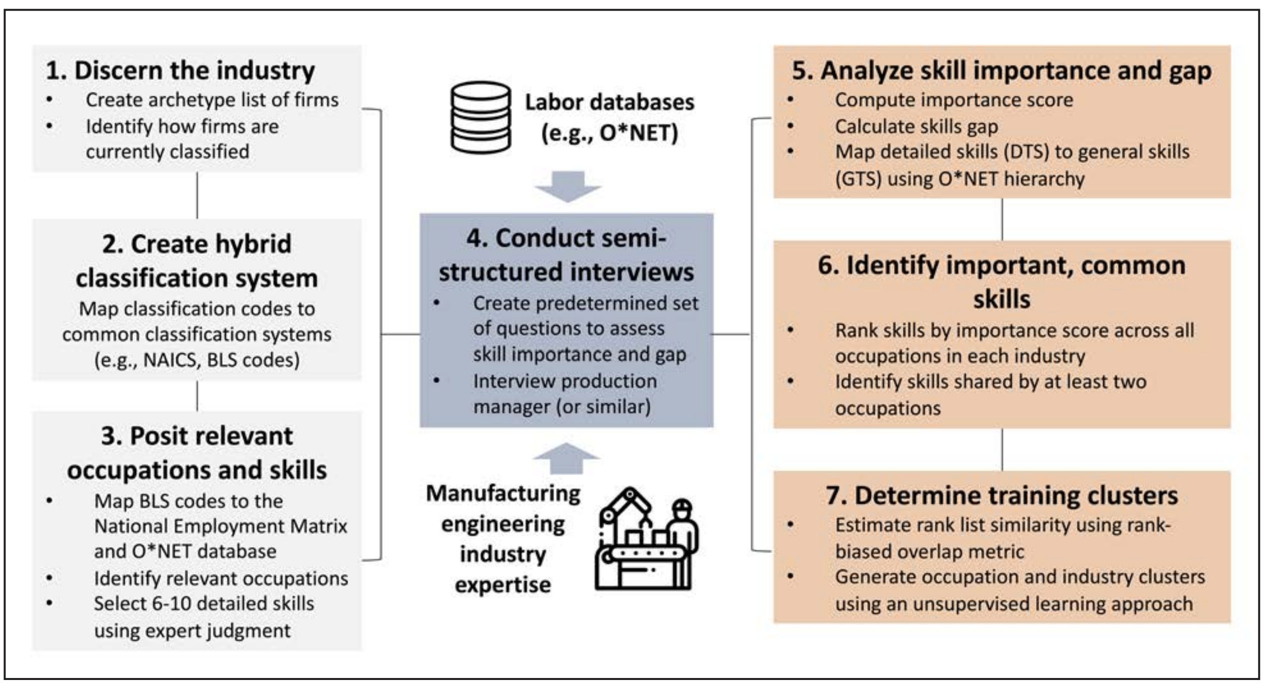

Figure 1. Flow chart detailing the methodology for 1) developing a classification system to identify relevant occupations and skills for emerging advanced manufacturing industries (gray), 2) conducting semi-structured interviews with industry leveraging existing labor databases (blue), and 3) assessing skill importance and gaps to determine training clusters (orange).

and the America Makes (AmMakes) Institute (3D/additive manufacturing).While there are specialized skills within each of these industries, an understanding of shared high priority skills can help reduce the resources needed for new training programs.

To characterize workforce needs within advanced manufacturing industries, firms were interviewed within the industry. A four-step process was followed: 1) classification of advanced manufacturing industries, 2) interview question development leveraging industry expertise, 3) interview question assessment, and 4) semi-structured interviews with industry, response analysis, and recommendations. This information was used to create a list of technical skills ranked by expected importance. Rank-biased overlap analysis was used to identify skill similarities among the five industries for all occupations. To inform similarities among occupations, hierarchical and K-medoid clustering results identify occupational clusters based on in-demand skill needs. Results highlight advanced manufacturing M-S worker clusters and the in-demand skills for each cluster. A flowchart summarizing the methodological steps is shown in Figure 1.

2.2 Discern the Industry and Create Hybrid Classification System

The first stage of this analysis aims to identify a sufficiently large sample of firms that are representative of the advanced manufacturing sector of interest and to identify how these firms are currently classified in some relevant industrial classification system. This classification system will be referred to as the discernment system.

The initial step was to identify firms that are representative of the industry of interest, referred to as archetypes. This is an inherently manual, expert-based process. For each industry, archetype firms were identified based on member listings from relevant professional associations and expert elicitation. Once archetypes were identified, information about those firms was queried from the discernment system. The most common economic activity type (EAT) codes associated with those firms within the discernment system were cataloged. This set of codes serves as one definition of the industry of interest and were used to identify a larger set of similar firms.

To leverage data catalogued by the US BLS, firms must be identified using the North American Industrial Classification System (NAICS) (Dalziel 2007). If the discernment system is not NAICS (as it was not in the case study here), then it is necessary to create an empirical mapping between the two systems. Here we do this by using the discernment system to identify a larger set of firms of the same type as the archetypes and then identifying the prevailing NAICS codes used to characterize those firms.

EAT codes for several industrial classification systems were collected for each archetype firm using the D&B Hoovers business database (Dun and Bradstreet 2020). The D&B Hoovers Proprietary SIC 8-digit Code (SIC8) classification system, an expansion of the original SIC system, was used to discern the industry. The SIC8 and NAICS EAT codes for archetype firms were collected for the five industries to help develop a description of the firms based on the industrial classification codes; see Supplemental Information (SI).

Using the D&B Hoovers companies database, unique firms for each of the five industries were identified. To demonstrate the method, the robotics industry is used here as an example and the remaining industries are discussed in the online supplemental information file (Moore et al. 2024). 169 unique robotics firms with more than 20 employees that are classified by one of 9 SIC8 codes were identified. These firms are classified into one of six NAICS codes. Occupation data available from the BLS are organized in a truncated version of NAICS, with most industries organized at the three- or four-digit level (see Moore et al. 2024 for robotic industry examples).

For all five industries, we discern the industry based on a hybrid of the identified classification codes. In robotics as an example, we discern the robotics industry as firms classified as one of the nine codes within the SIC8 system which maps to the three BLS equivalent industrial classification codes 334500, 3330A1, and 333500. Effectively, the industry of interest is defined as a hybrid of these industries. This hybrid industry description is used to identify relevant occupations within the robotics industry. Similar details for each industry studied can be found in the Supplemental Information file.

2.3 Posit Relevant Occupations and Skills

To leverage the extensive surveying knowledge embedded within the O*NET database (U.S. Department of Labor 2020), the BLS equivalent NAICS codes were used to identify a relevant set of occupations for the industry of interest.

Specifically, occupation codes were identified using a combination of the 2018 National Employment Matrix (NEM) (U.S. Bureau of Labor Statistics 2018) and the O*NET database. Using this dataset, occupations that met the following criteria were identified:

- Associated with the industry of interest (as defined by the codes identified previously)

- Technical in nature
- Primarily held by middle-skilled workers
- Represented more than 0.1% of the workforce across the defined industry

The definition of technical work is inherently subjective. For the purposes here, the search is limited to occupations involved in mathematics, architecture, engineering, life, physical, and social sciences, installation, maintenance, repair, and production. Computer-related positions were excluded because in early test interviews we learned that skills for those positions would not be influenced by the specific industry.

M-S workers are often defined as those with an education level that is greater than a high school diploma and less than a bachelor's degree. O*NET occupation classifications always span a range of educational levels. For this research, we define middle-skilled occupations to be those for which more than 30% of the workforce is middle skilled and less than 50% of the workforce is either lower-skilled or upper-skilled.

As an example, based on these definitions, we identified 17 relevant middle-skilled positions associated with the robotics industry. To facilitate survey data collection, these were grouped into eight representative positionsTo facilitate survey data collection, these were grouped into eight representative positions (see Moore et al. 2024 for details). For each identified occupation, an associated set of competencies (skills) was developed from the O*Net database (U.S. Department of Labor 2020). The O*Net database uses a hierarchical taxonomic approach to organize tasks and skills (Peterson et al. 2001). The database was originally developed through survey methods to create a relational database of occupation attributes for the U.S. economy and helps create a common language for job descriptors. For each occupation, the database includes tasks, tools, and technologies employed on the job. Using this information, six to ten technical tasks from each occupation were selected for an interview-based assessment of their importance and observed gaps between available and needed skill levels.

2.4 Conduct Semi-Structured Interviews

Using the hybrid classification codes for the archetype firms, a list of firms representative of the advanced manufacturing sector of interest was identified and these firms were contacted for 60-minute interviews. For firms that agreed to an interview, leaders (such as production managers) who were responsible for hiring, training, and interacting with the M-S workers were asked to participate on behalf of the firm.

The interview was structured into four main sections including firm characterization, hiring and training challenges, skills gaps, and human skill needs. Informed consent was obtained from all participants prior to beginning the interview.

Interview responses were captured in the Qualtrics online platform (Qualtrics XM 2021). 126 qualified responses where the respondent completed the entirety of the interview were received and incorporated into the results.

2.5 Analyze Skill Importance and Gap

In the interviews, participants were asked about the importance and observed gap of 6-10 specific skills from the list of tasks in the O*NET database for an individual occupation. For each skill, the respondent evaluated the skill level for a typical new hire as well as the expected skill level. The skill level categories included the following:

- Aware of = 1
- Familiar with = 2
- Competent at = 3
- Proficient with = 4
- Mastery of = 5

The gap was estimated as the difference between the expected skill level and the skill level the participant observes for a typical new hire. The participants were also asked to evaluate the skill importance for each task in five years compared to today. A weighting was assigned to each level of response for each specific task (Importance will Grow Significantly = 5, Grow= 3, Hold = 1, Not important = 0). Then weighted averages of these importance levels were computed for each specific task.

2.6 Identify Important, Common Skills

While it is valuable to understand the skills trends within individual occupations, in many cases, training programs or courses will need to be more broadly applicable, serving the needs of multiple types of learners. To that end, the research team sought to identify those skills that are both important and shared (common) for multiple occupations.

This identification was accomplished by making use of the hierarchical structure of the O*NET dataset from which occupation-specific skills were identified. In the O*NET hierarchy, tasks are the most specific representation of occupation requirements. Tasks are related to more generalized classifications of skills (see example in Moore et al. 2024). Specifically, Tasks can be associated with many detailed work activities, which are each associated with only one intermediate work Activity, which are themselves associated with only one general work activity. (To maintain a more consistent terminology we will refer to these classifications as detailed tasks/skills (DTS), intermediate tasks/skill (ITS), and general tasks/skills (GTS), respectively.) An example of the hierarchical relationship can be found in Figure S1 in the SI file.

Because of this hierarchical relationship, it was possible to compute an average skill importance at any level of aggregation. To do this, the weighted average score for each individual skill was estimated from the interview responses. Then weighted averages of these importance levels were computed for each specific task or skill and the corresponding DTS, ITS, and GTS. For this set of occupations, the DTS level of aggregation did not provide useful insights. As such, it is not discussed further here.

These weighted importance scores were then used to construct a ranked list of skills across all of the occupations in each industry. From these ranked skills, those that are shared by at least two occupations are identified and this set is referred to as important, common (as in shared) Skills.

2.7 Determine Training Clusters

The skills gap and common skills results were used to construct lists of the common GTS skills, ranked according to importance to the interview subjects, categorized by job type and respondent industrial sector. To develop a metric of rank list similarity between these lists and to then compare these lists across industries and M-S worker positions, the rank-biased overlap (RBO) method is used (Webber, Moffat, and Zobel 2010), an indefinite rank similarity measure. The gespeR R package (Schmich et al. 2015) was used to perform the analysis and is based on the study by Webber et al. (2010) This method is especially useful for comparing lists when there are only some items in common and it can construct consistent measures between lists having dissimilar lengths. This overlap metric has been used to compare rankings in a number of applications including search engine analytics (Rieder, Matamoros-Fernández, and Coromina 2018). In this study, the RBO metrics are used to develop insight into similarities and differences among industry preferences for job skills.

Ten clustering methods were used to groups the interview responses by occupation and industry sector, including eight agglomerative hierarchical methods (average, centroid, complete, McQuitty, median, single, Ward and Ward.D2), the divisive analysis (DIANA) clustering method (Murtagh and Contreras 2012), and K-medoid clustering (Park and Jun 2009). In general, each method's objective is to generate clusters that satisfy two criteria: (1) the members of each cluster are "close" to one another and (2) each cluster is "far away" from all other clusters. Because real data will exhibit dispersion within each cluster (i.e., all members do not occupy the same point in attribute space), several approaches to estimating "close" and "far away" have been developed, largely influencing the "shape" of each cluster in attribute space. As an unsupervised learning approach, clustering methods only require the user to supply the attributes of the items to be clustered (or their distance from one another in attribute space), the number of clusters to be generated, and the method to be used to establish distances within and across clusters.

For this analysis, a distance matrix was supplied to the clustering algorithm, where the distance between two lists, A and B, was defined as (1 – rbo(A,B)), since an rbo(A,B) equal to 1 signifies identical rank lists. Two cluster quality methods (Brock et al. 2008) were used to assess the results, including the Silhouette method (Mächler 2022) and the Dunn's index (Bezdek and Pal 1998). Both produced strategically equivalent results.

3. Results

In the following results, we identify cross-cutting skills most frequently reported to help inform curriculum development. First, we show results for organizing skills training around industries and highlight skills that are common and important across occupations. Using skills importance rank lists developed from interview data, cluster analysis is then performed for middle skills occupations by M-S worker class and by industry. These results can be used to inform ways to organize a smaller number of training programs without compromising the most in-demand skills given limited resources.

3.1 Skills Gaps and Needs by Industry

For each of the five advanced manufacturing industries, interview responses were used to identify the most important skills. Table 1 shows the top five most important skills (at the GTS level), for each of the advanced manufacturing industries. These skills were determined from interview responses where interviewees ranked the specific skills from the O*NET data and these skills were then mapped to the GTS using the O*NET hierarchy.

The importance of these skills can be compared by industry and occupation. For example, the GTS "Interacting with computers" and "Prepare specimens, tools, or equipment" are important and common skills across all five industries while "Making decisions and troubleshooting problems" has mixed responses. As shown in Figure 2, the rank-biased overlap (RBO) results show that ARM, AmMakes, and

Table 1. The top five important GTS for each of the advanced manufacturing industries. These skills were derived from the skill importance rankings from industry interviews and then mapped to the GTS using the O*NET hierarchy.

ARM	America Makes	NextFlex	AFFOA	AIM
Prepare specimens, tools, or equipment	Monitor processes, materials, or surroundings	Repairing and maintaining equipment	Information management	Controlling machines and processes
Repairing and maintaining equipment	Prepare specimens, tools, or equipment	Interacting with computers	Organizing, planning, and prioritizing work	Thinking and making creatively
Interacting with computers	Repairing and maintaining equipment	Prepare specimens, tools, or equipment	Data collection and synthesis	Analyzing data or information
Monitor processes, materials, or surroundings	Making decisions and troubleshooting problems	Test and evaluate for quality	Analyzing data or information	Making decisions and troubleshooting problems
Test and evaluate for quality	Analyzing data or information	Data collection and synthesis	Provide consultation and advice to others	Estimating and judging the characteristics of products or processes

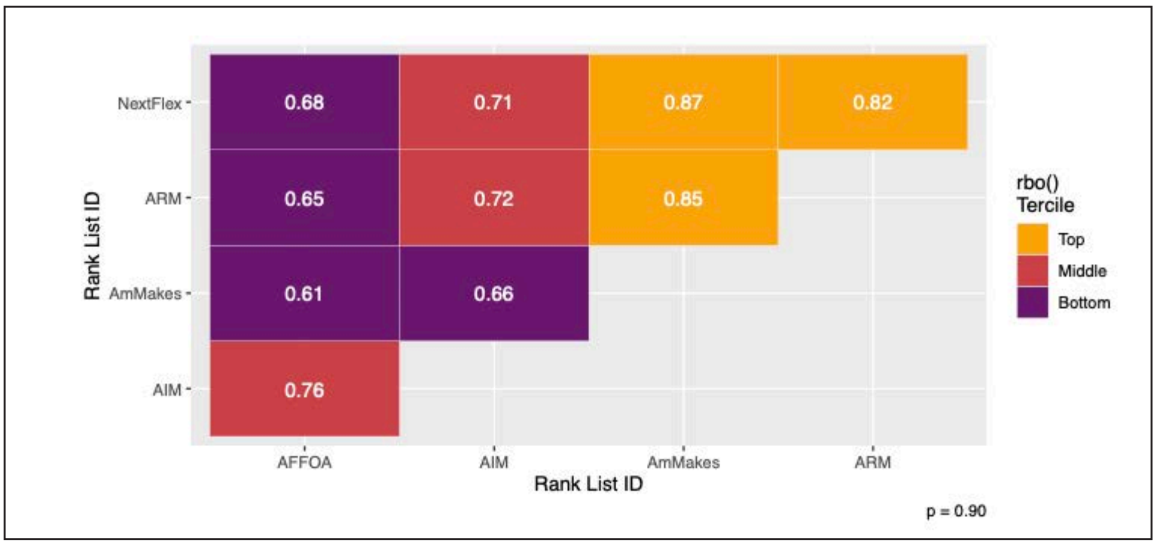

Figure 2. The RBO metric is used to compare skill similarities for the five industries. ARM, AmMakes, and NextFlex are the most similar (RBO>0.8, yellow square) while AFFOA and AIM have different skill ranks (red, purple squares).

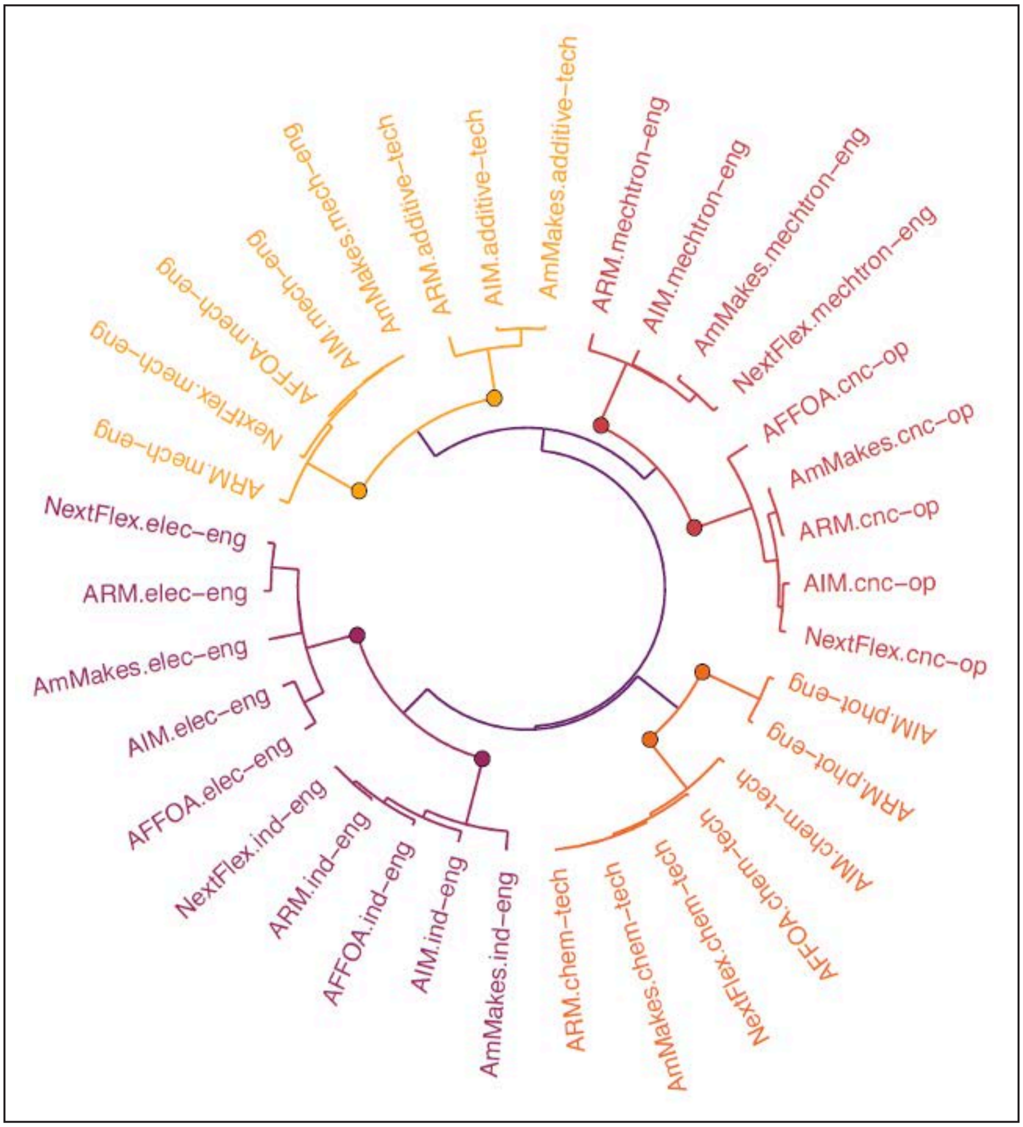

Figure 3. Hierarchical clustering results for each occupation for each industry studied. The results demonstrate that occupations are more likely to cluster together rather than occupations within an industry.

Nextflex are more similar to one another (RBO>0.8) while the AIM and AFFOA rank lists reflect decidedly different skill preferences.

The RBO results are confirmed by interview respondents. AIM and AFFOA respondents share the expectation that M-S workers can be flexible and adaptable in working with automation equipment and tools. They believe "automation will be a technology assist for M-S workers rather than displacing M-S worker work activities" (Participant 56 2021). The skill focus for M-S workers in these industries is centered on working with computers and equipment, repairing and maintaining equipment, and collecting information. While the other industries also expect M-S workers to have basic machining skills, ARM, AmMakes, and NextFlex respondents expect M-S workers to have greater judgement ability. For example, respondents shared that M-S workers in these industries should be able to "conduct failure analysis" (Participant 80 2021), and "make recommendations for process and product improvement" (Participant 141 2021). Skills for M-S workers in this industry are more focused at the process level rather than the equipment and tool level.

Although interviews were conducted by industry, historically, training has been organized by occupation. Clustering results reveal what occupations share the most common important skills. These results clearly support the more classical academic orientation of education and skills training by occupation. A representative result is shown in Figure 3 and the complete set of clustering results can be found in

Moore et al. 2024. Specifically, Figure 3 shows the result of the complete hierarchical clustering method for 34 clusters (at the edge) to 2 clusters (near the center). These results demonstrate that the strongest clusters form around occupation rather than industry. Specifically, occupation-specific clusters develop no later than the fourth grouping from the outer edge (colored dots in Figure 3). Also, occupation-specific clusters form before merging with any other occupations.

The overall performance of the optimal clustering solution was analyzed when the number of clusters ranged from 2 to 20 (see Moore et al. 2024). The results show the quality of the optimal clustering solution improves monotonically until reaching 8 clusters. Results from other clustering performance measures all show the same trend as the complete method result presented here. At one or two clusters, the average Silhouette measure is low (0.280) but improves to 0.82 as the number of clusters increases until each occupation has its own cluster at eight clusters. This information alone does not identify the best solution for any specific training institution. Institutions should select the level of clustering that is allowed by their budget. However, it is possible to discuss the implications of specific solutions. As an example, the four-cluster solution would halve the implementation costs of an eight-cluster solution while still generating a clustering quality measure of 0.503. This value is nearly double that of the two-cluster solution and more than 60% of the quality metric for the eight-cluster solution. This suggests that it may be possible to develop meaningful shared curricula without maintaining a training program for every occupation.

These trends are generally robust irrespective of clustering method. Figure 4 shows how the occupations cluster across the methods as cluster number moves from eight (top row in each block) to two (bottom row). At eight clusters, all ten clustering methods identify the same optimal solution–one skills/training cluster per occupation. As cluster number declines, there are always predominant solutions, but those are rarely unanimous. The most robust and persistent skills group is between the additive and mechanical engineering M-S workers which are clustered together in 94% of the analyses from six to two clusters. Mechatronic M-S workers and CNC operators are grouped together in 72% of analyses. Electrical engineering and industrial engineering M-S workers are grouped and chemical and photonics M-S workers are grouped in 60% of analyses.

Two other important outputs of the analysis are a) the specific make-up of the optimal clustering solution and b) the important tasks within those clusters. Table 2 shows a subset of this information for the optimal four-cluster solution. Specifically, we see that the four optimal clusters involve grouping training as 1) additive and mechanical engineering M-S workers; 2) chemical and photonics M-S workers; 3) cnc operators and mechatronics M-S workers; and 4) electrical and industrial engineering M-S workers. The value of separating into these four programs is made plain by examining the top skills associated with each

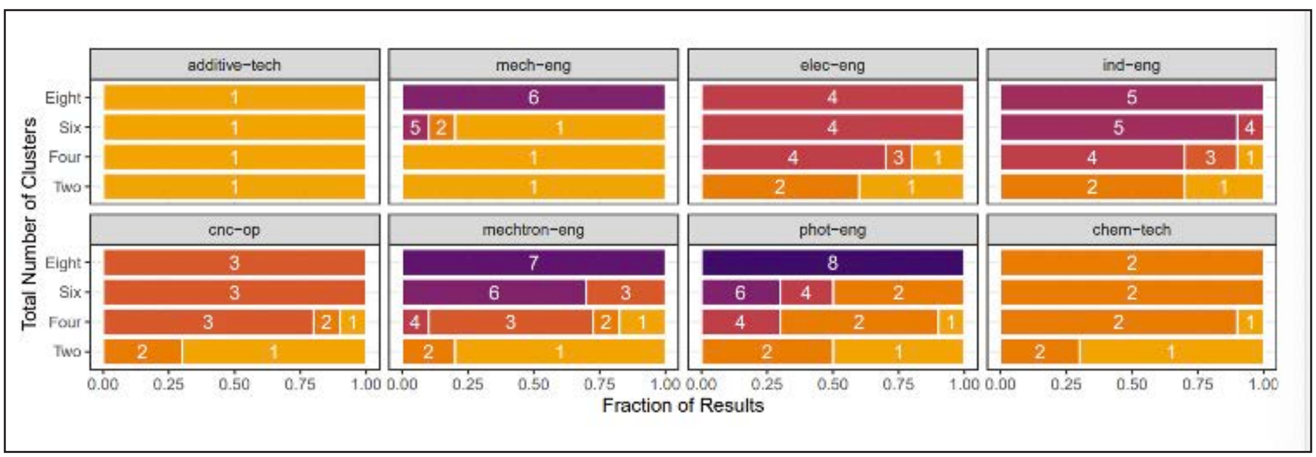

Figure 4. Ten different clustering approaches for the eight occupations across the advanced manufacturing industries. There is a strong similarity between additive M-S workers and mechanical engineering M-S workers and electrical and industrial engineering M-S workers. as shown in the first row. In the second row, CNC operators and chemical M-S workers are both shown to be unique positions with mechatronics most strongly connected to CNC operators but weakly connected to photonics M-S workers. Similarly, photonics M-S workers are most like chemical M-S workers but are weakly connected to mechatronics M-S workers.

Table 2. Top three ranked GTS for each of the groups from the optimal four-cluster solution. Of these twelve skills, only two appear twice: documenting/recording information (blue text) and handling and moving objects (orange text). The importance score of the GTS shown in the table is informed by the weighted average importance scores for the specific skills from the semi-structured interviews. Each specific skill (represented by n) was mapped to its corresponding GTS and each GTS inherited the importance score of the skills. The entire ranked skills list and their importance scores for each of the four clusters are shown in Moore et al. 2024.

Rank	#1: Additive and Mechanical Engineering Technicians	#2: Chemical and Photonics Technicians	#3: CNC Operators and Mechatronics Technicians	#4: Electrical and Industrial Engineering Technicians
1	Inspecting Equipment, Structures, or Material (3.001; n=441)	Performing General Physical Activities (3.512; n=161)	Handling and Moving Objects (3.273; n=360)	Controlling Machines and Processes (2.783; n=340)
2	Monitor Processes, Materials, or Surroundings (2.974; n=135)	Handling and Moving Objects (2.938; n=600)	Getting Information (3.185; n=456)	Repairing and Maintaining Mechanical Equipment (2.783; n=170)
3	Documenting/Recording Information (2.866; n=396)	Documenting/Recording Information (2.717; n=125)	Interacting With Computers (3.005; n=1284)	Communicating with Supervisors, Peers, or Subordinates (2.718; n=170)

cluster. Specifically, Table 2 shows that the top three skills associated with each cluster differs materially from each of the other three clusters. In fact, of these twelve skills (i.e., top three for four clusters), only two appear twice: documenting/recording information (blue text) and handling and moving objects (orange text). The entire ranked skills list for each of the four clusters are shown in Moore et al. 2024.

In the four-cluster result, mechanical engineering M-S workers and additive M-S workers are grouped. The top three skills for this cluster are: 1) inspecting equipment, structures, or material, 2) monitor processes, materials, or surroundings, and 3) documenting/recording information. This skillset includes critical thinking skills and an understanding of quality assurance. For example, skills include "verifying quality assurance specifications" or "compare readings to specifications to detect malfunctions." The specific skills in the documenting/recording information category involve cognitive activities such as identifying context-relevant information and physical activities such as recording information. However, there are also cognitive activities that require critical thinking and communication skills such as "write technical reports" or "prepare, review, or coordinate ongoing modifications."

The second cluster includes chemical/materials M-S workers and photonics M-S workers. The top three skills include 1) performing general physical activities, 2) handling and moving objects, and 3) documenting and recording information This skillset is much more focused on physical skills such as "using hands tools" or "build, calibrate, maintain" and on following procedures. However, some troubleshooting ability is expected for repairing equipment.

Cluster three includes CNC tool operators and mechatronics M-S workers with the top three skills of 1) handling and moving objects, 2) getting information, and 3) interacting with computers. While physical skills and machine training are a part of these positions, cognitive processing of specifications and blueprints is also necessary as well as an understanding of underlying "knowledge of electronic theory and components." This skillset involves critical thinking and creative problem solving on the part of the worker to not only set up and operate computer systems, but to also troubleshoot or debug programs. This cluster must understand how the control programs work and how to test or program robotic systems.

The fourth and final cluster result is for electrical and industrial engineering M-S workers. The top three skills include 1) controlling machines and processes, 2) repairing and maintaining mechanical equipment, and 3) communicating with supervisors, peers, or subordinates. This cluster requires workers to operate and troubleshoot equipment and processes but also to communicate and make recommendations for process improvement. Some of the specific skills include cognitive activities that require critical thinking such as "review new product plans and make recommendations" or "recommend modification to existing quality standards." There are also communication skills that are required such as "providing technical assistance." An understanding of these skills can be used to evaluate existing curriculum as well as to update curriculum based on the importance of the skills and the skills gaps. However, any improvement to existing training should consider that skills are interconnected and training for a broad body of knowledge, including human skills, is critical for preparing the next generation of M-S workers (Hora 2018). Manufacturing training focused on a broader set of skills could help create a more agile workforce.

4.0 Conclusion

As emerging industries introduce new technologies, they also introduce demand for new skills. This naturally creates or exacerbates skills gaps. In this study, a method was presented to diagnose the skills needs of emerging industries and to reveal how those skills can be grouped to create effective training with limited resources.

As a first step, a method was presented to classify emerging industries that do not yet have a standardized classification code. Companies were identified using this classification method and semi-structured interviews informed hiring and training challenges and skills gaps.

Ideally, training programs would be created around individual occupations with specialty courses for each advanced manufacturing industry. However, at the middle-skilled training level, resources are limited. One strategy to address skills gaps under constrained resources is to create programs that cover in-demand shared skills across occupations and industries. These results demonstrate how the rank-biased overlap method and clustering algorithms can identify clusters of occupations and industries that require similar skillsets.

The case analyses involved eight middle-skilled occupations shared across five manufacturing industries. Here the focus is on the implications of a four cluster result which would halve the training resource needs compared to an occupation-specific training solution. As was shown in Table 2, the top skills associated with the optimal four-cluster result are largely unique to each cluster. For this case, the grouping of occupations by skills importance proved robust across clustering methods.

Training programs that focus on middle-skilled occupations tend to be under-resourced and have limited interactions with industry. To continue to provide "just-in-time" training for local industries under technological change, the methodology presented in this study can be adopted to identify relevant occupations as well as the skills gaps found in local industries. Clustering results show that there are effective ways to prioritize skills within programs under resource constraints without compromising the skills needs of local industries. Although applied for middle-skilled workers, this method could be used in other industries where resources for training are constrained.

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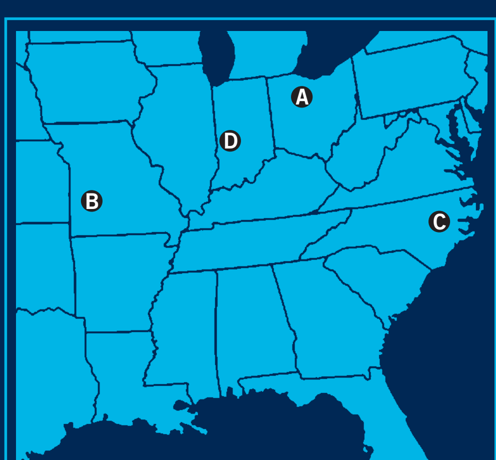

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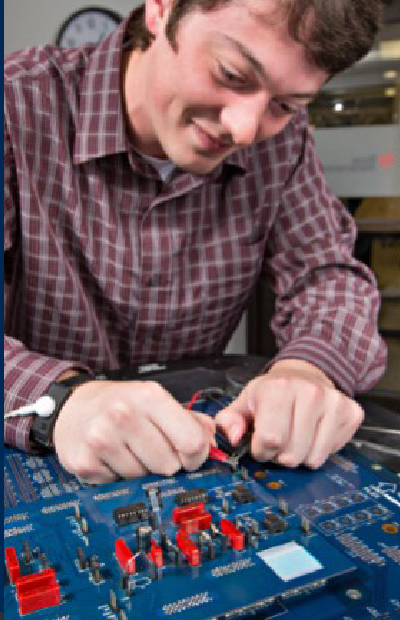



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