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# A Longitudinal Engineering Education Study of a Holistic Engineering Pedagogy and Holistic Design Thinking Methodology on Postsecondary Student Academic Success and Retention

**Mark J. Povinelli, College of Arts and Sciences, Syracuse University**

## Introduction

Over the past decade, there has been significant effort to increase the number of secondary students in engineering educational programs, and engineering colleges have been working to improve student academic success and retention rates. However, there is still uncertainty about how specialized commercial secondary engineering programs translate into future postsecondary educational outcomes as well as their impact on intellectual development and retention rates. To help educators understand pedagogical approaches and methodologies that result in academic attainment and retention outcomes, it would be beneficial to obtain direct feedback from secondary students as they move through their college engineering programs.

Analyzing the qualitative feedback data from secondary engineering students can provide insights into their future states and experiences. Coupling this with retention rate data can help ground the qualitative data. It would also be useful to gather information on students' experiences while in the postsecondary programs to understand how the secondary experience and knowledge modulated their ability to adapt, cultivate purpose, understand engineering concepts, and academic goals.

This paper presents a study investigating the effectiveness of an innovative Holistic Engineering pedagogy for secondary and postsecondary engineering students that includes a novel Holistic Design Thinking methodology. The approach emphasizes a holistic and transdisciplinary philosophy to engineering education, beginning with a foundation of knowledge on love, empathy, and ethics, and with a focus on engaging students' emotions in the learning process. The paper reports eight years of qualitative results in teaching this experiential pedagogy to secondary and postsecondary engineering students, with an emphasis on broad integrated transdisciplinary knowledge.

Furthermore, this paper describes an experiential college preparatory program for high school seniors embedded in an engineering company and reports the outcomes of a longitudinal study over four and half years. The study gathered feedback from three secondary graduate cohorts on what knowledge content and learning practices in their secondary program were most helpful in their success at the postsecondary level. Forty-eight secondary students entered the program, with forty-two completing it. The study also discusses the impact of low student-to-teacher ratios and teacher experiences in transforming experiential knowledge into acquirable student knowledge.

The research offers insights on the effectiveness of these pedagogies in promoting students' comprehension of engineering principals and interpersonal skills. It presents qualitative data from interviews and surveys, along with retention rate data. Overall, the goal is to provide awareness into this pedagogical approach to engineering education and contribute to ongoing discussions on approaches that promote holistic, transdisciplinary learning through emotional engagement of students.

**Background**

Retention rates for students enrolled in postsecondary engineering programs have shown fluctuations between forty to sixty percent over the past several decades [1]. According to a study conducted by the American Society for Engineering Education (ASEE) in 2017, the retention rates for students ending their studies in 2012 were higher than in previous years [2]. The study also highlighted an increase in four-year graduation rates from 29 percent in 2006 to 33 percent in 2011. However, the graduation rate dropped to 22 percent in 2015, and survey responses from colleges were inconsistent, making it difficult to determine the exact rate in that year.

Numerous studies have researched the factors influencing retention rates in engineering programs. In a 2013 Geisinger and Raman analyzed fifty studies on attrition rates in engineering education at the postsecondary level and found broad factors driving students to leave engineering including “classroom and academic climate, grades and conceptual understanding, self-efficacy and self-confidence, high school preparation, interest and career goals, and race and gender,” which they believed were interrelated [3]. Of these studies, twenty-eight indicated that high school preparation was a factor. The studies revealed a host of high school pedagogical reason for attrition, including inadequate mathematics (calculus) preparation, low performance in science classes, including physics, social sciences, and chemistry, overall high school GPA, and high school class rank. Some studies indicate that women and racial minorities may have less access to high quality educational resources and opportunities during their high school years, which could impact their level of preparation for engineering programs in postsecondary education. A significant number of studies also found that high school students who participated in Project Lead the Way, robotics club, or STEM activity experiences had no significant impact on retention [4] - [8]. Due to the complex and multifaceted nature of education, researchers are still exploring the correlations and causation between various pedagogies and their impacts on student retention rates. For senior high school students, cultural norms and other external factors can influence their motivation and habits [9] - [11]. Research studies have demonstrated that interventions such as goal setting, self-reflection, and providing feedback are effective in enhancing student motivation and academic achievement. At the highest level, these factors include the preparedness, dedication, and understanding of students, teachers, and administrators to face the academic challenges of engineering college [12], [13].

To address these issues, several engineering educational institutions, government departments, and standard boards have called for a change in engineering education at both the postsecondary and secondary levels. These recommendations have come from the ASEE; United States (U.S.) Department of Education; The Next Generation Science Standards (NGSS); National Academies of Science, Engineering, and Medicine (NASEM); National Science Board; National Science

Foundation; The Royal Academy of Engineering; and the Accreditation Board for Engineering and Technology [14] - [19].

The U.S. Department of Education has promoted the inclusion of engineering concepts and skills across all elementary and secondary levels and courses. In 2020, the NASEM called for building capacity for secondary engineering education by improving engineering literacy, subject-matter knowledge, and pedagogical content knowledge for engineering teachers. In 2013, the NGSS also called for increased engineering content across all curricula in secondary schools.

Together, these organizations have identified three main actions to improve secondary engineering education. Firstly, there is a need for accessible material to improve engineering literacy among secondary educators and students. Secondly, subject-matter knowledge and usable curriculums for these groups need to be improved and be applicable across a broad spectrum of subjects. Thirdly, resources and methods are required to help educate the increasing number of engineering, engineering technology, and science teachers hired to fill the national STEM gap in current education. They also called for the training of secondary teachers across all disciplines to incorporate engineering knowledge into their pedagogies and curriculum. A more accessible engineering curriculum would help the increasing number of secondary non-major engineering teachers provide knowledgeable curriculum with engineering pedagogies to students.

For secondary educators, this included the call for improving their engineering literacy, knowledge, pedagogies, curriculum content, and competencies. This curriculum content also includes interpersonal and professional skills, design, and team skills. Standardized testing strategies of secondary education have also left students in need of thinking and reasoning skills as well as practice in developing and using inferences and intuition in problem solving. Societal technological impacts have also left students struggling to understand the psychology of self and group dynamics [20].

Along with these studies there have been various hypotheses as to what secondary experience could impact postsecondary engineering study, including the rigor of the program and the environment and culture of the course [21], [22]. Academic grades in high school that are indicative of rigorous learning and challenging intellectual content can contribute to the students' postsecondary success, but there is a wide disparity of academic grading over secondary schools. This may lead to students falsely believing they are more prepared than they are. Students whose schools did not prepare them for the rigor of engineering coursework often feel overwhelmed, frustrated, and lose motivation [23].

At the postsecondary level, the Accreditation Board for Engineering and Technology curriculum standards include a greater emphasis on experiential, hands-on learning, as well as design, build, and test experiences, and the development of professional/interpersonal skills. This is not surprising, as design is ubiquitous in human nature and is at the core of engineering. Research at this level has also shown that combining traditional and experiential learning pedagogies can enhance overall cognitive competency [24] - [27]. These standards could help inform educational pedagogies for engineering curriculum at the secondary level.

**Theory**

The challenges facing engineering, including solving existing technological human-made global crises; simultaneously stabilizing existing and creating new infrastructure; and accessing technological impacts on quality-of-life issues, call for increasing the diversity of human and environmental voices in design. Increasing these perspectives can help students understand the impacts of proposed new technologies and reduce unforeseen consequences. However, the problems facing engineering educators is how to bring broad knowledge content, flexible design practices, and these real-world problems and dynamics into the classroom.

Providing students with a versatile way of engineering that will allow them to develop and use critical, causal, and creative thinking, life skills, and human knowledge with others remains a challenge. Although there are numerous approaches to teaching engineering design its focus is not typically on broad transdisciplinary knowledge required to engage students in self-discovery and the needs of others, the environment, and working in teams. Student acquisition of transdisciplinary knowledge and identification of educational needs are limited due to lack of educational emphasis; teacher and administrator experiences; curriculum; time constraints; availability of a robust design methodology; and focus on design and build.

This paper presents a new pedological philosophy called Holistic Engineering (HE) and a novel Holistic Design Thinking (HDT) methodology for secondary and postsecondary education that have been developed, researched, and refined over thirty years of practice teaching engineering at the secondary and postsecondary levels, as well as working as a design engineer in industry. The HE pedagogy emphasizes the use of emotions and metacognition in learning to increase students' agency and abilities. This holistic approach begins with individual emotional and cognitive challenges and growth, and includes social-emotional learning through experiential team-based design projects and cognitive engagement.

This pedagogy draws on Piaget's theories of action, object permanence, experimentation, and abstraction in preschool learning experience, as well as Dewey's exploration of the connection between education and experience [28], [29]. Kolb's theory of education extends Piaget and Dewey's work, emphasizing experiential learning beyond the classroom and into everyday life settings which are relevant to design practices. Kolb's cyclical model of experiential learning, which uses feeling and thinking as a basis for observation and action to achieve learning through adaptation, provides a useful foundation for this approach. The HE pedagogies discussed in this paper involve experiential and active learning methods based in part on Kolb's experiential learning theories [30], [31].

In addition, Zull's 2002 work on whole-brain transformational learning, rooted in a neurobiology understanding of the learning process, emphasizes the significance of emotions, sensory experiences, and spatial relationships in making connections to previous knowledge, with implications for enhancing design educational methodologies [32]. Additionally, Zull and other Mind, Brain and Education researchers studying the neurobiology and psychology aspects of learning, have begun to show a connection between emotions, cognition, refection, and creativity being principal factors that either facilitate or impede learning [33], [34]. The implications of this work have the potential to enhance effective engineering design education.

HE emphasizes the connection of mind, body, and spirit in learning and the value of small learning communities with teachers who hold degrees in engineering and possess design work experience. Low student-to-teacher ratios have been found to have a positive impact on teacher-student engagement, learning, student motivation, and future academic outcomes [35] - [37]. The ability of experienced educators to draw on their episodic memories to create personalized images and examples is crucial in helping students recognize and integrate details that trigger complex ideas and emotions, leading to a deeper understanding, connection, and formation of new concepts [33], [38], [39]. Furthermore, it advocates for a combined approach to learning pedagogies that includes holistic, active, and experiential methods along with broad integrated transdisciplinary knowledge.

The HE pedagogy used in this research aimed to connect the students' emotional, cognitive, and bodily abilities in learning. To achieve this goal, the pedagogy provided students with an understanding of the various learning mechanisms available to humans from an evolutionary perspective and through the study of the behavioral and cognitive sciences. These mechanisms include associative, instrumental, conscious, and goal-directed deliberation [40], [41]. By exploring the impacts of emotions and dopamine on habit changes, students can move from habit building and character development to motivation and purpose. This approach emphasizes the significance of understanding how the brain and mind function, as well as the role of emotions, cognition, curiosity, and creativity in the learning process. It also promotes student understanding of their cognitive learning abilities based on mental representations, higher-order reasoning, and complex internal deliberations. Furthermore, it raises awareness that decision-making processes can be driven by habits and goal-directed instrumental behavioral and learning systems.

The HE pedagogy focuses on connecting students' understanding of habit changes to these practices and enhancing agency in goal-directed deliberative and cognitive learning practices essential for college and beyond. The pedagogy incorporates deliberative practice methods for knowledge acquisition and transference, which tie into the formation of episodic memories. Episodic memories are crucial for creativity in engineering design, problem solving, and building executive awareness [42]. To achieve this, experiential, active, and reflective learning with teacher feedback loops is critical. As a result, students can engage in more powerful goal-directed deliberation and other cognitive learning practices, as well as creative design and enhanced problem-solving capabilities. This approach underscores the significance of incorporation psychology, experiential, and neuroscience/neurobiology-learning findings into engineering classroom practices.

**Pedological Philosophy**

The HE philosophy aims to guide students in a holistic understanding of themselves and others, fostering the development of life, social, interpersonal, technical, and leadership skills through the practice of love, compassion, empathy, and ethics. It emphasizes the interconnectedness of people, the environment, and the planet as a whole system that is greater than the sum of its parts or any individual problem. The HE pedagogy values the role of student emotions in engineering education, providing a foundation for students to observe, be curious, and creative, develop empathy, and reflect on what it means to be human in terms of developing their gifts and their ability to love and empathize with others. It promotes the acquisition of broad, integrated, and transdisciplinary knowledge that includes various types and flexibility in modes of thought and operations and levels in thinking.

The core of this pedagogy is the HDT methodology, which aims to improve students' ability in creating and collaborating in effective design teams both inside and outside the classroom. By fostering experiential design practice that engage with people and environmental needs, students learn to collaborate and co-design as they innovate and create ethical solutions that looks at the larger picture of how technology, humanity and the environment are interrelated. They also develop the ability to weigh ethical decisions and understand the growing conflict between empathy, the environment, and technology, driven by our rapid pace of technological innovation.

Specifically, the teaching philosophy in HE is based on eight overarching principles. First, it emphasizes the uses of emotions and metacognition as a process to increase students' self-motivation, learning, and agency. Secondly, it guides students in the development of interpersonal, technical, and leadership skills through the practice of love, compassion, empathy, and ethics. Thirdly, it helps students become more self-reflective, curious, intrinsically motivated, creative, independent learners, and discovering and cultivation of their gifts, talents, and purposes. Fourthly, it provides students with a broad base of integrated transdisciplinary knowledge to develop critical and creative and other thinking and design skills. Fifthly, it helps students understand the connection between love and empathy, empathy, and technology, in the context of responsible ethical development and the important role they have in advancing economic, social, and environmental justice. Sixthly, it provides students with social-emotional and experiential learning through an innovative HDT that engages them in team-based design projects focused on addressing the needs of both people and the environment. Seventhly, it engages students in analog sketchbook practices. Finally, it prepares students for success during and beyond their college years.

**Pedological Approach**

The HE pedagogy comprises a diverse range learning approaches, including holistic education, analog, social, experiential, ecological system theory, critical pedagogy, cognitivism, humanism, constructivism, behaviorism, and psychology and neuroscience/neurobiology-informed learning. This pedagogy views engineering education as a holistic practice that places equal emphasis on both emotional, cognitive, and physical aspects of students' well-being and learning, recognizing the central role of psychology and neurobiology in understanding how learning takes place. It also incorporates affective and experiential education, which includes neurobiology learning through student cycles of testing, experience (gathering), reflection (meaning), and abstraction (creation).

Moreover, it embraces transdisciplinary education and determination theory, whereby the dialogical and student-centered learning process involves students' agency in changing their knowledge, beliefs, and behaviors. This approach encourages motivation through emotional learning and emphasizes collaborative, integrative, and constructive learning. The approach integrates placed-based learning with journaling and sketching to foster observation, curiosity, imagination, and creativity while also employing rigorous homework practices that involve critical reading and reflective, analytical, and critical writing. The approach of providing students with cumulative and integrated transdisciplinary learning content, equips them with the necessary knowledge and heuristic abilities to work effectively in HDT teams, even before they embark on their design projects.

**Pedological Methodology**

Learning methodologies in Holistic Engineering (HE) draw on numerous established practices and those developed in teaching this pedagogy over the past eight years. HE embraces a variety of learning methodologies including holistic, inquiry-based, reflective, traditional, neuroscience, active, collaborative, self-directed, experiential, sense modalities, empathetic, experimental, and psychology and neuroscience/neurobiology-informed learning. These learning methodologies are used in conjunction with teaching methods and strategies that include 1) starting each class with a student sharing, learning, and reflection circle, 2) developing student intrinsic motivation through emotions, excitement, love, interest, and curiosity; discovery of gifts thorough self-awareness and reflective practices; self-learning and intellectual/academic habit formation through prototyping and practice, 3) fostering student transformational learning practices focused on love, compassion, empathy, ethics, diversity, and sustainability, 4) encouraging student acquisition, practice, and integration of transdisciplinary knowledge, 5) cultivating student acquisition of flexibility in modes, operations, and levels of thought, 6) utilizing student analog sketchbook practices of capturing and sharing of knowledge through reflective, observational, analytical, and critical writing, sketching, notetaking, research, ideation, and drawing, 7) assigning rigorous homework practices in critical reading; reflective, analytical, and critical writing; sketching; and weekly grading reflections, 8) incorporating Holistic Design Thinking student learning and practice, and 9) engaging students in experiential team design projects using the HDT, centered around equity.

Transdisciplinary knowledge topics are introduced through lectures, readings, dialogues, multimedia content, and learning methodologies. The transdisciplinary knowledge includes critical thinking and reading; reflective , analytical, and critical writing; time management and organizational skills; causal thinking; love; empathy; ethics; visual thinking; modes of thought (including critical, causal, visual, analytical, systems, connective, creative, categorical, verbal, language, bodily, tactile) and flexibility in type, operation, and level; psychology; communication and design theory; creativity and ideation techniques; prototyping; research; civics and politics; economics; art; neuroscience and neurobiology (how the brain and mind works and memory systems); physics, philosophy; history and physics of engineering, technology, and science; how to engineer; biomimicry; team dynamics; reality belief systems; privilege and diversity; mindfulness and patience; character; and leadership.

Students engage in a variety of structured reflective practices to actively test and transform transdisciplinary information including questioning; readings; case studies; analytical and critical writing; personal and work experiences; class dialogues; individual and team projects; presentations; critiques; student weekly grading reflections; and conferences. These practices facilitate connections between their memory, learning, reasoning, and knowledge acquisition, resulting in emotional and cognitive engagement and actionable knowledge. The methodology for active learning in each knowledge topic is through teacher feedback loops, starting with an introductory lecture, notetaking, and questioning, followed by dialogue; personal and written reflection; assigned critical readings using annotation and marginalia; analytical and critical writing on reading; additional dialogue; active or experiential learning project exercise around reading or knowledge topic; presentation; and homework practices.

**Holistic Design Thinking Methodology**

Proficiency in the various knowledge topics is crucial before engagement in the Holistic Design Thinking and working in design teams. This is because knowledge topics are integrated, with each aspect of a topic relating to the next and building a deeper understanding and relationship of the former from a design perspective. Figure 1 illustrates the HDT methodology.

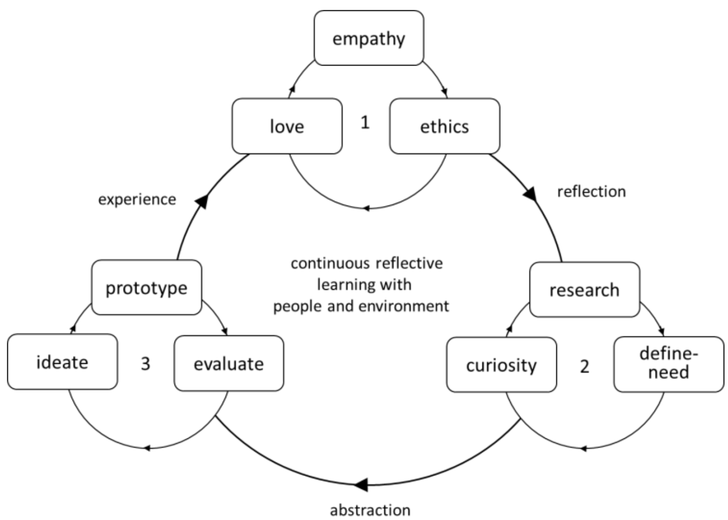


Figure 1. Holistic Design Thinking Relationship

The methodology is characterized by its cyclical and iterative relationship. It consists of three main cycles that move through understanding, observing, and resolving needs. The first cycle focuses on love, empathy, and ethics in need finding, followed by the second cycle of curiosity, research, and defining needs, and moving to the third cycle of ideation, prototyping, and evaluation. Throughout the relationship, the designers move between analysis and synthesis to arrive at solutions or resolutions that advance love, empathy, and ethics with the people and environment they are engaged with.

The process is continuous and iterative, with the first cycle overlapping experience and observation, flowing into the second cycle of reflection and hypothesis, and finally into the third cycle of abstraction and evaluation.

Each cycle consists of several micro cycles. Figure 2 shows the micro cycle of love from the first cycle depicted in Figure 1.

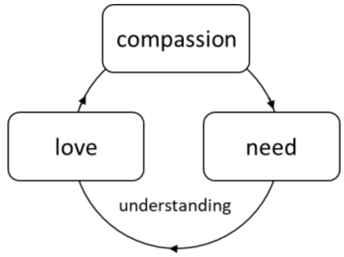


Figure 2. Micro Cycle Within Love

This expanded view of love is itself a cyclical process involving love, compassion, and the process of finding needs. Finding needs with the designer, people, environment is a central aim in the HDT. Love for oneself and others flows from understanding. Compassion is reported to be the natural state of the mind and an attribute closely tied to empathy. Figure 3 depicts the micro view of curiosity from the second cycle of Figure 1 as a continuous cycle of curiosity, imagination, and creativity, moving with observation.

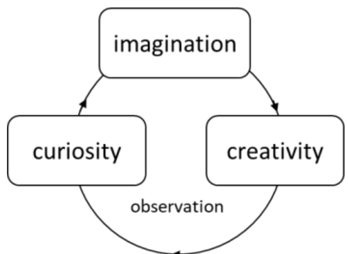


Figure 3. Micro Cycle within Curiosity

Similarly, creativity is a central aim in design, and curiosity arises from observation through feelings and emotions of interest. Although drawn as cycles these attributes of feelings, emotions, and cognitions are not self-contained within a linear cycle but are continually accessed in HDT. For instance, in the ideation phase the third cycle, after ideas are generated, they are re-valuated for ethical impacts, starting with love and empathy before prototyping. In HDT, all previous cycles continue into the next cycle as the designer moves forward in the syntheses process. Figure 4 depicts this synthesis over cycles with dashed lines.

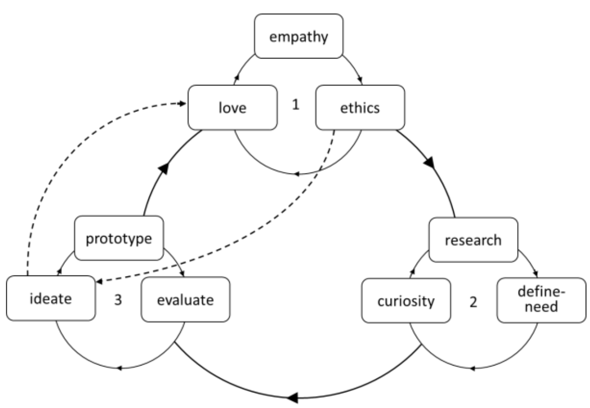


Figure 4. Continual Access to Cycles of Assessment within the Nonlinear Process

In this relationship, the cycles of feelings, emotions, cognitions, and actions can be engaged nonlinearly over the sphere of understanding, observation, and resolution. Figure 5 illustrates how these attributes of the process can be engaged at any point or time and do not need to follow a specific order or process.

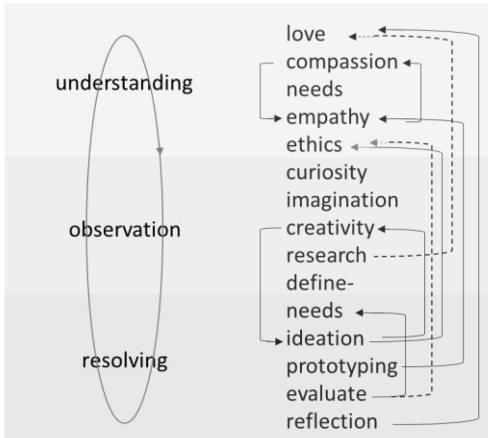


Figure 5. Nonlinear Attributes of the Holistic Design Thinking Relationship

**Holistic Engineering Methodology in Practice**

The HE pedagogy teaches that engineering requires more than just math and science skills; it also demands conceptual knowledge, intuition, and real-world experiences. By engaging in active foundational learning practices, students can develop and enhance these abilities. Several examples are provided to illustrate how students' progress in the HE pedagogy, learning to integrate transdisciplinary knowledge and ultimately leading to the use of HDT.

At the beginning of the program, a visible wall chart was created to map out the transdisciplinary knowledge to be covered. Students were encouraged to engage with the chart and create their own chart of knowledge topics they would like to integrate into the map. Additionally, each student was given a blank-page sketchbook at the start of the course, which they could use for reflective, analytical, and critical writing analysis, note-taking, research, sketching, drawing, ideation, thought capture, and homework, among other activities.

The HDT methodology is introduced to the students at the beginning of the course through a visual graphic and a short lecture. The stages and attributes of the design process are connected to the transdisciplinary knowledge they will be learning. The course methodology provides students with integrated knowledge and practice before organizing them into project design teams. This includes students first playing the role of end-users and stakeholders with set design problems. The next step is for students to work on design projects out in the community using real world end-users and stake holders. Finally, students move through the cycle of love, empathy, and ethics, discovering needs proactively born out of self-motivated interest in topics or opportunities, reactively driven by eventful experiences, or through social learning exposure to an opportunity or interest.

Each class starts with an opening circle check-in and reading used to establish the social, emotional, and intellectual environment that fosters student agency in learning. The teacher monitors and provides feedback on how students organize and utilize prior knowledge, as well as how they incorporate new knowledge and adjust. This process helps students develop skills in monitoring, adjusting, and motivating their learning and knowledge acquisition. Additionally, during the opening circle students share a positive and negative feeling or a recent event in their lives. A student then reads a short text, and everyone shares their thoughts and experiences before moving out of the circle to do personal reflective writing on the reading. The philosophy of HE is that vulnerability in the sharing of emotions and feelings helps students develop agency, trust, and a learning community that acts on its knowledge. When introducing a new transdisciplinary topic, the morning circle reading is used to connect it to the students' prior knowledge and experiences. This is accomplished through dialogue and reflective writing before the topic is formally introduced.

Students are provided with hard copies of all readings and are expected to demonstrate their critical reading skills through annotation and marginalia written directly on the homework readings. They are also expected to engage in handwritten analytical and critical writing of the readings, as well as participate in class dialogues and projects to demonstrate their understanding. The purpose of the annotation and marginalia is to help students develop their critical reading skills by connecting their real-time reading comprehension to active notation that helps them discover and identify the author's thesis and main points. It also helps to connect the reading with previous knowledge and experiences; circling and define unknown words; and note agreement and disagreement with author's ideas, which enhances analytical and critical writing skills. While no highlighters are used to annotation, students may use different colored pens or pencils to underline information that ties together their annotation or marginalia.

Students engage in both reflective, analytical, and critical writing by first identify the author's name, background, and genre to determine credibility, objectivity, accuracy, consistency, relevance, and transparency when assigned a reading. The course methodology emphasizes the use of analytical and then critical writing, in which the students first demonstrate an understanding of the authors' thesis and main points, and then analyze their relationship with the reading.

The analytical and critical writing analysis consisted of four handwritten paragraphs in the sketchbook that cycle between comprehension at the macro to the micro level. The first paragraph is used to show comprehension of the authors' thesis and three main points. The remaining paragraphs are prompt-driven and aim to answer the question "why," including connections to prior knowledge or personal experience. The second paragraph is used to explore interest, usefulness, and challenges. The third paragraph is used to identify areas of importance and agreement and or disagreement. Finally, the fourth paragraph is used to assess changes in thinking, connect with previous knowledge, and determine what the reader aspires to or wants to act on based on the new knowledge gained.

Homework plays a crucial role in the methodology of HE, particularly for secondary students. The course seeks to strike a balance between the level of rigor typically found in high schools and engineering college courses. The aim is twofold: first to reinforce the introduction and learning of new knowledge to prepare the student for in-class dialogues and projects, and second, to challenge their comfort levels in terms of the amount of homework and effort required, thereby helping them adjust their habits. These habits include time management, organizational strategies, sustained critical reading and writing, and voluntary attention spans. Through this approach, students are actively engaged in cultivating the purpose, outcomes, and goals of their learning, with an emphasis on intrinsic motivation and student-led habit formation.

The philosophy of this course is to provide individual support to students as they prototype new strategies to achieve a higher level of intellectual work and emotional development. For most students, one of the biggest challenges in effective time management is their addiction to social media and other smart technology, which can disrupt their ability to focus their attention. Therefore, HE provides the foundation for students to be challenged and frustrated, so that they can receive assistance in developing strategies and practices for growth before entering college.

**Example of Empathy in Holistic Engineering Methodology**

For example, after an introductory lecture on compassion, sympathy, altruism, and emotional and cognitive empathy, methodologies in building empathy start by students researching current theories on empathy. The students receive empathy-focused readings, writing, and project assignments. Students next do an exercise on what factors determine one's empathetic capacity. They present their research to the class and perform self-tests and reflections on their empathetic abilities. Students also research abstract philosophical concepts of belief systems about reality and engage in dialogues on objective, subjective, collective or compatibilist philosophies of reality to determine their view and beliefs. They conduct an exercise aimed at understanding each other's perceptions of realities and beliefs, with the goal of enhancing their empathizing abilities. They explore Theory of Mind cognitive abilities in predicting others' mental states as a further tool to use with empathy skills. They come to understand how factors, such as evolutionary, genetic predispositions, and early childhood environments all play a role and their empathetic abilities. Students examine how culture, technology, and their own behavior and implicit and explicit biases all impact their empathetic ability. They next engage in exercises with peers to practice perspective taking, empathic listening, and dialogue skills to build their emotional and cognitive empathy using empathy map written work sheet exercises. They work in teams, role-playing as the environment, designers, end-users, and stakeholders using empathy capture work sheets. This practice is crucial since engineering students are not accustomed to empathizing with humans impacted by their ideas.

In a collaborative class that brought together postsecondary engineering and industrial design students, participants were exposed to a social learning collaboration with people with disabilities on a vertical lift wheelchair adaptation. When the teacher described the problem, the engineering students immediately arrived at a possible solution. However, the design students reminded them that they had not yet met with the person with the need. After meeting the person with a disability to explain and demonstrate his idea for help, the engineering students stated that it changed their entire design perspective and made them more accepting of other ideas and opinions. Students also had to empathize to understand appropriate and respectful language that emphasizes the person first and recognizes the need as just an aspect of being human.

The practice of using empathy to better understand team members working in design teams is central to the HDT. Students are taught that all teams experience difficulties, and they are provided tools on team psychological safety and effectiveness traits and dialogues to navigate these issues. Additionally, they are encouraged to seek support from their instructor. The methodology also includes mentoring and conflict resolution knowledge, utilizing these attributes to manage the dynamics of experiencing conflicts and finding resolutions in diverse team makeups.

For instance, in a design team composed of students from several different countries, communication difficulties arose. To solve this problem, the instructor conducted research and introduced new knowledge on language inferences based on culture into the course. These resources include knowledge and practices such as using *The Cultural Map* as a reading in fundamental lessons and exercises [43]. Part of the HDT methodology is to adapt the process to the student's needs through new knowledge and feedback. Students stated that the practice they had in understanding team dynamics, including empathy, personality types, and psychological team safety, was beneficial to their team roles as they began to practice tasking, scheduling, and management skills and then conduct design projects.

Through regular practice of sharing their emotions at the beginning of each class in a circle, students were able to recognize the connection between sharing feelings and empathetical listening and transforming these practices into their own lives outside of class. One student shared that, as the stage manager in her school play, she was struggling to manage the stage crew. Drawing from class practices in sharing emotions, empathetical listening, and leadership, particularly beginning with a circle and setting examples instead of giving orders, she implemented these practices at the beginning of each evening with her stage crew to great success. The student reported that they continued to use these methods throughout the play, resulting in better understanding, cooperation, and happiness among the crew. This type of transfer of knowledge from the classroom to other aspects of their lives is common among students in the class.

**Example of Curiosity in Holistic Engineering Methodology**

Transdisciplinary knowledge content gives students the opportunity to explore and practice the cycle of observation, curiosity, imagination, and creativity through multivariate data. After an introductory lecture on visual thinking and practice with seeing, imagining, and drawing and a reading on multivariate data students engaged in a biomimicry project. In their sketchbooks they dissect and draw all the parts of a burr to see how it allows for plant dispersal and make the observational connection to the engineering of Velcro. They dissect other natural objects including a hornet's nest to build up their sense of curiosity of how organisms evolved ways of adaptation in terms of behavior and structures they build. Through this process students learn to engage in self-motivated research from the emotional feeling of curiosity, interest, and imagination and then to the production of ideas. After investigating and researching an organism, their curiosity is piqued about whether it may hold any interesting physical attributes, behavior, or building habits that could be innovative if applied to engineering design. Figure 5 shows sketchbook examples from secondary students' biomimicry investigation of Tardigrade worm and jellyfish.

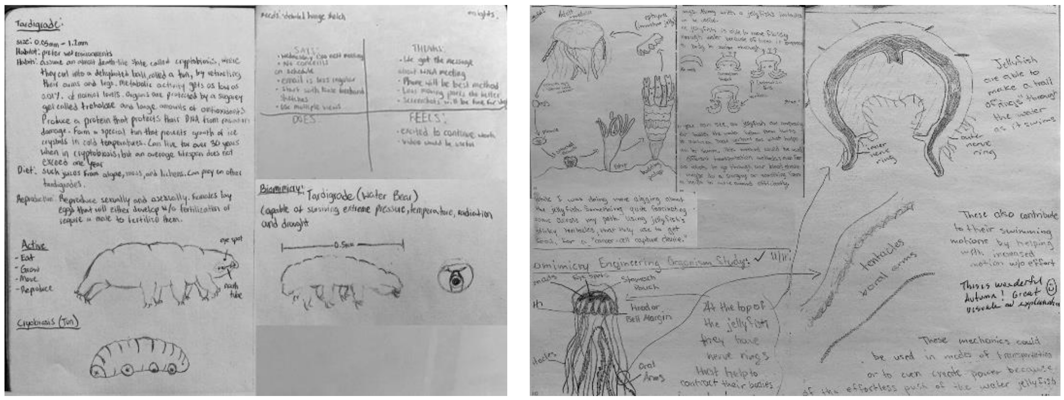


Figure 5. Students Curiosity on Biomimicry

Similarly, when secondary students embark on individual needs-based research with love, empathy, and ethics their curiosity and interest is proactively sparked, leading to ideation. Figure 6 illustrates secondary students' investigations of trash receptacles in a minivan driven by emotional curiosity to find ways to keep the family car cleaner and a wearable blanket driven by the desire to stay warm in the winter.

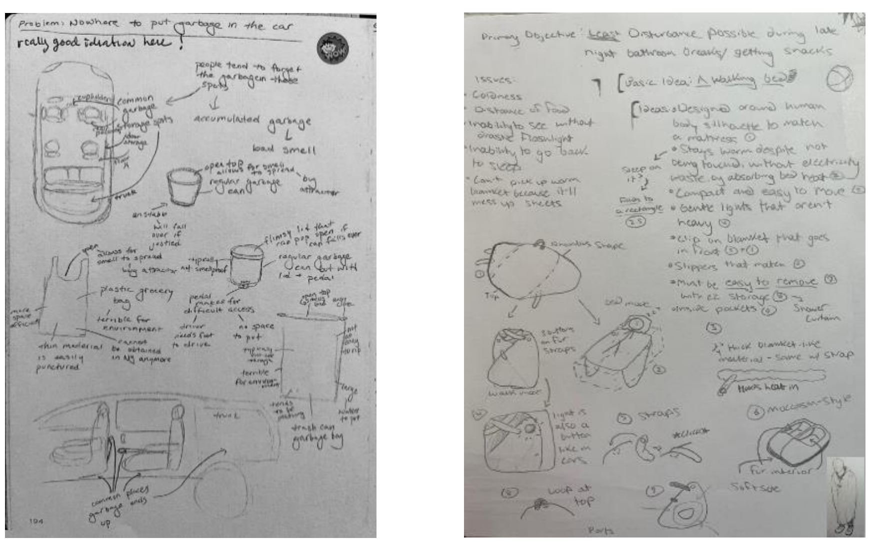


Figure 6. Student Proactive Ideations on Needs-Based Research

**Example of Ideation in the Holistic Design Thinking Methodology**

Curiosity serves as a gateway for students to engage in research and then ideation. As part of their transdisciplinary knowledge students learn numerous ideation techniques including idea sketching, emersion, questioning, dreaming, reframing, observational visits, storytelling, top five, insight statements, how might we, brain swarming, brainstorming, webbing, role playing, and what I know and do not know. Figure 7 illustrates an example of secondary students' ideation sketch process, depicting multiple iterations on a recycling-adapted trash receptacle with an esthetic component.


Figure 7. Student Ideations on Recycling-adapted Trash Receptacle

The student inspiration for ideation stemmed from their curiosity, examining other artistic trash receptacles, and feedback from fellow design team members and the community. Students practice ideation techniques as individuals and in teams to improve their creative processes.

**Example of Prototyping in the Holistic Design Thinking Methodology**

Prototyping is introduced to students using the same pedological methodologies employed previously in the course, and is taught through a series of smaller object prototypes. The students are engaged in the use of integrated knowledge in the methodology of ideating, prototyping, and evaluation through several simpler projects. For example, a pierced hole exercise is used to help students move from verbal, visual, drawing, tactile, and bodily thinking to find a tactile solution. This exercise allows students to become more flexible and creative problem solvers by moving between different modes of thought. Other prototyping projects use aspects of HDT to actively evaluate knowledge including a kinetic/potential energy device to do work, a pendulum clock, and a prototype Mars landing vehicle. These projects also connect to scientific and engineering concepts of physics, chemistry, biology, and the environment. Through this process, students learn the art of building, evaluation, and iteration using the mind's eye, ideation, sketching, drawing, intuition, and working with materials and tools.

The practice of using HDT on smaller projects helps students integrate and process knowledge of design practices and team dynamics before engaging in more complex projects involving their own ideas, people, and the environment. The instructor monitors the progress and provides feedback to individual team members and the team as they progress.

To further develop their skills, student design teams work with role-playing the environment, end-users, and stakeholders to practice empathy and weigh ethical considerations, while engaging in the HDT cycles. This allows students to practice problem solving using HDT in a diverse collaborative environment while considering the needs of others. After practicing HDT with role playing, design teams take up real world challenges with the people and environment impacted by the need and possible solutions. The following are examples of student design teams using HDT in real world challenges.

**Example of Undergraduate Holistic Design Thinking Project**

An example of an undergraduate team project that utilized HDT to prototype and evaluate was a multi-semester design project of adaptive design for people with disabilities. The project started in an HDT course and continued in a capstone project. This project started with the cycle of love, empathy, and ethics by investigating the needs of an inclusive preschool where loaner wheelchairs for younger children were not readily available. The teams used HDT to iterate through several prototypes of a transitional vehicle using adaptive assistive technology.

The students contacted the school and met with the occupational therapist to conduct an environmental assessment. They researched human-machine interfaces and the ethics of the development and usage of this technology. Students and the teacher obtained Institutional Review Board approval for conducting research with human subjects. Through the cycles of the HDT the students met with the occupational therapist and other stakeholders impacted by the design to form an understanding of expressed needs through a perspective of love, empathy, and ethics.

They received feedback from the occupational therapist who expressed that a lighter vehicle design could enhance the social participation and allow the elementary student to move down the hall in a device that is appropriately sized and shared with her peers. Students provided feedback to the teacher and reflected on their perceptions and motivations. Figure 8 shows the adaptive mobility prototype vehicle.

Figure 8. Adaptive Mobility Vehicle Prototype

Once the safety and ethical standards were met the vehicle was tested by a kindergartener with neurodevelopmental delay at the elementary school. On the first day of testing with the elementary student the design students expressed that the child was ready to go, and they were thrilled to see her move independently and have a source of independence. One student remarked “what I liked about this, we are making a physical device and you could instantly see the impact it was making and that’s why I wanted to get into engineering.” The occupational therapist said it was exciting to watch the child show her appreciation for the work and her joy in helping test it out. As the elementary student seated in the vehicle hugged one of the design students they were brought to tears “for me it was the first time interacting with [neurodevelopmental delayed] children and to be able to build something for them, to be able to help advance their social skills, seeing it in action was…unspeakable…I’m not able to use words at the moment...to see it all come together work and move - brought tears to our eyes.”

This moment when students see their empathetical and ethical engineering design work in the real world with people and experience transformation of learning is the higher purpose of HDT and the HE philosophy. In practice, helping teams become intrinsically motivated and reach a transformative learning experience is central to HDT experiential learning projects [44].

**Example of Secondary Holistic Design Thinking Project**

A secondary design team project illustrates using HDT through the custom design of permanent recycling trash receptacles. Two senior high school design teams collaborated with a design firm and community organizations over the course of a year to design recycling trash receptacles for a neighborhood business district. Several objectives were established for the design teams, such as using all previously learned transdisciplinary knowledge to work collaboratively in a team; creating fun and vibrant receptacles that enhanced the feeling of the neighborhood; ensuring efficient removal of waste and recyclables; and minimizing materials and fabrication time.

To begin the HDT methodology the student teams engaged in the love, empathy, and ethics cycle. They researched recycling and urban waste removal and walked through the neighborhood business district and engaged in dialogues with the community and design firm to uncover needs. The students completed empathy and ethics worksheets.  They engaged in observation, curiosity, and imagination by inspecting, photographing, and sketching existing trash cans, discovering usable features, mapping locations, and exploring foot traffic patterns in the neighborhood. They did personal writing reflections on their visits and the vibrancy of the community. Based on their observations and interviews the teams explored and researched dimension of receptacles, ease of removability of recyclables, removable liners, hinges, and color schemes. They created challenge statements related to the environment and issues of sustainability, and recycling practices, followed by insight and “how might we” questions. Throughout this process they met regularly with the design firm and community members to gather feedback.

The student teams worked collaboratively with the design firm and community, undergoing multiple review and iteration phases of ideation, prototyping, and evaluation before arriving at a final design. Both teams created small-scale mockups along with full-scall feature prototypes. After feedback from the design firm and community, they built full-scale prototypes of their designs and iterated several features through a collaborative process with the community and stakeholders. Figure 9 shows the full-scale recycling trash receptacle prototypes.

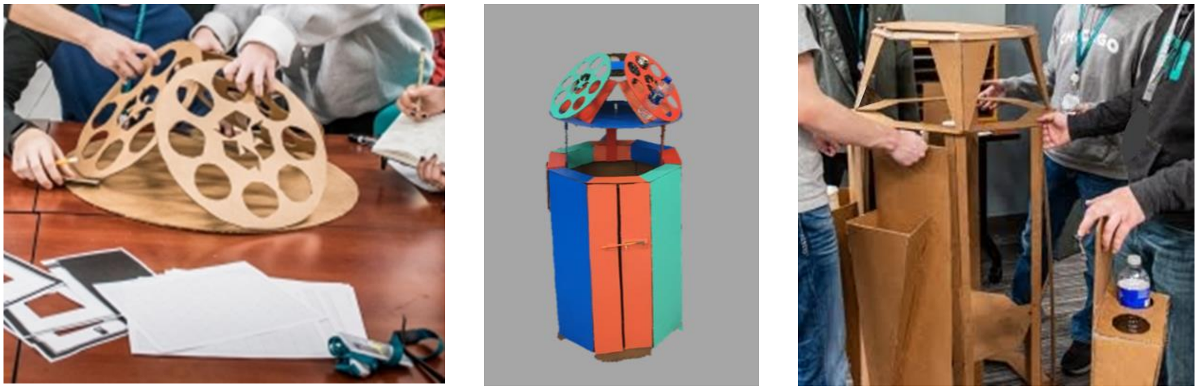

Figure 9. Full Scale Prototype Recycling Trash Receptacles

The teams sought out expertise from engineering professionals to help analyze the mechanical strength of the aluminum cover based on full scale mockup evaluations. They also solicited feedback on design features that would promote ethical and environmental awareness of recycling, as well as color schemes that reflected community vibrancy values. Using these designs, the students, design firm, and community created further iterations before proceeding with the final design, fabrication, and installation.

Through the practice of HE and HDT students learn through engaging in real world challenges the value of their skills. They see how prototyping iteration can help build intuition and episodic memories in problem solving, and how it is necessary to embrace failure as a part of learning. This, in turn, promotes self-confidence and self-learning and personal growth. By emphasizing love, empathy, and ethics as an intersection with design, students internalize how what they are learning connects to their ability to achieve design outcomes [27].

**Qualitative Response Data**

The pedagogical research presented in this paper covers an eight-year period. Feedback was collected from students on the courses, including the HE pedagogy, HDT methodologies, classroom learning methodologies, and knowledge content using direct oral feedback, surveys, and end-of-course reflection writings.

In relation to the HDT methodology, most secondary, undergraduate, and graduate students thought the inclusion of love, empathy, and ethics in the process was beneficial, and they reported that it differed significantly from other design process used in other engineering courses. Graduate students described HDT as eye opening, while undergraduate and graduate students both felt it brought significant meaning to their understanding of the power of engineering and their role in it.

Undergraduate students ranked empathy, ethics, HDT, team dynamics/teamwork, and love in that order as the most valued knowledge they received. In contrast, graduate students indicated HDT, empathy, love, and ethics as the most important knowledge they received.

Students have shared that this pedagogical approach provided them with “skill sets that I didn’t know I struggled with as well as ways to improve those skills.” An undergraduate senior found the HDT methodology "made sense of how an effective design process works in real life." Graduate students who worked with HDT mentioned that it "reshaped my understanding of the missing intricacies of my concepts about being an engineer" and "the better you can interact and connect with others the more of a positive impact you can have on each other's lives." Students who engage in the HDT methodology reflected that empathy "is the most important part of the design process," "we delved into our identities as individuals and human beings in order to unearth the deeper meaning behind why we decided to become engineers, who we were, and how to shape our futures" and "how to relate to others better, how to understand them, and [it] completely changed my preconceptions of what it means to be human."

Secondary students expressed that the HDT "has taught me how to become an engineer by studying key topics such as how to think like an engineer, communication, and HDT, which are critical to using my engineering knowledge and skills to prepare me to become part of the future of engineering." A secondary student reflecting on previous high school engineering HE course said that it "taught me so many valuable skills about empathy, love, ethics, and creativity that I would have not obtained anywhere else."

Through the transdisciplinary knowledge and working in designs teams, students were "able to understand the importance of ethics and morals, and how they play a part in engineering." Students expressed that they felt "the lessons I learned from the class, I feel that I will be capable of making a positive impact on the world through engineering." Students expressed that they had learned "many new and important lessons about how to approach problem solving …considering ethics and love before making decisions…I feel that I will be capable of making a positive impact on the world through engineering." Furthermore, "the design process we learned is based so much on empathy and ethics because of the responsibility that engineers have when designing and developing solutions." Students also shared that it helped them "consider factors such as ethics and love into all aspects of engineering and even everyday life."

Critical in psychology/neurobiology learning theory, students were able to connect their emotions to learning outcomes, expressing "I believe the three most important things I learned in this course are how to critically think, the importance of emotions in careers related to Science, Technology, Engineering, and Math (STEM), and how thinking about other people is important in Engineering." Secondary students were able to connect that through the "iterative process of self-reflection, I believe I was able to gain a much deeper understanding of myself and how certain things affect me. Once I gained that deeper knowledge of how things made me feel, I found it much easier to draw parallels to how others may be feeling. The concept of empathy was very important in this class, as we constantly exercised it in almost everything that we did."

Students found that "the first super surprising thing I learned from the class is just how involved love is in engineering. To be able to help others and fulfill their needs you need a base of love that then leads into empathy." Students felt the broad integrated transdisciplinary knowledge was reinforced with readings "I thought it was a bit of a joke to be reading that [love] in an engineering class when all I had ever been taught about engineering was that you needed to be creative and have a mathematical brain," and "we learned just how connected we are to each other and how connected love is to everything we do, even engineering. For us to fully understand how empathy can be used in the design process" and giving students "a far deeper understanding of what love actually is and how it can be used when engineering the needs of others." As to the transformative power of love student's related "the importance of learning to love yourself. Once you trust yourself and can properly self-reflect on mistakes you can learn how to love yourself and then empathize with others."

During a discussion on the impact of using empathy practices, a student reported "engineering is more than just using materials to build a product; it includes the use of empathy towards yourself and others." and added, "The next time someone brings up the word "empathy" I will think back to all the lessons that I have learned in this class and educate the people around me about how much that single word is truly worth. In these last few months of being in this class I have seen a change in myself." By providing transdisciplinary learning and practice opportunities students, "recognize the importance of and how to empathize, communicate, and truly listen." They expressed making connections across transdisciplinary learning and how that connects to the HDT as "once you build a sense of empathy and understanding towards others, you can also build a stronger connection with people around you. If you understand yourself and others, communication and expression of ideas can become much easier, allowing for greater teamwork," and "In order for a team to function properly, all members need to be understanding of one another, but also understanding of themselves."

Students who engage in HDT methodology based on empathy and ethical considerations reflect that it "not only making engineers better entrepreneurs, but better people" and "understood my cognitive empathy but hadn't realized that I could develop and practice my emotional empathy to help me understand people better as part of design process."

They express an understanding of the need for ethics in engineering and technology because a lot of technology "has been built on a lack of ethical and empathetic designs driving us further into this isolated world. The hope is that in the future, with the realization of these things, we can change the way that we deal with designs and create a more empathetic and ethical future of technology." Having ethics as a central part of the HDT methodology allowed students to see that "ethics is a huge part of engineering, and to be completely honest, I had never thought of this before you taught it to us." They were inspired to think about the "ethics surrounding the products we as engineers make. In the future I hope to apply this knowledge to my career and focus on products that have a net positive for humanity." Students expressed an understanding of the benefit of central aim of HE and HDT that "has allowed me to have a greater understanding of what I hope to do in the future, and I hope they will allow me to help people as ethically and empathetically as possible."

## Holistic Engineering Program Description

The engineering college preparatory program described in this study is a one-year experiential program using the Holistic Engineering (HE) pedagogy designed for high school seniors who plan to attend college. It is a collaborative effort between a state educational institution, an engineering company, and a community college. The program has three main student components: high school classroom instruction, college classroom instruction, and work assignments as employees of the engineering company. It is located within a fortune five hundred engineering company facility, which has built a dedicated classroom space for the students. The engineering company is situated in a campus setting and has three main engineering /manufacturing buildings with over ten thousand square feet and several smaller outbuildings. Student engineering work assignments are located throughout the campus buildings. Each year, the program has two classes of high school seniors, with a total of sixteen students, half of whom attend the morning session and the other half the afternoon session. The students spend the other half of the day at their home school, nominally taking calculus and physics. The students were selected through an application process across fifteen school districts. The program is currently in its fourth year.

The program consists of an integrated high school course offering five credits, two college courses of three credit each, and as employees in an engineering role, rotational work assignments in different disciplines of engineering. Students spend on average 2.5 days per week in the classroom for high school credit, 1.5 days per week working with engineers, and one day per week in college courses. The high school portion of the program integrates Engineering, English, Participation in Government, and Economics high school credits into the HE classroom experience. The HE pedagogy further integrates broad transdisciplinary knowledge and Holistic Design Thinking into the curriculum. The program includes a high school teacher and a separate college course instructor. The high school teacher holds a Ph.D. in Electrical and Computer Engineering with thirty years of professional engineering and secondary and postsecondary engineering teaching experience, and coordinates between all the collaborative partners while overseeing the students. The program offers six possible English college credits from a local community college in English Composition and Technical Writing, which are designed to be transferable to all state universities and colleges. Students are hired by the engineering company as regular employees, receive payment, and have an overall manager who coordinates work assignments. They are assigned cubicles and work with an engineer for either four- or six-month rotations, with the engineer acting as the supervisor of the work assignments. The students extend their classroom learning as they engage in real-world learning in a professional engineering setting, working side-by-side with engineers. The high school classroom acts as the central hub for all the students' experiences, including their college classes and work assignments. These experiences are coordinated and integrated into the high school classroom learning, allowing students to refine and apply what they have learned outside of the classroom.

The classroom is 800 square feet and has a six-foot by five-foot window. The furniture is movable and consists of eight rolling tables, twelve rolling chairs, four movable sofa units, four bookshelves, four wall mounted whiteboards, two rolling whiteboards, two lamps, a supply cabinet, one smart board, and two toolboxes with tools. Additionally, the students have access to several adjacent classrooms, and there are picnic tables and group chairs set up outdoors on the campus.

The student selection process has evolved over the four years of the program but currently includes an evaluation of an application, high school transcripts, a student essay, two letters of recommendation, a homeschool guidance counselor recommendation, and any other relevant information. In addition, the engineering firm has a separate employee application process and hiring criteria that the students must meet.

The engineering company offers a limited number of summer internships and co-ops for students who have completed the program. The college preparatory program teacher aids in facilitating these opportunities for the students with the employer. The engineering program teacher also organizes networking events between the engineers and students from all four years of the program, which includes classroom visits from former students, and guest speakers. The program has also resulted in summer internships for graduating high school seniors whose assignments are mutually beneficial to the student and employer prior to attending college. Furthermore, the engineering firm offers engineering college co-ops for college students enrolled in five-year programs. Over the course of the program's four and half years, which include the pandemic years when no students worked over the summer, the engineering company has hired former students for seven internships and two co-op positions.

**Longitudinal Study Parameters**

The study examined the HE pedological approaches to engineering education and their outcomes. The study focused on six areas: 1) the introduction of broad and integrated transdisciplinary knowledge and its impact on students as they progressed through college, 2) evidence of student learning linked to engineering college success, 3) student reaction to love, empathy, and ethics as core knowledge subjects in an engineering course, 4) the attributes of HDT valued as secondary students progressed through college, 5) the impacts of small class size on learning and future college retention rates, and 6) the impacts of specific transdisciplinary and design knowledge tied to retention rates.

The specific goals of this research study aimed to answer five specific questions: 1. What transdisciplinary knowledge did students value upon completing the secondary program, and how did this affect their present and future states? 2. Did shifts in valued knowledge occur during the students' college years, and if so, why? 3. How did intrinsic motivational levels displayed in the program translate into college success? 4. Were students able to retrieve transdisciplinary knowledge flexibly over the college years? and 5. What were the perceptions of students from the program that started and then left engineering college? To answer these questions, more than twenty courses were taught using the HE pedagogy and the HDT methodology. The data presented here was collected over a four-and-a-half-year period and includes three years of the secondary senior high school program and their subsequent years in college. The program had a total of forty-eight students, with forty-two completing it. Course surveys were administered, and follow-up interviews with secondary students were conducted after graduation and during their college years.

The selection process aimed to choose students interested in studying engineering in college or careers in engineering. The selected students represented a diverse cross-section of cognitive and emotional abilities, as determined by the documentation collected during the application and interview process. Some of the students were self-motivated to join the program and improve their academic achievement, while others were influenced by factors such as parental decision, dissatisfaction with their current school, paid work opportunities during the school hours, a desire for reduced schoolwork, or a need for greater independence.

Upon entering the program, seniors were assessed in six main areas: 1) critical thinking, 2) critical reading, 3) reflective, analytical, and critical writing, 4) causal and visual thinking, 5) engineering intuition, and 6) intrinsic motivation. Post-assessments were conducted to track improvements in intrinsic motivation, time management, voluntary attention, homework practices, and organizational skills. These assessments were monitored through in-class observations, homework, written reflections, interviews, and performance evaluations. Additionally, anonymous surveys were administered to the students at three different intervals: two months into the program, mid-way through the program, and at the end of the program. However, the second year of the program, only mid-way and end of the year surveys were conducted.

The research utilized a variety of assessment approaches, such as observations, prototyping, evaluations, and learning outcomes. Data sources included students' sketchbooks, homework assignments, class participation, student weekly grading reflections, design project presentations, surveys, dialogues, weekly conference interviews, and final exit survey reflection papers were analyzed. The team and class dialogues, critiques and presentations provided opportunities to further observe and evaluate the demonstration of learning objectives, including knowledge and result oriented practices of compassion, empathy, and applied ethics in the design process. Students also provided weekly verbal and written feedback, contributing to a more comprehensive evaluation.

The data collected after graduation involved conducting telephone interviews in December of each year using a standardized set of seven questions with recorded responses. These questions included the following: 1) What university or college are you attending, and what is your major? 2) How many credit hours are you taking per semester and what is your GPA? 3) What was your most difficult and easiest class, and why? 4) What were the most challenging aspects of the transition to college in terms of social, emotional, and academic factors? 5) What high school course content from the program do you find valuable in college, and why? 6) What changes do you think could be made to the high school portion of the program to increase its benefit to freshman college students, and why? and 7) What are your next plans for college? Additionally, other data were collected through phone calls, text messages, and in person meetings, which were often initiated by the students.

In the 2019-2020 school year, the student selection process for the program consisted of an application, and all seventeen students who applied were admitted. However, prior to entering the program, the students had a limited understanding of its objectives. The student population comprised of three females and fourteen males, with one international Asian and one brown student. Unfortunately, three students exited the program before the midway point. In March of 2020, due to COVID-19, the program switched to online learning, consisting of video conference during classes five days a week for the remainder of the school year. During this time, participation in class was approximately 87 percent. Upon completing the program, four students did not immediately pursue a four- or five-year engineering college program. Two students enrolled in a pre-engineering program at a community college, one student enrolled in an art program at a community college, and one did not attend college.

In the second year of the program (2020-2021 school year), the application process consisted of the same material as the first year with an additional criterion. Candidates and parents also had in-person and phone call interviews with the teacher and the engineering employer. From a pool of twenty-three, sixteen candidates were selected. The student population consisted of six females and ten male students, with three black or brown students and one indigenous American student. While the candidates had a moderate understanding of the program, due to COVID-19 pandemic, they were unable to attend classes at the engineering facility and instead met in-person off site. Additionally, they did not receive any high school homework during the first six months of the school year. The students worked virtually with their engineers. One student dropped out of the program during the first month, and after graduation one student did not immediately pursue a four- or five-year engineering college program but entered a community college pre-engineering program.

In the 2021-2022 school year, the application process was the same as the previous year. Out of twenty students who applied, sixteen were selected for the program, including five females and eleven male students, one brown and one Asian student. The students had a moderate to high understanding of the program before starting. The program was held at the engineering company, and three students withdrew from the program by mid-year. However, all the students who completed the program enrolled directly into a four- or five-year engineering college program, except for one who enrolled in Architecture.

In the 2022-2023 school year, the application process for the fourth year of the program remained the same as the previous year, except that in-person and video call interviews were conducted with each candidate. Sixteen of nineteen students were admitted. The student population comprised of two females and fourteen male students, with one brown student.

**Data Results and Analysis**

The study collected and analyzed qualitative and quantitative data over four and a half years. The primary data presented in this study are in the form of exit survey reflection papers, which each student wrote at the end of the secondary program, and interviews conducted at the end of the students' first, third, and fourth semesters in college. Three high school graduating cohorts who completed the program self-identified three types of knowledge they learned and valued, along with the reasons why. During their college years, students were interviewed and asked to self - identify what knowledge, if any, they found useful from the program at the time of the interview.

Pre-assessments conducted over the four-year period consistently showed a majority (90 %) of students struggled with critical reading and comprehension. Specifically, the students had difficulties identifying the author's thesis and main points, as measured by their annotation and marginalia content and connection; analytical writing; in class and individual dialogues; and oral quizzes. This difficulty was observed among both honor roll and non-honor roll students, who struggled with critical reading and comprehension. However, reading comprehension improved for students by the end of the program, with 60 percent of students demonstrating proficiency in the first cohort, 79 percent in the second cohort, and 90 percent in the third cohort. Observational data and student feedback indicate that the small class size was essential to the students' improvement. The small size allowed for detailed individual teacher attention and feedback on students' prototyping of reading strategies tied to author thesis and main point identification using annotation and marginalia.

At the beginning of the program, most students (between eighty to ninety percent) were not able to define what critical thinking was, and only fifty percent demonstrated the cognition and behavioral practice traits associated with it. To address this issue, learning content was provided, including analyzing bias and beliefs, evaluating, and synthesizing information, and applying reason in problem-solving techniques. However, over the three years of the program only fourteen percent of exiting students self-identified critical thinking as valued knowledge they received. By the fourth year of the study, 47 percent of students remaining in engineering college programs identified critical thinking as valuable knowledge they received.

**Results for Year One Cohort - Post Graduation**

At the end of the first year of the secondary program, students were asked to self-identify three types of knowledge they learned and valued, along with their reason for valuing them. The most identified knowledge categories, in order of frequency, were ethics, self-reflection, empathy, and HDT. Critical reading, critical thinking, team dynamics/teamwork were each identified three times. Love, patience, emotions, episodic memory, and time management were each identified once.

Ten of the thirteen first-year students were interviewed after their first semester in college were interviewed and asked seven standardized questions. One student had dropped out of college, and another delayed entering college due to the pandemic. Their free-response answers were not limited to only three attributes of knowledge valued. Results showed instances of transdisciplinary knowledge identified that had not previously been mentioned by the students when they exited the secondary program. The results showed homework practices; reflective and analytical writing; ideation; and psychology/interpersonal skills which were identified multiple times by students, while modes of thought, overcoming adversity, emotions, and use of the sketchbook method were identified once. There was a decrease in importance of ethics and self-reflection, and a slight increase in communication, team dynamics/teamwork. The most significant increase from the exiting identification was in time management. Critical reading and thinking, empathy, communication remained about the same.

In the second year after graduation, six sophomore college students were interviewed over the phone. From the original graduating class, one student did not attend college, two students did not continue in college, one was majoring in art, and one switched major out of engineering. The responding students continued to pick within the previous categories except for one student who added diversity as a knowledge content learned in the high school course that they valued.

In the third year after graduation, nine college junior students were interviewed over the phone. Students continued to self-identify in previously identified categories except three students who selected new attributes of notetaking and internship. At this point, three students had internships or co-ops. Increased value of previously gained knowledge was most significantly indicated in team dynamics/teamwork; reflective and analytical writing; critical thinking; and notetaking.

Slight increases were seen in HDT, critical reading, rigorous homework practices, ideation, self-reflection, and ethics. Other selections were in existing valued areas.

Looking across the data for students who responded to all four interviews, shifts in importance of knowledge valued can be seen, with only visual thinking and team dynamics/teamwork constantly listed across the four and half years. For students who responded three or more times self-reflection, critical reading, and time management were constantly listed three times.

Looking across the data and totaling the number of times a particular category of knowledge was deemed important results in a set of clustered knowledge categories with the highest ranked being team dynamics/teamwork, critical reading, ethics, and self-reflection. The next highest ranked knowledge of importance is empathy, critical thinking, HDT, time management and communication, homework practices, and reflective and analytical writing. The final grouping includes visual thinking, intrinsic motivation, ideation, psychology/interpersonal skills, notetaking, emotions, patience, modes of thought, overcoming adversity, love, episodic memory, sketchbook method, leadership, and diversity.

Overall, the data suggests that the students' self-identification of valued knowledge varies from year to year, with only a few fixed categories of knowledge deemed important across all four years. This could be explained by the fact that the college courses and student experiences are constantly changing, and the knowledge they learned in the HE course resonates with them based on their current needs. The diversity of transdisciplinary knowledge given in the secondary program has been available to them as they progress through college, supporting the claim that the students achieved agency through their acquisition and application of knowledge. Providing more diverse and integrated transdisciplinary knowledge to high school seniors bound for college could be beneficial, and further analysis of data is needed to determine what knowledge is crucial for college.

**Results for Year Two Cohort - Post Graduation**

At the end of the second year of the secondary program, students self-identified three types of knowledge they valued, along with their reason for valuing them. The top ranked knowledge areas, in order of frequency, were visual thinking, empathy, HDT, self-reflection, and ethics. Modes of thought and critical thinking were each self-identified three times, and ideation, communication, team dynamics/teamwork, love, critical reading, and time management were each identified once or twice.

Twelve out of fifteen second year students were interviewed after their first semester in college and asked to respond to the seven standardized interview questions. One student had left college and two did not respond. The students' free-response answers were not limited to only three attributes of knowledge valued. The results were of interest, as they identified transdisciplinary knowledge that was not previously mentioned by the students upon exiting the program. This included significant identification of rigorous homework practices, intrinsic motivation, notetaking, and reflective and analytical writing. There was also a significant increase in the identification of value placed in critical reading and time management. However, there was a decrease in empathy as valued knowledge. Additionally, psychology/interpersonal skills, sketchbook method, lectures, and diversity as new and mentioned only once. The most significant identification of values was in rigorous homework practices, time management, intrinsic motivation, critical reading, and notetaking.

In the second year after graduation, six sophomore college students were interviewed over the phone. From the original graduating class twelve remained in engineering college. The responding students continued to select attributes from the previous valued categories, except for organizational skills which were selected once. The highest-ranking categories were rigorous homework practices, HDT, critical reading, and time management.

Based on the responses of students who responded to all three surveys, there was a consistent emphasis of valued knowledge for empathy, ethics, HDT, ideation, and time management. For students who responded two or more times, rigorous homework practices, critical reading, intrinsic motivation, and psychology/interpersonal skills were separately listed twice. The data revealed an intriguing pattern, consistent with the findings from first-year cohort students. Exit survey report responses did not indicate that homework practice and reflective and analytical writing were valued knowledge. However, these skills were stated as valued after the students first semester of college.

Looking across all the year two data and totaling the number of times a particular category of knowledge was deemed important results in a set of clustered knowledge categories, ranked in order of importance as HDT, time management, rigorous homework practice, ethics, empathy, and visual thinking. The next highest ranked knowledge of importance was critical reading, critical thinking, and team dynamics/teamwork. The next grouping includes modes of thought, intrinsic motivation, and ideation. Followed by communication, self-reflection, and notetaking. Finally, love, organization skills, lectures, and diversity were each selected only once.

This data also supports the conclusion that students can effectively apply the transdisciplinary knowledge they acquired during their high school program and use it flexibly as they advance through their college years.

**Results for Year Three Cohort - Post Graduation**

At the end of the third year of the secondary program, students were asked to self-identify three types of knowledge they learned and valued, along with their reason for valuing them. The top ranked knowledge areas, in order of frequency, were empathy, HDT, communication, self-reflection, and visual thinking. Time management and critical reading were next in importance, followed by modes of thought, team dynamics/teamwork, and creative thinking each with two selections. Ethics, self-reflection, intrinsic motivation, love, episodic memory, careers, and engineering principles were each mentioned once or twice.

Twelve out of fourteen third-year students were interviewed after their first semester in college, and they were asked to respond to the seven standardized interview questions. All students remained enrolled in four- or five-year colleges, with one enrolled in an Architecture program. The students' free-response answers were not limited to only three attributes of knowledge valued. Notably, the interviews revealed several transdisciplinary knowledge categories that had not been previously mentioned by students at the end of the secondary program. These included rigorous homework practices; reflective and analytical writing; sketchbook method; psychology /interpersonal skills; notetaking; and lectures. Voluntary focused attention, organizational skills, and leadership skills were also identified as new areas in single responses. However, there was a decrease in empathy and visual thinking compared to the initial survey. The most significant increase in valued learning was in rigorous homework practices; reflective and analytical writing; and critical reading. Love and self-reflection remained the same, with only one mention each.

The survey results indicate a strong correlation among students, except for rigorous homework practice; reflective and analytical writing; and critical thinking. These findings align with data from the earlier cohorts of high school graduates who completed the program and reported that rigorous homework practice, critical reading, and reflective and analytical writing became apparent only after the first semester in college.

**Overall Data Results and Analysis Discussion**

There is a significant clustering of valued knowledge of empathy and HDT which is consistently seen across all three cohorts of students exiting the program. The data for students exiting the high school program is shown in Table 1. The data in the table demonstrates the frequency in which students self-identified the transdisciplinary knowledge topic as valuable in a final reflection survey paper. Each student was instructed to limit their self-identified valued topics to three, although some included four.

Table 1. Totals of Student Self-Identified Valued Knowledge Existing High School

| transdisciplinary knowledge topic | total student- identified values exiting high school cohort one | total student- identified values exiting high school cohort two | total student- identified values exiting high school cohort three | totals |
|---|---|---|---|---|
| critical reading | 3 | 1 | 3 | 7 |
| self-reflection | 6 | 4 | 1 | 11 |
| intrinsic motivation | 1 | 0 | 1 | 2 |
| time management | 1 | 1 | 4 | 6 |
| modes of thought | 0 | 3 | 2 | 5 |
| critical thinking | 3 | 3 | 0 | 6 |
| visual thinking | 0 | 9 | 5 | 14 |
| creative thinking | 0 | 0 | 2 | 2 |
| love | 1 | 1 | 1 | 3 |
| empathy | 4 | 6 | 7 | 17 |
| ethics | 7 | 4 | 1 | 12 |
| communication practices | 2 | 2 | 6 | 10 |
| ideation | 0 | 2 | 0 | 2 |
| team dynamics/teamwork | 3 | 2 | 2 | 7 |
| patience | 1 | 0 | 0 | 1 |
| candor/trust | 1 | 0 | 0 | 1 |
| Holistic Design Thinking | 4 | 6 | 7 | 17 |
| emotions | 1 | 0 | 0 | 1 |
| episodic memories | 1 | 0 | 1 | 2 |
| engineering principals | 0 | 0 | 1 | 1 |
| engineering careers | 0 | 0 | 1 | 1 |
| | | | | |
| Mean | 2.6 | 3.38 | 2.81 | 6.1 |
| Standard Deviation | 1.96 | 2.4 | 2.26 | 5.40 |

When totaling the valued knowledge over all three cohorts, a consistent selection of empathy, HDT, visual thinking, ethics, self-reflection, and communication were clustered in the top responses. Team dynamics/teamwork, critical reading, critical thinking, time management, and modes of thought were clustered in mid responses, while intrinsic motivation, love, episodic memories, and ideation were clustered next. Patience, trust, emotions, careers, and engineering principles were self-identified only once each.

The cumulative results of the knowledge areas valued by all college students demonstrated a distinct clustering in order of importance of knowledge. Specifically, students self-identified rigorous homework practice, critical reading, time management, HDT, and team dynamics/teamwork in the top responses. Reflective and analytical writing, empathy, ethics, communication, and critical thinking were clustered in mid responses. The next clustering included intrinsic motivation, notetaking, psychology/interpersonal skills, self-reflection, notetaking, visual thinking, sketchbook, and ideation were clustered next. Modes of thought and lecture practice were next. Followed lastly by diversity, organizational skills, love, voluntary attention, leadership, emotions, patience, internship, and overcoming adversity.

Table 2 displays the response data totals for the three cohorts, including those exiting high school, those in college, and cumulative totals.

Table 2. Totals of Student Self-Identified Valued Knowledge High School and College

| transdisciplinary knowledge topic | total student- identified values exiting high school | total student-identified values during college | total of values student-identified in high school and college |
|---|---|---|---|
| critical reading | 7 | 21 | 28 |
| reflective and analytical writing | 0 | 12 | 12 |
| self-reflection | 11 | 7 | 18 |
| intrinsic motivation | 2 | 8 | 10 |
| time management | 6 | 20 | 26 |
| organizational skills | 0 | 2 | 2 |
| modes of thought | 5 | 4 | 9 |
| critical thinking | 6 | 10 | 16 |
| visual thinking | 14 | 5 | 19 |
| creative thinking | 2 | 0 | 2 |
| love | 3 | 1 | 4 |
| empathy | 17 | 12 | 29 |
| ethics | 12 | 12 | 24 |
| communication practices | 10 | 11 | 21 |
| ideation | 2 | 6 | 8 |
| team dynamics/teamwork | 7 | 19 | 26 |
| psychology/interpersonal skills | 0 | 7 | 7 |
| leadership skills | 0 | 1 | 1 |
| diversity | 0 | 2 | 2 |
| voluntary focus | 0 | 1 | 1 |
| patience | 1 | 1 | 2 |
| candor/trust | 0 | 1 | 1 |
| Holistic Design Thinking | 17 | 20 | 37 |
| emotions | 1 | 1 | 2 |
| episodic memories | 2 | 0 | 2 |
| rigorous homework practices | 0 | 23 | 23 |
| lectures | 0 | 3 | 3 |
| notetaking | 0 | 8 | 8 |
| overcoming adversity | 0 | 1 | 1 |
| sketchbook method | 0 | 6 | 6 |
| engineering principals | 1 | 0 | 1 |
| engineering careers | 1 | 0 | 1 |
| internships | 0 | 1 | 1 |
| | | | |
| Mean | 6.35 | 7.79 | 10.70 |
| Standard Deviation | 5.41 | 7.04 | 10.68 |

It is interesting to note that rigorous homework practice; reflective and analytical writing; notetaking; psychology/interpersonal skills; sketchbook practices; lecture practice; diversity; organizational skills; voluntary attention; leadership; internship; and overcoming adversity did not show up in any of the high school student exiting polls even though they were important aspects of the program and included in the transdisciplinary knowledge they received. The findings support the benefit in high school of rigorous homework practice, critical reading, time management, and the engagement in HDT in subsequent colleges success. It also shows a benefit in team dynamics/teamwork; reflective and analytical writing; empathy; ethics; communication; and critical thinking.

The shift identified in the data over the cohort's college year responses is of importance. Students reported a change in the transdisciplinary knowledge from the program they valued and found useful, from when they existed the secondary program to when they were in engineering college. Significant student shifts occurred in the increased value they placed on rigorous homework practices, time management, critical reading, and reflective and analytical writing. The two highest-ranked values from college students were rigorous homework practices, critical reading and HDT. This indicates the students, in their college years, grew to increasingly value the knowledge and practice they received in these areas, which were not valued as highly in the secondary school exit polls.

The combining of responses from both high school exit and college surveys, revealed a clear clustering of knowledge categories, with HDT; empathy; reflective and analytical writing; time management; team dynamics/teamwork; ethics; rigorous homework practices; and communication ranked higher.  Additionally, each cohort of student classes had several smaller and distinct categories of valued transdisciplinary knowledge unique to, such as patience and leadership skills.

Feedback and observations from secondary students during the program showed a moderate correlation between their adherence to rigorous homework practices and their perception of the importance of homework in the exit survey. However, this may be due to underdeveloped decision-making ability, which is crucial for goal-directed deliberation learning. The overemphasis of declarative memory over semantic memory and episodic memory in the educational system may also contribute to this issue by failing to encourage students to embrace homework practices associated with higher-order cognitive learning that involves complex internal deliberations. During an interview with a first-semester student, they explained that they were better equipped to adapt and succeed in college compared to their struggling peers. The students attributed their success to the Holistic Engineering content and the individualized teacher attention, which helped them develop effective strategies for acquiring knowledge through deliberative homework practices, time management skills, and interpersonal abilities. Research conducted over the years of this program has shown that with individualized teacher support, students can take agency over habit formation and goal setting, adapting to a more rigorous workload and internalizing the changes needed to improve acquisition of knowledge.

To explore this area of research, undergraduate, graduate, and professionals were asked to describe their homework college experiences to secondary students. Observational and verbal response data collected on the last two secondary classes suggested that students focused more on what the previous secondary graduating class told them about the difficulty and benefit of college homework, rather than on when they meet with a group of master's degree engineering students or engineers who had graduated and were working within an engineering company. This may be due to students being conditioned to be grouped into age brackets, creating perceived hierarchy of trust. However, this did not translate into a significantly larger percentage of students embracing homework attitudes differently in their secondary program.

Overall, the students expressed that the knowledge gained from the course would be useful to them in the long term, suggesting that the acquisition of knowledge was integrated into their thought processes and memory. One student even said, "The information I gained in this class will stick with me throughout my life. I will use it throughout my college years, and…be able to add to the information I already have…to build onto… I actually took something away from the class."  Another student said, "It helped me realize the tools I possessed and how to think in different ways best suited to the situation at hand."

The students also expressed that the class helped them "become more aware of myself and how I can apply what I learned into everyday life." One student said, "I've learned how to become a strong visual thinker" and "how to incorporate empathy into everything I do." One student even said, "This class inspired me to buy my own personal notebook, so that I can record and sketch as I please, to further stimulate my creativity." A student reflecting on the holistic nature of the course said, "I now look at the world around me differently and find myself more curious of the things that occupy my daily life."

Furthermore, the students indicated that they plan to take the new knowledge from the class and "apply it to my future" and "implement it into my life" in "college and the workplace." One student said that they "learned the majority of knowledge from the classes and then was able to apply that to the real world while interning." Finally, a senior postsecondary student said that potential employers were most interested in what experiences he had working in teams and design projects in college. He believed that it was his description of his experience in the HE course that got the attention of interviews, and he wondered why there were not more experiences like that for students.

This study not only examined the attributes of students in the pre-engineering programs, but also investigated the retention rates of students who pursued four- or five-year engineering college programs after graduation. The retention rates for the first cohort were 73 percent, including those who enrolled in pre-engineering at a community college. For the second cohort, the retention rate was 77 percent, and for the third cohort, it was 92 percent, with one individual's status unknown and counted as dropping out. The study suggests that the program's small class size had a positive impact on students' habits and abilities, contributing to their success in college, as evidenced by feedback received from students. Furthermore, the study found high college retention rates for all students, even those who did not enter or switched out of engineering majors. Specifically, retention rates for the first year were 83 percent, second-year 90 percent, and third-year 93 percent. This can be attributed to the program's holistic approach to student engagement, which integrates broad-based transdisciplinary knowledge to help students understand and develop their gifts, talents, and their own life purpose.

**Conclusions**

Creating an engineering education pedagogy that supports the introduction of the Holistic Design Thinking methodology for engineering education has proven to be a useful approach for students in this study. The Holistic Engineering pedagogy emphasizes the importance of connecting with students' emotions and feelings as part of cognitive engagement. It also prioritizes providing students with rigorous, broad, and integrated transdisciplinary knowledge that is essential for understanding themselves and their broader purpose of life.

As one student said of the HE program, "Throughout this course, I have learned a lot about how much of the world around us is connected in ways we never realized." While another student reflected, "Self-discovery is a powerful idea that I took away from this class. It has allowed for me to understand how and why I operate in the ways I do and how to be more productive as a person when working towards my goals." Finally, a student summed up the experience by saying, "This class has made me think about how I can use my career path as not just a fulfillment for me, but for the world around me."

This study provides valuable insights into the skills and knowledge that are critical for success in college engineering programs, particularly the first five semesters. The results suggest that rigorous homework practices, critical reading, time management, and engagement in the HDT methodology are important skills for high school students to develop. The study also highlights the benefits of transdisciplinary knowledge in such areas as team dynamics/teamwork; reflective and analytical writing; empathy; ethics; communication; and visual and critical thinking.

Notably, there was a shift in the value placed on transdisciplinary knowledge categories among students who completed the program and their successive semesters in engineering college. Significant shifts occurred in the increased value they placed on the rigorous homework practices, time management, critical reading, and reflective and analytical writing. This change in beliefs about valued knowledge was simultaneously accompanied by access to valued knowledge, which points to retention over time. This shift in beliefs about valued knowledge highlights the benefits of significant integrated and transdisciplinary knowledge provided to students.

Additional information gleaned from telephone interviews and other contacts with students provided insights into areas where students struggled and identified what potential changes to the program could help them succeed in college. One significant finding of this study is that high school students who were open-minded and willing to protype new learning strategies, as well as reflect upon them in written weekly grading reflections, were able to alter their habits regarding voluntary focus, time management, and rigorous homework practices and succeed in their freshman year of college. In contrast, students who dropped out of college and engineering college programs cited a lack of intrinsic motivation, rigorous homework practices, time management skills, voluntary focus, and critical thinking and reading skills as key factors that contributed to their struggles in college. These students self-identified in interviews that these were systemic problems during their high school years. It is worth noting that the difficulties faced by the last two cohorts of the program reported here may have been influenced by the COVID -19 pandemic, which coincided with their enrollment in the secondary engineering course. However, it should be noted that the first cohort also reported similar difficulties despite not being affected by the pandemic in their first three years of high school.

A concerning finding from the study is that even honor roll students struggle with critical thinking, critical reading, and analytical and critical writing. This study suggests that these are challenging concepts and skills for students to master in large groups typical of high school and college course settings.

It is also worth noting that more than half of the students in the program had taken some engineering courses at their home school. Of those who had taken engineering courses, the majority reported that their teachers did not have engineering backgrounds, which left them with a fundamental misunderstanding of what engineering entails. This research has demonstrated the crucial importance of experienced engineering teachers providing learning content that challenges students to grow. However, for these teachers to succeed in their mission, they need essential support from parents and administrators. This issue of teacher expertise is linked to scalability of the results presented here. Therefore, it is critical to further examine how teacher background affects outcomes, as this can have a significant impact on the students' understanding and success in engineering academia.

Smaller class sizes also allowed for improved assessments, greater attention to students' emotional and cognitive needs, as well as understanding and effecting learning deficits, which may be responsible for lower attrition rates in college. There may also be a correlation and causation between the teacher's experience and educational background and their ability to provide active and experiential learning opportunities in which students acquire knowledge. The retention rates could also be indicative of the holistic focus of the program and outreach to these students as they make their way through college giving them a further sense of purpose and identity.

In summary, this research provides valuable insights into the potential benefits of a holistic approach to engineering education, which includes acquiring integrated transdisciplinary knowledge centered on love, empathy, and ethics. It also highlights the role that student emotional responses and feelings can play in promoting academic success. The findings of this study continue to inform the Holistic Engineering pedagogy, equipping students with skills that are useful for success in college, as well as for defining their life's purpose.

More comprehensive data will be available in a year and a half when all students are scheduled to complete their college engineering programs. It is also posited that centering an engineering curriculum around the holistic and transdisciplinary skills that are essential in Holistic Design Thinking, and providing experiential learning opportunities, will equip students with the necessary competencies to work in effective and creative teams and tackle the intricate design challenges in the real world as they transition from high school to college and into their chosen vocations.

Overall, the study suggests that the Holistic Engineering pedagogy and Holistic Design Thinking methodology is an effective approach for engineering education that can help students develop the necessary competencies and skills to succeed in life and college. However, more research is needed the determine scalability and generalizability of these findings to other contexts and populations. Further examination of the impact of prioritizing emotions and feelings in cognitive development, teacher expertise, class size, and experiential learning opportunities on student outcomes is also needed to inform the development of effective engineering education pedagogies.

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