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# Designing a Design-Driven Human-Centered Engineering Program*

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In this paper, we take a systemic design approach to the design and development of the undergraduate Human-Centered Engineering program at Boston College, a Jesuit, Liberal-Arts University. We provide details on how the program is evolving and how we are weaving human-centeredness, design, and reflective practice into the program. We share a 2-D representation of our approach to the program's design in the form of a GIGA map using systemic design principles. In doing so, we adopt the metaphor of the tree of life to represent the program design, comprising human-centeredness as a design value, design as a mode of engagement and thinking, and reflection as a mode of thinking and becoming. Human-centeredness has been a guiding design value of this project. Being situated in a liberal arts university provides unique opportunities to converge the technical and human in engineering. Design as a mode of engagement allows us to introduce students to engineering in an applied context using thinking, ideation, and prototyping for problem exploration and idea refinement. Reflective exercises will support students in integrating their learnings in engineering with the liberal arts contextually as they develop their own identities and understandings of engineering.

**Keywords:** undergraduate engineering; systemic design; program development; human-centered design

## 1. Introduction

During the Clive L. Dym Mudd Design Workshop XI in 2019, we shared that Boston College (BC), a Jesuit, Liberal-Arts University, will be launching a new program in Human-centered Engineering, enrolling students in Fall 2021. At the time, we presented the high-level concept design of this program and received valuable feedback from the Clive L. Dym Mudd Design Workshop XI participants.

The engineering program's development is a product of strategic planning activities using design-driven methodologies at the university starting in 2014. In alignment with BC's vision and mission, the development of an engineering academic and research program was one of the recommendations of this planning effort. In 2018, creating a program representative of BC's mission, and educational experiences relevant to engineering for social good gained further momentum. The office of the Associate Vice Provost for Design and Innovation Strategies initiated several working meetings and conversation sessions between institutional stakeholders and external advisors were held, including the President, Provost, Vice Provost for Research and Academic Planning, University Trustees, administrators at other universities, and industry liaisons, to name a few. These meetings developed a shared understanding of questions like: *Where is engineering education headed in the near and the distant future? Why engineering at BC? What type of engineering? Why should the program be placed within the college of arts and sciences?* These activities resulted in a situated understanding of the landscape of needs and opportunities, which led to the generation of this new program.

The department's first faculty member was hired in Fall 2020, followed by two more faculty members in Spring 2021, including the department's new chair. This team of inaugural faculty members and the original development team at the university have been tasked with implementing the vision and plans of the program, as well as creating new learning experiences and curricular structures aligned with the original motivations and needs of the students and community. With the new program set to launch and welcome its first cohort of students in the Fall of 2021, we believe this to be an opportune time to share the program's unique elements, their evolution over time and connections between them. Such a practice supports the program's development as the core team of faculty responsible for the program are coming together as a team. The practice is also helpful for communicating our vision and plan for the program to an external audience comprising prospective students, partners at other undergraduate engineering education institutions, and others who may be curious about the approach and plans.

The intent of this paper and presentation is twofold:

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- First, to provide details on how the program has evolved and how we are weaving human-centeredness, design, and reflective practice into the program since the last meeting with this community.
- Second, to share a 2-D representation of our approach to the program's design in the form of a GIGA map using a lens of systemic design principles. We believe that such an approach can be useful for designing and planning similar programs and help communicate and navigate the space of generating a program comprising multiple disciplinary domains and societal dimensions.

Hence, in this paper and the associated presentation, we treat the complex problem of designing a design-driven human-centered engineering program from a systemic design lens using the technique of GIGA mapping. The program needs to adopt agile and flexible approaches to evolve, and when required, pivot promptly in response to industry and societal needs. GIGA mapping affords planning for such future maneuvers. We focus on human-centeredness as a design value, design as a mode of engagement and thinking, and reflection as a mode of thinking and becoming, situated within the undergraduate engineering program at a university with a liberal arts educational tradition. Focusing on these three aspects allows us to share what we believe is novel about our program and receive feedback to learn from other participants' experiences at the conference.

## 2. Systemic Design of an Undergraduate Engineering Program

Systemic design principles draw from both systems thinking and design disciplines' strengths, providing a resolution between the two and creating systems-oriented design practices [1]. Systemic design offers opportunities to work with complex systems that comprise multiple subsystems. Thus, the systems thinking and design approaches inherent to systemic design are well suited to work with complex problems with various subsystems and stakeholders using design practices like reasoning, design-based generative research approaches, and representation practices like sketching and visualizing [2]. The focus of systems thinking on understanding complex systems using analytical methods and that of design approaches on creative solutions using generative techniques makes systemic design an ideal strategy for situations which require both an analytical, systems-based way of understanding the design space and generative methods that result in creative solutions. This paper focuses on a design problem well suited for systemic design inquiry, i.e., designing a design-driven human-centered engineering program. The complexity of the systems and subsystems involved in the design space (of developing a new program) and the need to create a new artifact (in the form of a new program) merit using systemic design inquiry to approach this problem space.

The subsystems that comprise the larger system of designing the program are (1) human-centeredness as a design value; (2) design as a mode of engagement and thinking; and (3) reflection as a mode of thinking and becoming. These subsystems are enabled by an undergraduate general engineering program within a liberal arts educational tradition. As a way to interrogate societal needs and develop a sense of responsibility, human-centeredness has been a guiding design value of this project, and being situated in a liberal-arts university provides unique opportunities to converge the technical and the human side of engineering. These human-centered values form the bedrock of and inform the external-facing attributes of the program. The program, which is an undergraduate program (awarding B.S. degrees in General Engineering), provides a venue for design and reflection practices that embody the program's human-centered motivations. Design as a mode of engagement allows us to understand society's needs in an applied context using thinking, ideation, and prototyping processes for problem exploration and idea refinement before developing solutions. We also believe that the extent of practicing reflection and its role in helping students contextually integrate their learnings in engineering with their non-technical curricular and non-curricular activities is a distinguishing feature of the program.

## 3. GIGA Map as an Approach to Systemic Design

Very simply put, GIGA maps can be thought of as multi-layered and dimensional concept maps that depict complex boundaries and interactions between various elements. Some uses of GIGA mapping as an approach within systems-oriented design include grasping complexities of multiple systems and subsystems, designing and critiquing complex situations, understanding and sharing problem spaces, and moving between the analytical and the generative [3]. In explaining the function and possibilities of use of GIGA maps, Ryan [4] writes,

> "GIGA – maps provide a multi-scale, multi-layered framework for [visualizing] information gathered during a systemic design inquiry. The GIGA – map helps to draw system boundaries, as well as to show

and name connections and potential interactions across domains and categories" (p. 11)

GIGA maps draw upon design skills of synthesizing and visualizing to frame and treat design spaces using systemic design or systems-oriented design principles [5, 6]. In addition to serving as a means to understand and visualize complex problems, GIGA maps provide opportunities to engage with systems problems using research through design (RTD) practices [7].

Approaches and frameworks such as Sevaldson's [5] matrix for suggesting types of maps for different design activities, the GIGA mapping process [6], and the GIGA mapping ladder for pedagogical use [8] have been developed. However, these frameworks are suggestive and in their initial stages of development. Ryan [4] also warns of over-reliance on methods, especially prescriptive first-generation methods, that can undermine the rationale for pursuing systemic design approaches. We explain our motivations and intentionality behind our approach below.

## 4. Approach

We use a GIGA map to visualize and communicate our approach to the complex design problem of designing a program with multiple dimensions. The subsystems we focus on include (1) human-centeredness as a design value; (2) design as a mode of engagement and thinking; and (3) reflection as a mode of thinking and becoming, all supported and enabled by an undergraduate engineering program within a liberal arts university.

The program possesses unique features beyond meeting the requirements for an undergraduate degree in general engineering and the students' engineering education supplemented by courses in the university's liberal arts core. Namely, its human-centered motivations, design practices embedded in the coursework as a way of engaging with course content and developing ways of thinking, and weekly reflections throughout the four years of the program to develop ways of thinking and crafting ways of becoming engineers *for others*. Thus, to develop a way of communicating and developing a shared understanding of the program, we looked toward different design practices and principles for approaches that can help make collective sense of the system we have at hand. The multiple subsystems within the program's more extensive system and the need to generate new types of experiences merit a systems-oriented design approach to develop. We use GIGA mapping as a method to formulate artifacts for shared understanding and communication.

As a group, the authors have met several times since January 2021 for an average of approximately five hours every week for planning meetings. These planning meetings have informed the elements, nodes, and connections of the subsystems in the GIGA map, in addition to prior work done by the development team. The lead author created concept maps of each of the subsystems, and the team of authors collaboratively edited the individual concept maps. The group discussed the placement of connections between the subsystems, which the authors believed were analogous to *the roots, trunk, and branches* of a tree. Hence we adopted the metaphor of the *tree of life* to frame the system representing the program's design.

The *roots* represent the design value of human-centeredness that informs the program's design and is the underlying value throughout the undertaking. The *trunk* represents the scaffolds on which the program is built, i.e., engineering, liberal arts, and reflection. The *branches* represent design and reflection practices that inform the students' development. In the following section, we will zoom into the three subsystems of the GIGA map and then arrange them together to assemble the final map. It is essential to acknowledge that this paper's language and figures represent the current thinking and plan. True to engineering design, an iterative process that includes stakeholder feedback will drive changes as we implement the plans.

## 5. GIGA Mapping

### *5.1 Human-Centeredness as a Design Value*

The new Department of Engineering, which has been deliberately housed in a college of Arts & Science (Morrissey College of Arts and Sciences (MCAS) at BC) will offer this program. This intentional arrangement aims to provide BC engineering students with opportunities to understand complex sociotechnical problems and appreciate the impact their engineering will have on society from multiple perspectives. Key elements of the undergraduate experience include a rigorous liberal arts core, user-oriented inclusive design, general engineering fundamentals, technical engineering electives, service-oriented capstone projects, and reflective practice spanning the program's four years. The BC Core curriculum includes a 15-course requirement that "broadens students' intellectual horizons while shaping their characters and helping them learn how to discern well – preparing them for meaningful lives and rewarding careers" [9]. Engineering students will take these courses throughout their eight semesters. Fig. 1 represents the concept map of the major aspects of how human-centeredness is used as a design value in structuring this program.

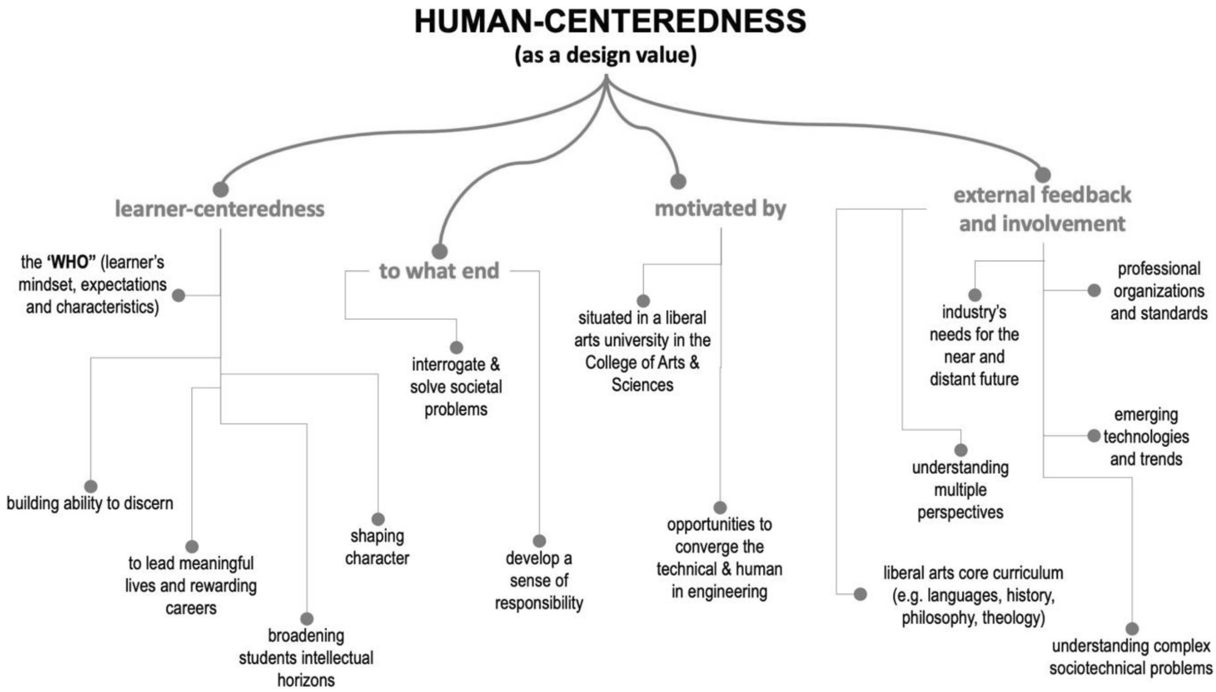


**Fig. 1.** Human-centeredness as a design value.

### *5.2 Design as a Mode of Engagement and Thinking*

The curriculum's user-oriented design elements begin in the students' first semesters in one of two courses: Innovation through Design Thinking or Making the Modern World. The first course is a collaborative effort between an industrial designer and an engineering faculty member. This course precedes the development of the engineering program, and is intended to catalyze design and innovation across the university in response to student expectations and industry needs for holistic problem solvers. In the most recent iteration, the latter course was collaboratively taught by an engineering faculty member, a historian of science and an environmental theologian. Both these courses are offered to all majors at the university. The practice of inclusion and empathy leading to the co-creation of user-validated solutions with quick prototypes and simulations are some of the course outcomes. In their second semester, engineering students will take an Introduction to Human-Centered Engineering and Design course, which builds on their previously acquired design thinking, sketch prototyping, and story-telling skills to integrate them with introductory technical concepts of modeling, fabrication, and computation. Techniques of extended reality like augmented and virtual reality will also integrate simulated prototyping and immersion into this course. The students will learn physical prototyping skills as part of this course in a Makerspace. They will also discuss the societal impacts of engineering and design from anti-racist and feminist perspectives. The weekly reflection seminar will also support these discussions.

Students will take 16 credits of engineering fundamentals in studio courses spread over two semesters in the second year. In these courses, students will learn fundamental engineering, mathematics & science concepts and skills in an integrated 'liberal arts' approach, all including a significant project-based learning component. Students will take a human-factors in engineering design course in their third year and work on a capstone project with significant service and community-based work. Project-work and hands-on experiences in this course will focus on human-centered application and problems, such as access, inclusion, and cultural relevance. Students will take a course on engineering for development and a project-based final senior capstone project course in their fourth year. The prototyping skills that the students learn in the first year will be practiced and further developed during these courses in the third and fourth years. Fig. 2 represents the concept map of this subsystem.

### *5.3 Reflection as a Mode of Thinking and Becoming*

Motivated by the role of reflective practice in educating engineering designers, developing a sense of professional and individual identity, and developing a quality of ethics and discernment within the liberal arts tradition, we envision three *branches* of reflective exercises running through the four years of the

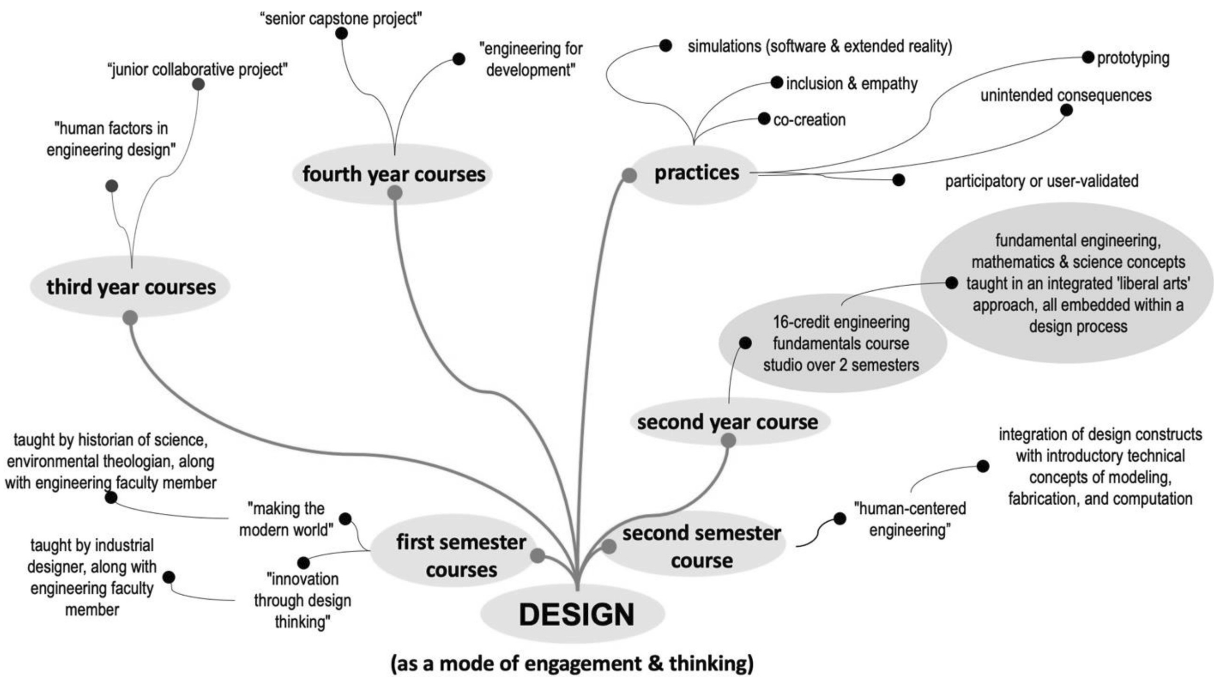


**Fig. 2.** Design as a mode of engagement and thinking.

program. Students will develop reflective practice via weekly joint reflections, individual reflection, and formative reflection during course activities. The objectives of these reflection sessions are: (1) to develop engineering knowledge and practice by integrating experiences in technical and non-technical courses; (2) to develop ways of thinking to understand complex sociotechnical problems leading to an understanding of the role of engineering in society, so that they can carry out their vocation responsibly. All the objectives will be grounded in an environment focused on cultivating the whole person. A priority of the reflection activities will be to engage with ethical dimensions of engineering and design and to connect to the humanistic and social justice-oriented motivations of the HCE program. As students become practiced in weekly reflection through their four years, it will become a venue for programmed activities (e.g., speakers, workshops) and self-directed introspection.

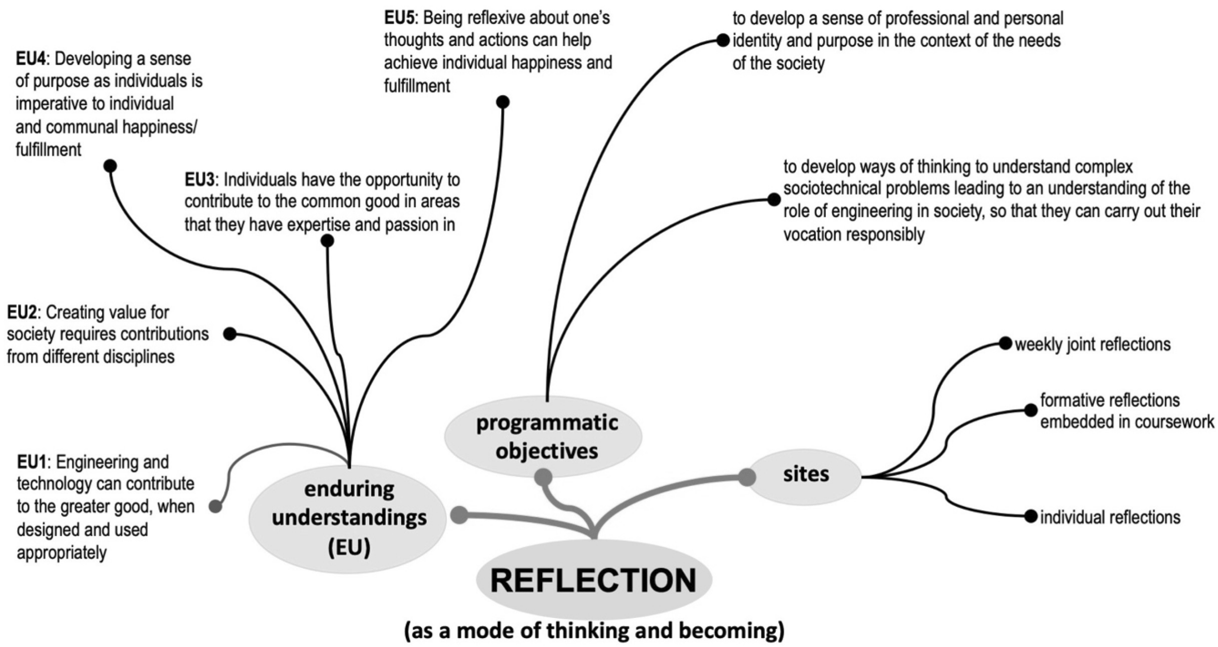


**Fig. 3.** Reflection as a mode of thinking and becoming.

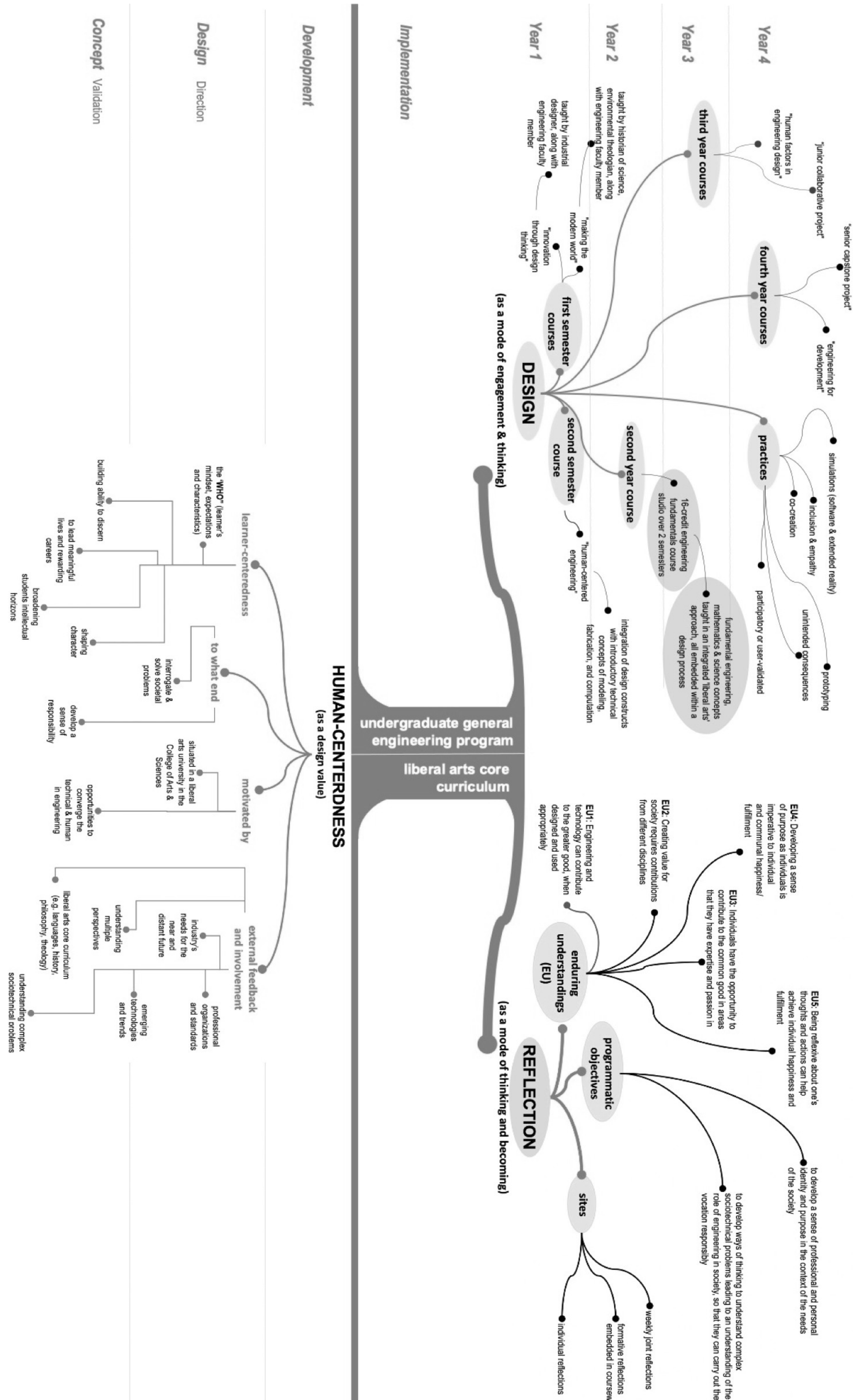


**Fig. 4.** 2-D representation of our approach to the program's design in the form of a GIGA map.

After four years in the Engineering program at BC, students will develop enduring understandings aligned with the following statements:

- Engineering and technology can contribute to the greater good when designed and used appropriately.
- Creating value for society requires contributions from different disciplines.
- Individuals have the opportunity to contribute to the common good in areas that they have expertise and passion in.
- Developing a sense of purpose as individuals is imperative to individual and communal happiness/fulfillment.
- Being reflexive about one's thoughts and actions can help achieve individual happiness and fulfillment.

As students progress through the program, they will be supported and encouraged to construct individual narratives of their experiences by asking questions like, *how am I becoming who I think an engineer is? How does engineering present itself in who I am as a person and my place in society?* Fig. 3 represents the concept map of this subsystem.

### *5.4 Complete GIGA Map*

Fig. 4 is the completed GIGA map with the three subsystems of human-centeredness as the *roots*, design as one of the *branches*, and reflection as the other. The *trunk* of the *tree* shows engineering and liberal arts, representative of the support structures. The human-centeredness *roots* have been developed over phases of concept validation and design directions, culminating in the program's development. The elements above the *land* represent the implementation of the plans. The engineering and liberal arts *trunk* support the design and reflection *branches.* The design *branch* is marked to show the progression of using design to think and engage over the program's four years.

## 6. Tradeoffs in Program and Curriculum Development

We were faced with several tradeoff decisions in the development of the program. We share a few that could be relevant to other liberal arts engineering programs and new programs aiming to seek ABET accreditation. We decided to house the engineering program and department in the MCAS rather than a separate college or school of engineering in order to ensure a high-level of integration between the engineering program and the liberal arts focus of the college. The university has a significant liberal-arts-based core requirement with fifteen requirements including in philosophy, theology, history, social sciences, art and cultural diversity. In addition, the college of arts and sciences has a language proficiency requirement at the intermediate level. Further, we decided to pursue accreditation by ABET in order to ensure external recognition and validation of the program, as well as elements such as continuous improvement. Combining ABET requirements, the significant curricular content required to train practicing engineers, and the requirements of the University and the MCAS results in limited flexibility in the curriculum for students who do not have advanced standing when they enroll. This limited flexibility is in contrast with the liberal arts ethos of providing students with the opportunity of exploring a range of different areas of knowledge. On the other hand these constraints have resulted in distinctive courses such as "Making the Modern World", which is co-taught by a historian and an engineering faculty member, which satisfies one history, and the cultural diversity core requirement, as well as providing engineering credit. As such, we view these constraints as catalysts for curricular innovation. Ultimately, we concluded that the benefits of housing the program in MCAS and pursuing ABET requirements were substantial enough to warrant the limited flexibility in students' course schedules.

## 7. Conclusion

In this paper, we use systemic design principles to share the development of the undergraduate human-centered engineering program at Boston College. We use the tree of life metaphor to represent the three primary aspects of the program, namely, human-centeredness as a design value, design as a mode of engagement and thinking, and reflection as a mode of thinking and becoming. We share details on the courses and learning experiences that contribute to these aspects and the connections between them. We also share tradeoffs that we made in developing the program that may be relevant to other programs in their infancy or considering redesign. We hope this work provides an example and framework for developing programs comprising multiple disciplinary domains and societal dimensions.

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**Avneet Hira** is an Assistant Professor of Engineering in the Human-Centered Engineering program at Boston College where she is a founding faculty member of the program. Her scholarship is motivated by the fundamental question of how engineering and technology can support people in living well in an increasingly engineered world. Her research, which is in engineering education, focuses on affordances of technology, humanistic design, and engineering epistemology. Her work is inspired by Making and tinkering practices, especially those from different local knowledge systems. Prior to Boston College, Avneet worked at the MIT Scheller Teacher Education Program and Education Arcade as a research scientist and at MathWorks as an education program manager. She partners with students and educators (middle school to undergraduate), youth and their families, community organizations, artisans, Makers, designers, and technologists in her work. She is passionate about creating technology-rich inclusive spaces for supporting purpose and connection in engineering education. Avneet received her PhD in Engineering Education and MS in Aerospace Engineering from Purdue University, and BE in Aeronautical Engineering from Punjab Engineering College. The lab's current work includes projects focused on: using emerging technologies for sustainability education and intergenerational learning in open-ended project-based settings; interrogating the affordances of mixed reality for embodied experiences in design education settings; understanding the impact of the pandemic on school STEM learning; and developing human-centered engineering and design frameworks to support capacity building in communities.

**Sunand Bhattacharya** is Boston College's design and innovation strategist. As a learning architect, design educator and an industrial designer, he has been spearheading the design and development team to create BC's first human-centred engineering program. He is also tasked to help build a future-forward culture of collaborative innovation across BC using design-driven methodologies to address real-world challenges. His professional experience covers management of design-driven projects and education-related endeavors at various leadership levels, including curriculum research and development for new academic programs and campus initiatives. Before returning to academia, Sunand was the Global Learning Strategist for Autodesk Inc., leading its Learning Futures team dedicated to Autodesk's future influence advocacy in design related STEAM and engineering education. Prior to Autodesk, Sunand was the principal and co-founding partner of Arjuna Learning Designs LLC., a firm specializing in the creation of interactive learning objects to enhance quality of teaching and learning for leading publishing houses. He has also been a tenured professor and head of industrial design at Southern Illinois University at Carbondale. Sunand is a recipient of the 'Innovative Excellence in Teaching, Learning, and Technology' award from The International Conference on College Teaching and Learning. He holds advisory positions at US institutions like Franklin Olin College of Engineering, Purdue University Polytechnic Institute, Cal State Northridge and Station1-MIT, Nirma University, as well as serves on the boards of Mass College of Art & Design, Global Minimum Inc. (GMin) in Kenya and Agastya International Foundation (US) in India. Sunand received his Master of Design (MDes) in Industrial Design from the National Institute of Design in India, and holds a terminal post-graduate degree in Industrial Design and Human Factors from The Ohio State University.

**Glenn R. Gaudette**, PhD, is the inaugural John W. Kozarich '71 Chair of the Department of Engineering at Boston College. Working together with his colleagues, they have developed the first Engineering program in the history of BC. His research has pioneered the use of plants as scaffold for heart regeneration. This work lead to significant recognition, including Prof Gaudette and his colleagues being featured throughout the world including Bill Nye Saves the World (on Netflix), CBS's Innovation Nation, the BBC (live interview) and Popular Science. The work was displayed at the Centre Pompidou (Paris) as part of an exhibit entitled "The Factory of Life". Recently, a children's book (From Plant to Human: The Extraordinary Spinach-Leaf Heart by Oscar Silver) was published about this inspiring work. His recent research aims to develop cost-effective methods for growing meat in the laboratory setting, which could reduce our reliance on conventional animal agriculture. Dr. Gaudette also teaches engineering mechanics, design and innovation, biomechanics and physiology. He promotes the development of a mindset for helping others, especially in the technical courses he

teaches. He was named the 2015 Faculty Member of the Year by the Kern Entrepreneurial Engineering Network and was elected a Fellow of the American Institute of Medical and Biological Engineering (AIMBE) and the National Academy of Inventors.

**Siddhartan Govindasamy** is a Professor of Engineering in the Human-Centered Engineering program at Boston College where he is a founding faculty member of the program. He was also a member of the team which created the initial design of the program prior to its establishment. From 2008–2020, he was an Assistant, then Associate Professor of Electrical and Computer Engineering at Olin College of Engineering where he was an integral member of the team that redesigned the early-stage mathematics and science curriculum and created an analysis stream at the college, in addition to being a faculty member in their Affordable Design and Entrepreneurship program. He has served as an advisor and consultant to multiple institutions in the United States, Asia and Europe in their efforts to make their engineering programs more integrated and student centered. From 2000–2008, he was a DSP and then senior DSP engineering at Aware Inc. where he worked on developing broadband technology. His technical research interests are in wireless communications and signal processing where he works on multi-antenna radio communications and optical wireless communications. He is a co-author of the text, Adaptive Wireless Communications: MIMO Channels and Networks, Cambridge University Press, 2013. Dr. Govindasamy completed his high school education in his native Malaysia and received his Bachelors, Masters and PhD degrees from the Massachusetts Institute of Technology in 1999, 2000 and 2008 respectively. He has been at Boston College since 2020.