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A Community Framing of Integrated Engineering

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A Community Framing of Integrated Engineering

Abstract

The term "integrated engineering" is being used in new education programs. As a framing concept, we believe it has value for the wider engineering education community. A small group of program heads has facilitated conversations about how integrated engineering could benefit other programs and the community in general. This paper provides background and describes some of the outcomes of past conversations with the goal of including more voices in the conversation and initializing the formal use of integrated engineering as a prompt for improving engineering education.

Introduction

Building on a long history of multidisciplinary engineering programs, the term "integrated engineering" expands the notion of integration across disciplines to include other aspects of what it means to be an engineer and interact with the global community. With the emergence of integrated engineering programs that look very different from each other but are appearing across continents, educators have come together at colloquia and the SEFI (European Society for Engineering Education) [1] and Frontiers in Education (FIE) [2] conferences to discuss and develop a community vision of what integrated engineering can mean and how it can benefit our students, our programs, and our community relationships. These discussions have included engineering educators from various disciplines, backgrounds, professional societies, pedagogical viewpoints, and countries about the unifying aspects of integration as seen from different perspectives, how different programs are being implemented, and what others might learn from these experiences. One commonality among the programs is a desire to innovate in ways that were not seen as possible within traditional engineering disciplines. The variation in implementations could be considered a strength in contrast to the homogeneity of experiences within traditional engineering disciplines. These programs have won awards and recognition for innovation, leadership, and supporting student pathways to engineering degrees.

This paper briefly describes the three integrated engineering programs that have been used to frame earlier discussions as well as a fourth program that does not (yet) formally use the term but enacts integration in their program implementation. Rather than describing all benefits and challenges of these programs, citations allow interested readers to discover more about the programs and their specific implementations. This paper then presents various related topics including reflections from faculty at other programs who have participated in earlier conversations, key points from earlier discussions, and a starting point for the engineering education community to use for future consideration.

Four Perspectives on Integrated Engineering

Integrated Engineering is used as the name of a cross-department programme at University College London (UCL), the name of an undergraduate major at Minnesota State University, Mankato (MSU) and University of San Diego (USD), and as a useful concept at Campbell University (Campbell). The American programs (Campbell, MSU, and USD) have been ABET accredited or are in the process of accreditation as BS in Engineering programs. This section provides information about the four programs with a summary overview provided in Table 1.

Table 1: Summary of integrated engineering context at four institutions.

	UCL	**USD**	**MSU**	**Campbell**
Setting	Metropolitan, London	International border, San Diego Private school	Outstate (rural/suburban), Mankato and off-campus sites Public school	Rural but metropolitan adjacent, North Carolina Private faith-based institution
Mode	Teaching Framework	Degree (BS/BA)	Degree (BSE)	Degree (BSE)
Structure	Faculty based, Cross-Department	Department in School of Engineering with 3 other engineering majors (ME, EE, ISYE) and CS	Department, Project-based above the course-level In a college with 4 other engineering majors and CS	School of Engineering (no departments, one program and faculty)
Student Identity	UCL Engineer (Discipline majors with minors)	Integrated Engineer	Integrated Engineer	Campbell Engineer
Curricular Options	Discipline-specific degree programmes with IEP Minor Pathway chosen by students from Year 2 (disciplines: Biochemical, Biomedical, Chemical, Civil, Electrical, Mechanical, and Computer Science)	Concentrations (appears on transcript): Embedded Software, Sustainability, Biomedical Engineering, Individual Plan of Study, Engineering and the Law	Focus Areas: Integrated, Electrical, Mechanical, “Other” (civil, computer, biomedical, aerospace, software, mechatronics, chemical, process have been transcripted)	Concentrations: Mechanical Engineering, Chemical/Pharmaceutical Engineering, Electrical Engineering

Admission Standards/ Expectations	Selective admission to department/ degree programme	Selective admission to the institution, students all admitted to institution not major	Competitive admission to the upper-division program based on an application and completion of program prerequisites	No admissions criteria beyond institutional requirements (not a selective admissions institution; students admitted to engineering first semester; alternate pathways for under-prepared students)

University College London (UCL)

Students can pursue BEng and MEng degrees in discipline-specific engineering disciplines associated with the departments in the Faculty of Engineering Sciences. The disciplines include Biochemical, Biomedical, Chemical, Civil, Electrical and Mechanical as well as Computer Science. The Integrated Engineering Programme (IEP) at UCL is not a degree programme but a teaching framework shared by most undergraduate engineering programmes within the faculty. The IEP is completely embedded in the student's chosen undergraduate degree programme. The IEP emphasizes creativity, communication, choice, interdisciplinarity, teamwork, professional development and responsible innovation by learning through projects and the social context of engineering. A main goal of the IEP at its inception was to position people and the complex challenges of our world at the center of engineering thinking and practice for students by changing the way we teach engineering at UCL. The IEP is 8 years old with the first intake of year 1 students under the new IEP curriculum in 2014-15 and our first graduating class in 2017. Over 6,000 students have graduated so far.

The IEP has several innovative curricular features. An interdisciplinary cornerstone engineering design module (problem-based learning (PBL) format) for 800-1000 students is taught in parallel with the Year 1 module of our Design and Professional Skills thread (skills-based learning) aimed at strengthening student employability and individual development. The Engineering Design and Project Spine through the first two years of every degree programme includes approximately 9 team-based projects referred to as Challenges and Scenarios, culminating in a two-week intensive project scenario called How to Change the World, where students from across all the disciplines come together to create engineering solutions to global societal challenges. A faculty-based mathematics curriculum for year 1 and year 2, employs active flipped learning and scenario-based learning to teach applied mathematics supplemented with computational tools for engineering applications. Embedding authentic and contextual learning opportunities throughout the degree programmes supported by industry and community partnerships provides catalysts for embedding EDI values. Interdisciplinary capstone engineering design projects and the choice of an IEP Minor, an interdisciplinary area of study, allows student to personalize their undergraduate studies. For more information about the IEP, see these references [3, 4, 5].

University of San Diego (USD)

Students earn a BS/BA in Engineering. The BA comes from the significant amount of liberal arts courses that students take by completing the university's core curriculum. Students take foundational courses in engineering and all of them take courses focused on integrated engineering including an Integrated Approach to Energy, Integrated Approach to Electrical Engineering, Materials Science, Experimental Engineering, and Engineering and Social Justice. Students then can choose a concentration in embedded software, biomedical engineering, the law, sustainability, or an individual plan of study. Typical class sizes are about 15 students with our first graduates in 2018. The department includes six faculty members.

The program focuses on helping students see engineering as sociotechnical. This requires a strong technical foundation and an understanding of the profound impact engineers have on society. This is demonstrated in our educational outcomes which include the ability to

- apply an interdisciplinary set of technical, leadership and other professional skills to address important challenges facing society
- practice engineering with a holistic understanding of how engineers engage with stakeholders and impact society
- have a critical awareness of their personal attitudes, behaviors and values and the ways in which these align with their professional aspirations

Early thoughts on our vision for this program are described in [6]. Examples of our sociotechnical curricular approach have been published for courses including circuits, An Integrated Approach to Energy, and Materials Science [7, 8, 9, 10, 11, 12, 13].

Minnesota State University, Mankato (MSU)

Students earn a B.S. in Engineering with a major in Integrated Engineering and optional focus areas. Focus areas can be in a variety of disciplinary areas including mechanical, electrical, biomedical, process, civil, architectural, aerospace and chemical engineering. Admissions requirements include completion of program prerequisites, a 2.5 cumulative GPA, a reference addressing teamwork ability, and essays showing awareness of and desire for the learning approaches in the major. This helps prepare students for their educational experience. As a project-based program, students work closely with industry, either on industry-sponsored projects conducted on campus in teams of 3-5 student engineers or in co-op experiences where they embed in existing projects and work with industry teams. The educational experience integrates technical knowledge, professional skill development, and engineering design experience. Student engineers come into the upper-division programs with prior knowledge and experience that inform their learning and many students are non-traditional. As such, the program addresses the development of the whole student to support their development into being the type of engineer they want to be. Self-directed learning and autonomy are program values that drive the student experience and faculty decision making. More information about the specific implementations of this degree (Iron Range Engineering, Twin Cities Engineering and the IRE Bell Program) can be found in [14, 15, 16, 17, 18].

Campbell University (Campbell)

Students pursue a broader B.S in Engineering with concentrations (mechanical, chemical/pharmaceutical, electrical) rather than separate disciplinary departments. The program has approximately 180 students, 35-40 graduates per year, ten full-time tenure-stream faculty, one professor of the practice. The typical delivery is in-person on-campus. The mission, vision and value are as follows:

- Mission: To provide transformational learning experiences for a diverse community of future leaders through an integrated and experiential approach to engineering education, grounded in meaningful service and Christian principles.
- Vision: To be the leader in faith-based experiential engineering education serving diverse students and communities.
- Values: Community, Professionalism, Resilience, Relevance, Excellence, Service, Ownership, Ethics

Curricular features include a focus on hands-on project-based learning and design across all four years, using classlabs that integrate lecture and lab; strong professional development (including national engineering professional organizations) and service components and a strong focus on summer internships, industry connections, professional engineering licensure as well as K12 and community college partnerships.

Common Themes Across our Four Programs

Problems engineers tackle aren't siloed so curricula shouldn't be either. This affects both what we teach and how we teach. The curricula underpinning each of the integrated engineering programs listed above, cover a breadth of learning which have in some ways moved away from a traditional engineering education offering. For example, at USD, the program is no longer tied to a BSE degree offering and welcomes a more liberal arts approach with opportunities to enroll in a module on engineering and social justice. Similarly, UCL now offers an interdisciplinary IEP Minor pathway that gives students' choice aimed at broadening and personalizing their studies in their senior years. Campbell and MSU offer BSE degrees, however both have focus areas or concentrations that allow students to develop knowledge, skills, and behaviors through the embedded breadth of content. All programs offer explicit skills-based learning experiences aimed at building student competencies and confidence.

Fundamental to the four programs included in this paper is problem/project-based learning, which has been wholly embraced as a central part of each program's pedagogical approach to teaching and learning. Taking advantage of engineering education research, the projects students work on are authentic and rich in context so that students are able to engage in practices aligned with the profession. Additionally, projects cause students to participate in research of their own which reinforces and grounds many of the skills that these programs have been designed to support students with in their own personal and professional development. It is well known that projects provide partnership opportunities, with industry but also communities, NGOs/charities, other HEIs, K-12 education, and two-year colleges, within the curriculum to enrich the educational experience of students and better prepare them for career opportunities upon graduation. PBL is known to reinforce learning of core concepts taught elsewhere in the curriculum whilst also availing students' various occasions for skills development through the application and often practical hands-on nature of the learning experience. They are, however, also important learning opportunities for students to create new knowledge, often in an environment that is student-led and supported by peer-learning.

A core aspect of each of these four relatively young programs is the deliberate integration of values which have provided a foundation from which to build and grow for each. Positioning people and the complexities of the world in which we live, as a major focal point of the educational engineering experiences of undergraduate students is something each of the programs has done to help create engineering graduates who are able to tackle existing known and future unknown global challenges. Building student autonomy goes hand-in-hand with this as the approaches to learning adopted by these four rely on students exercising a certain degree of independence whilst faculty/staff hold less “sage on the stage” and more fostering roles.

Conversation History

Two of the authors had created an informal group of Integrated Engineering department chairs in the United States. At an international gathering of engineering programs named in Ruth Graham’s 2018 report [3], it became clear that the term was being used in other settings, specifically in the UK, Canada, and Australia. Original attempts to gather the entire group were thwarted by time zone challenges. A group of three were able to gather and had a series of conversations about the similarities, differences, and values of their programs, including the benefits seen for program students and graduates. These stimulating conversations sparked the idea that others may enjoy and benefit from extending the conversation to other groups, particularly to faculty and programs attempting to innovate engineering education in ways that increased both student engagement and inclusion.

Two workshops or special sessions were proposed, one at SEFI [1] and one at FIE [2] to ensure that the conversation included international participants. Continuing these conversations at ASEE and AAEE (the Australasian Association for Engineering Education) conferences is also planned. The format of the workshops has been similar, starting with an overview of existing programs as exemplars of integrated engineering and then asking for personal and group reflection on local contexts and potential extensions that are founded in local experiences, needs, resources, and values.

Questions Used for Framing the Conversation

The three questions used for reflection were:

How could or does the concept of integrated engineering affect:

- Your home program?
- Classroom experiences for your students?
- External partnerships and engagement (academic-industry-community) with your institution or program?

Session Conversation Outcomes

SEFI Conference

Our session at the SEFI conference was in September 2021 and was held online due to the COVID-19 pandemic. Fourteen participants attended including 11 women and 3 men. They came from a range of countries and colleagues and from industry. As expected, conversations ranged from sharing best practices as well as cross community ideas for addressing persistent challenges. Some participants were eager to share exciting things happening at their institutions demonstrating the breadth of innovative offerings across Europe. Interesting examples included interdisciplinary MAKE projects [19] and a course on Improgineering combining arts and engineering [20] at EPFL. The idea of using projects or modules where students work in teams as pedagogical tools came up many times. Some participants emphasized the importance of "real world" or "less artificial" projects including case studies and projects from industry. For some participants, the integration was between industry and academia or academia and community organizations while for others it included going across traditional academic silos and others discussed integrating presentation or teamwork skills into engineering classes. Challenges included communicating the benefit of interdisciplinary knowledge to students. This interdisciplinary knowledge extended beyond engineering for many participants including design thinking, project management, teamwork, presentation, peer feedback. The importance of alumni networks came up. Some participants cited the existence of many successful interdisciplinary programs as a challenge to establishing normalized integrated engineering programs. Many participants agreed that there is no single solution to a successful integrated engineering program and that the key is transversal, transdisciplinary skills to better prepare students for their careers.

FIE Conference

Our workshop at the Frontiers in Education (FIE) was in October 2021 and was held in a hybrid manner with some participants and one facilitator in person and the rest online due to the COVID-19 pandemic. Roughly thirty people attended this session with about one-third online with more women than men overall. Participants included faculty from across the USA and Europe in various engineering disciplines. The internet in the meeting room was unreliable making conversation between the groups challenging. As with the SEFI conference, several participants shared examples of innovative interdisciplinary efforts on their campuses. For example, University of Illinois has a CS+X degree program where students obtain a foundation in CS with a goal of applying this learning to a second discipline such as advertising or linguistics [21]. University of Colorado, Boulder offers an Engineering Plus program to provide flexibility as students choose an engineering emphasis and an additional concentration outside of engineering [22]. Cal State LA with a majority Latinx, low-income, first-generation student population is creating a holistic approach to engaging students with engineering education tied to their communities and recognizing their strengths and assets. Participants discussed how silos at public high research (R1) institutions block interdisciplinary efforts and do not reflect industry practice. The challenges of identifying projects and partnerships was a common theme. For community and industry partnerships the importance of developing long term relationships was critical to success. Preparing students to work with partners is also a challenge that must be considered. Working with communities such as Native Americans requires specific faculty development.

At both conferences, we saw a lot of diversity of thought and that people were very willing to engage in ways that the concept of integrated engineering could be useful for them, their students, and their institutions. A key value for the engineering education community is creating time and space to have conversations about ways that we can extend how we support students in their learning. This brought about the realization that much of what is happening is a chance to look at systems thinking across multiple systems that affect engineering education.

Further questions raised in discussions that we hope to address in future conversations include:

- What value does the concept "integrated engineering" have for identity development?
- What value does the concept have for employers?
- Who are your students and what do they need to be successful as they define it?
- What does engineering mean in the 21st century?
- How do students find meaning and connect that to their learning?
- How can we help student engineers develop an authentic focus on lifelong learning?
- How can we implement innovative education approaches given resource challenges (e.g., space, faculty time, and constrained thinking about what engineering education is)?

Systems Thinking & Integrated Engineering

We are growing to see that integrated engineering is an implementation of systems thinking, which allows the field to consider integrated engineering as both a moniker and a potentially useful framework for developing systems thinking in student engineers. According to Senge [23], systems thinking cultivates the ability to see the "wholes" of the system, versus domain-imposed silos, as well as the interactions and connections with the surrounding environment. The literature [24] suggests that well-designed and well-taught courses may accelerate the development of systems thinking in students. There are a number of systems thinking competency models [25, 26, 27] which emphasize principles (like lifecycles), professional and technical competencies (such as design, validation and verification, logistics, teaming and communication, broad system-wide viewpoints), skills or characteristics (like critical thinking and innovation), behaviors (including adaptability, integrity, stakeholder or customer orientation, a results focus) and knowledge (for example, domain knowledge from multiple disciplines and systems engineering management). Davidz and Nightingale [28] point out that systems thinking can be enabled through experiential learning, open-mindedness, curiosity, questioning, thinking outside the box, and a tolerance for uncertainty. The literature also looks at the relationship between design-thinking and systems thinking (in engineering), including which skills they share and where they might diverge [29]. Integrated engineering programs, while varying widely from institution to institution, do provide students with broader viewpoints and domain knowledge. Many are design and project-focused, which develops team and communication skills while fostering curiosity, questioning, critical thinking, problem-solving, innovation, adaptability, and a tolerance of uncertainty.

Moving Forward

The programs presented here use projects which provide autonomy in multiple ways for students. While this is an example that could be extended to other programs, the approaches used by these programs could change in the future as we continue to learn more about how humans learn. We honor the knowledge, values, goals and passions that students bring to the table and suggest that one useful form of integration is better integrating student experiences with their individual learning.

The energy and engagement at SEFI and FIE show that this is a conversation that should continue. We plan to continue examining what the concept of integrated engineering could include for our community, starting with the initial questions used at SEFI and FIE and moving into the deeper questions raised by the community about the impact and value of integration. One possibility is providing a framework that lets people actively integrate the most important aspects for their context. We look forward to continuing the conversation at the 2022 ASEE Annual Conference & Expo and future conferences.

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