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Developing a Consensus Model of Engineering Thriving Using a Delphi Process*

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A large number of engineering educators, researchers, administrators, staff, and advisors have advocated to shift the narrative on engineering students from "surviving" to "thriving." In this study, we developed a model of engineering student thriving based upon input from 47 experts participating in a Delphi process. The research question for this study is, "To what extent do experts agree on the completeness, conciseness, clarity, accuracy, and utility of the model on engineering student thriving?" The experts included engineering administrators, professors, staff, and advisers who had considerable experience in teaching, supporting, advising, mentoring, or working directly with undergraduate engineering students. Each round of the Delphi process provided opportunities for the experts to identify the most important components of engineering student thriving, the relationships among these components, and the assumptions (often tacit) regarding engineering thriving. After three rounds, our experts reached consensus on a model of engineering thriving that they considered complete, accurate, concise, clear, and useful. Findings from this study revealed three key components of engineering thriving: Internal thriving competencies, external thriving outcomes, and the engineering culture, systemic factors, resources, context and situation. First, undergraduate engineering students have direct and immediate control over only their internal thriving competencies, and our experts overwhelmingly agreed that engineering student thriving should focus more on non-cognitive competencies and non-academic outcomes. Second, the experts identified external thriving outcomes that include characteristics of well-functioning engineering students within the context and structures of the engineering system. However, these outcomes should not be used to determine whether an individual student is thriving, as they are not directly malleable. Third, the engineering culture, systemic factors, resources, context and situation is most directly influenced by the engineering program or institution. The experts agreed that this bridging component between internal competencies and external outcomes represents key concerns for engineering programs. We present highlights from each round of the Delphi process followed by applications of the model for engineering students, staff, administrators, programs, and institutions. These findings build upon prior research by broadening perspectives on engineering student thriving and can inform efforts to support holistic engineering student development.

Keywords: thriving; Delphi method; engineering education; student success; positive psychology

1. Introduction

1.1 Background and Motivation

In the engineering education literature, "thriving" has not been the typical term used to describe the undergraduate engineering experience; rather, "surviving" has been a more common term associated with students' journeys in earning their engineering degree. To illustrate, it is well documented that many undergraduate engineering students experience barriers such as the culture of "suffering and shared hardship" [1], "meritocracy of difficulty" [2], and "chilly climate" (especially women and minoritized groups) [3]. It is also well-documented in the literature that many engineering students who experience these barriers end up underachieving academically or leaving their engineering major [4]. While understanding these barriers is important to address them, they only provide a limited perspective of the undergraduate engineering student experience. This framing often takes a deficit approach in framing engineering students and does not consider what students need to not only "survive" but also to thrive.

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Recent studies indicate that thriving is an important way of understanding the student experience and outcomes and asserts that addressing barriers will not, by itself, lead students to thrive [5, 6]. The skills engineering students need to thrive academically, socially, and personally differ from the skills they need to survive in the face of barriers [18]. However, there is no common understanding or way of studying this phenomenon in engineering education. The essential first step towards understanding engineering students' thriving is to operationalize a common definition of thriving in the context of undergraduate engineering (not thriving in the professional workplace).

This study addresses the growing need for a clear definition of engineering thriving for undergraduate engineering students so that instructors, advisors, administrators and others can have a common vocabulary to recognize and discuss it. The research question guiding this study is, "To what extent do experts agree on the completeness, conciseness, clarity, accuracy, and utility of the model on engineering thriving?" We answer this research question using a Delphi process to obtain a consensus from a group of experts with varied backgrounds and experiences. Based on the experts' feedback, we developed a model of engineering thriving that accounts for the relationships among seemingly diverse categories of competencies, outcomes, and cultural/systemic factors.

1.2 What is Engineering Thriving?

We define *engineering thriving* as the process in which engineering students develop and refine competencies that allow them to function optimally in undergraduate engineering programs. To unpack this definition, we draw upon relevant research from other fields since thriving is underexplored for undergraduate engineering students. In positive psychology, optimal functioning is defined as "a multi-dimensional and holistic concept [which] includes both hedonic and eudaimonic components" [7, p. 149]. Simply put, thriving includes both feeling pleasure (hedonic) and richly engaging with life in meaningful and authentic ways (eudaimonic) [8–11]. Furthermore, we define *competencies* as "the knowledge, skills, abilities, attitudes, and other characteristics that enable a person to perform skillfully (i.e., to make sound decisions and take effective action) in complex and uncertain situations such as professional work, civic engagement, and personal life" [12, p. 476]. These competencies "ultimately reside within the individual student" [13, p. 3]. Engineering student thriving is not a binary state, but a continuous process of development. Thus, the desired outcomes of engineering thriving not only complement those achieved from addressing barriers but also offer new perspectives towards achieving shared desirable outcomes, such as retention or academic performance.

2. Literature Review

2.1 Undergraduate Engineering Culture

We draw upon Schein's conceptualization of culture as "a pattern of shared basic assumptions. . . to be taught to new members as the correct way to perceive, think, and feel" [14, p. 18]. Pedrotti [15] extended the impact of culture to shape the ways characteristics and traits are defined, manifested, and valued. Within engineering education, many researchers already provided examples of characteristics and traits (such as identity) that are specific to engineering culture. For example, several authors argue in favor of engineering identity being distinct from other identity constructs [16, 17]. Given the cultural context for engineering education, we hypothesize that engineering student thriving could be substantially different from thriving for other populations.

Since thriving is culturally dependent, it is imperative to understand key components of thriving in undergraduate engineering programs, specifically those that directly influence what thriving means for engineering students. Engineering thriving is a unique reflection of engineering student experiences in a challenging and competitive engineering culture. It is well-documented that engineering students hold different expectations, values, norms, and behaviors than students in non-engineering fields [19], and they expect a comfortable material existence upon their graduation [2]. Engineering culture promotes a mentality of "suffering and shared hardship" [1, p. 12] that is greeted with pride by some students [2] but can be especially detrimental for minoritized groups (i.e., women, Black, Latinx, and Native students) [20]. Engineering students also might 'take the pain' for the sake of growth [1]. The common underlying assumption is that engineering education should be a highly stressful experience.

A plethora of research indicates that prolonged durations of unmanaged stress rarely lead to positive development. Based on a series of studies started by O'Leary and Ickovics [21], people's response to high-stress situations (which they label 'adverse events') followed a distribution with four outcomes: thriving, resilience, survival, or succumbing. People respond to adverse events in different ways, with most people surviving and recovering their original level of functioning or worse [21]. Only a few people grow to a state of thriving with better functioning than before they experienced the adverse event [21]. According to these findings, the highly stressful culture of engineering education militates against thriving.

The few people who thrive under a culture of adversity offers a perspective consistent with engineering's low retention rates, particularly for minoritized groups. Research suggests that the culture of engineering education plays a large role in students' identities, engagement, and persistence in the major. For example, the culture of engineering contains overt and covert stereotypes that minority groups (such as women, Black, Latinx, Indigenous, lesbian, gay, or bisexual identifying students) are less suited to become professional engineers than their peers [22]. This stereotype is so pervasive that the minoritized students in engineering majors who were able to redefine their identities to align with the prevailing culture were much more likely to persist in the major [23]. The engineering culture even extends to these students in high school, who can be discouraged from pursuing STEM majors despite being highly competent in math and science courses [24, 25]. As a consequence, it is no surprise that women and Black, Latinx, or Indigenous students are less represented in engineering than in other undergraduate majors [26, 27]. Overall, these are several unique aspects prominent in engineering culture that call for a unique model of thriving for engineering students.

2.2 The Need for a Unique Model of Thriving for Engineering Students

A better understanding of engineering thriving, and the culture that supports thriving, could benefit engineering students in many ways. According to research in positive psychology, when college students improve their abilities to thrive, they achieve desired outcomes such as academic performance, retention, engagement, and satisfaction [28–30]. More specifically, Suldo and colleagues [31] found that middle school students with higher well-being demonstrated the highest grades and lowest rates of school absences one year later. Similarly, Howell [32] found that students who thrived reported superior grades, higher self-control, and lower procrastination. In addition, there is consistent evidence that positive emotions are associated with broad, creative, and open-minded thinking, whereas negative emotions restrict focus and narrow attention [33, 34]. Further, improving students' thriving in college results in improving their thriving after college [35]. Might these previous results apply to engineering students? Since thriving is contextually related to culture, *engineering* thriving specifically focuses on the processes that support these desired outcomes for the undergraduate engineering students in the unique engineering culture.

Since little is currently known about engineering thriving in the literature, the objective of this study was to develop a model of thriving based on consensus from experts in the field. We recruited engineering professors, staff, advisers, and others with experience teaching, supporting, advising, mentoring, or working directly with undergraduate engineering students. Then, we asked them to come to a consensus on the most important competencies, and relationships among them, that contribute to thriving for undergraduate engineering students. This information was used to generate a model of engineering thriving based on expert consensus. Ultimately, this research could inform interventions and policies to better support undergraduate engineering students to thrive.

3. Methods

3.1 Research Design and Purpose

This study employed the Delphi process to obtain a consensus from experts in engineering education about a model of engineering thriving. The Delphi process involves structured communication that enables a group of experts to reach consensus regarding a topic, often complex or broad, without physically bringing them together [36, 37]. Delphi processes are expected to result in group consensus over several rounds of feedback from the experts. According to Linstone and Turoff [38], the Delphi process is particularly useful when five conditions hold.

1. The problem does not lend itself to precise analytical techniques but can benefit from subjective judgments on a collective basis.
2. The individuals needed to contribute to the examination of a broad or complex problem have no history of adequate communication and may represent varied backgrounds with respect to experience or expertise.
3. More individuals are needed than can effectively interact in a face-to-face exchange.
4. Time and cost make frequent group meetings infeasible.
5. The heterogeneity of the participants must be preserved to assure validity of the results, i.e., avoidance of domination by quantity or by strength of personality ("bandwagon effect").

All these five conditions were relevant in this Delphi study. First, since research on thriving in the context of undergraduate engineering students remains underexplored, feedback from a group of experts was necessary to provide insights into the broad and complex model of engineering thriving. Second, the topic of thriving in the context of undergraduate engineering students is highly complex, especially given the multidimensional nature of students' competencies and their overall experiences within the engineering culture. This complexity motivated input from a heterogeneous group of experts with varied backgrounds and expertise. Third, the Delphi process enabled our experts the flexibility of participating from various geographic locations, time-zones, and schedule availability. Fourth, due to time and budget constraints, we lacked the ability to gather a large number of stakeholders representing engineering staff, professors, department chairs, deans, and advisors from several universities and community colleges for this study. Fifth, the Delphi process provided a structure for experts to share observations anonymously with one another such that each can become more informed throughout this process. Prior research indicated that the Delphi process was more effective than traditional focus groups since the "...anonymity and isolation of the participants facilitated a freedom from conformity pressures" [36, p. 619]. All these aspects of the Delphi process allowed us to include participants whose perspectives on engineering thriving would otherwise not be captured. Overall, the Delphi process allowed a structured communication process between experts to collaboratively reach a consensus regarding a model of engineering thriving.

3.2 Position and Experience of Delphi Experts and Criteria for Expertise

Since the experts determine the quality of the data in this Delphi process, we recruited a group of experts with varied backgrounds and experiences. For this study, we were most interested in capturing the expertise from engineering faculty and staff who support engineering student thriving that may not have been captured in the literature. Since no established standards for professional expertise currently exist in engineering thriving, we chose to define expertise broadly, in alignment with Geier's recommendation to select "the individuals involved in the work rather than a selected panel of experts" [39, p. 390].

Our experts consisted of engineering faculty and staff – including instructors, administrators, academic advisors, and others – who were experienced with teaching, supporting, advising, mentoring, or working directly with undergraduate engineering students in academic institutions. The experts represented 23 academic institutions, 15 academic disciplines, three administrative offices, nine position types, and between 3–20+ years of experience. In our study, Mechanical Engineering and Bioengineering/Biomedical Engineering were the most represented fields. Our sample also captured few perspectives from engineering staff, directors, and department chairs. Our experts were primarily focused on research (45%) or teaching (32%). The experts represented an even balance of experience, with 36% having 3–10 years, 26% having 10-20 years, and 38% having over 20 years of experience. Table 1 describes the information of the 47 experts who met these criteria for expertise and participated in the Delphi study.

Experts on the Delphi study were chosen based on three criteria. First, experts must have worked at or were associated with an undergraduate engineering program at an academic institution such as a university or college. This criterion was essential because the target audience for the model of engineering thriving are undergraduate engineering students. Second, experts must have taught, supported, advised, mentored, served in an administrative role, or otherwise worked directly with undergraduate engineering students. This criterion was developed to select professionals who were actually working directly with undergraduate engineering students in some capacity. Third, they must have sufficient professional experience in applying features of the first two criteria to their job roles. We defined sufficient professional experience to include at least three years of experience, a criterion consistent with those in other Delphi studies [40, 41]. For individuals in instructional roles, for example, we defined sufficient professional experience to include at least three years of experience in all facets of course delivery, such as design and delivery of materials, creation of assessments, and assigning grades. This criterion therefore generally excluded graduate students and post-doctoral scholars, who have most likely not held that level of authority in a course (or if they have, generally not for at least three years). On the other hand, this criterion includes perspectives from pre-tenured instructors and faculty.

Because specific experts who fit these selection criteria were recruited, convenience and snowball sampling were used at the 2019 American Society for Engineering Education Annual Conference and Exposition. We sent out a link to an initial survey to the chair of every ASEE division and asked the chairs to share the link with their division's listserv. We also recruited by word of mouth during the conference. Since the Delphi process is time-consuming, potential experts were asked at the beginning of the study to commit to all rounds of the research study. The general rule-of-thumb for participant size is 15 to 30 experts [37]. Out of the 72 participants who completed the initial survey, only 47 participants met our selection criteria and were invited to continue in the study as our Delphi study

Table 1. Position and Experience Information of the Experts (N = 47)

Information of the Experts	***n***	**%**
Current Position Held		
Research Focus: Professor, Faculty Member	21	45
Teaching Focus: Professor, Faculty Member, Instructor, Lecturer	15	32
Adviser	2	4
Student Affairs	2	4
Staff	1	2
Associate Dean	2	4
Department Chair	1	2
Engineering Career Coach/Counselor/Psychologist	2	4
Director of Engineering Education Center	1	2
Years of Experience		
3–10 Years	17	36
10–20 Years	12	26
Over 20 years	18	38
Engineering Department Affiliation		
Aerospace/Astronautical Engineering	1	2
Bioengineering/Biomedical Engineering	8	17
Chemical Engineering	2	4
Civil Engineering	2	4
Computer Engineering	2	4
Computer Science	1	2
Electrical Engineering	4	9
Environmental/Ecological Engineering	1	2
Industrial/Systems Engineering	4	9
Materials Engineering/Material Science/Metallurgical Engineering	3	6
Mechanical Engineering	9	19
Multidisciplinary/Interdisciplinary/General Engineering/Engineering Management	4	9
College of Engineering	1	2
Engineering Education	1	2
Humanities, Social Sciences, and the Arts (at an Engineering School)	1	2
Engineering Career Center	1	2
Engineering Undergraduate Programs Office	1	2
Engineering Student Services	1	2

experts. Out of the 47 participants who completed Round 1, 33 participants completed Round 2, and 27 participants completed Round 3 (see Table 2).

3.3 Delphi Process and Survey

The Delphi process involved iteratively collecting data from our experts in response to five evaluation criteria regarding the model of engineering thriving until consensus was reached. We defined consensus by 75% agreement among experts. Since the overall purpose of this study is to develop a model of engineering thriving by evaluating the components and the relationships embedded between these components, we established five consensus criteria: completeness, conciseness, clarity, accuracy, and utility. These five criteria were deliberately adapted from existing criteria used to evaluate theories [42–44]. Adapting these existing criteria for theory development was essential to refine the model of engineering thriving.

We developed an electronic survey with these five criteria. For each criterion, the experts selected one of three options for feedback along with their explanation: (1) No change, acceptable as is; (2) Minor change, please explain; or (3) Significant change, please explain. The initial survey was pre-tested independently by six reviewers, and minor modifications were implemented. Then, we invited our experts to evaluate the model based on the five criteria. The experts came to a consensus on all five criteria in three rounds. Details regarding the procedure for the three rounds of the Delphi study include:

Round 1: First, we collected participant consent and information about their position and experience. Then, the experts were asked to define what thriving means to them and offer a list of the most important competencies and their definitions.

Table 2. Results of Delphi Process. Consensus (defined by >75% agreement) are bolded

	Expert Feedback		
Model Criteria	**Round 1** $n = 47$ **[%]**	**Round 2** $n = 33$ **[%]**	**Round 3** $n = 27$ **[%]**
Complete			
No change, acceptable as is	36	64	**81**
Minor change	40	15	11
Significant change	23	21	7
Concise			
No change, acceptable as is	62	**76**	**89**
Minor change	30	18	7
Significant change	9	6	4
Accurate			
No change, acceptable as is	38	67	**85**
Minor change	34	15	7
Significant change	28	18	7
Clear			
No change, acceptable as is	57	70	**81**
Minor change	28	15	15
Significant change	15	15	4
Useful			
No change, acceptable as is	64	70	**93**
Minor change	26	12	4
Significant change	11	18	4

Recall we defined competencies as "the knowledge, skills, abilities, attitudes, and other characteristics that enable a person to perform skillfully (i.e., to make sound decisions and take effective action) in complex and uncertain situations such as professional work, civic engagement, and personal life" [12, p. 476]. These competencies "ultimately reside within the individual student" [13, p. 3]. Next, we presented experts with a preliminary model of engineering thriving developed based on findings from a scoping literature review [18]. Experts were asked to provide feedback on whether they believe the model to be complete, accurate, concise, clear, and useful. Also, experts were notified that this information was used to revise the model of engineering thriving for the subsequent round.

Round 2–3: Each subsequent round of the survey incorporated a revised model of engineering thriving along with a summary of revisions and themes from responses in the previous round. The experts were asked to evaluate this revised model for completeness, conciseness, accuracy, clarity, and utility. We also presented experts with the percent agreement for each statement: (1) No change, acceptable as is; (2) Minor change, please explain; or (3) Significant change, please explain. We continued this process for three rounds, at which point the experts achieved consensus for all five criteria (indicated by at least 75% selecting "No change").

Once data were collected for each round, the research team reviewed the responses using an inductive thematic analysis approach in accordance with Braun & Clarke [45]. For the first round of data analysis, the main reviewer (Gesun) reviewed all experts' definitions of thriving and categorized them into broader themes. The main reviewer also met with a second reviewer (Gammon-Pitman) who also reviewed the raw data and created categories to discuss our findings and resolve discrepancies in interpretation. A third reviewer (Berger) was consulted to resolve major discrepancies in categorization between the first and second reviewers. Then, at least two reviewers (Gesun and either Gammon-Pitman or Berger) independently reviewed all expert feedback regarding the model's completeness, conciseness, clarity, accuracy, and utility. After each round, at least two reviewers (Gesun and either Gammon-Pitman or Berger) organized experts' feedback for "minor changes" and "significant changes" for each of the five criteria, as well as an "additional suggestions" section. Modifications to the model of engineering thriving were implemented based on the main themes that emerged from experts' feedback. Then, the key themes that emerged from each section, as well as their corresponding modification to the model were summarized and shared with the experts during the next round of the Delphi process. After being shown the summary of themes and modifications, experts were asked to evaluate the updated model's completeness, conciseness, clarity, accuracy, and utility. This process of data analysis and reporting continued for each round until the experts reached consensus in Round 3.

3.4 Trustworthiness

The steps taken to establish the trustworthiness of data analysis were guided by Lincoln and Guba's criteria for trustworthiness [46]. First, all experts' personally identifying information were removed from the data prior to data analysis. Removing experts' identifying information prior to data analysis reduces biased evaluations from the reviewers, such as due to experts' gender, race, or years of experience. For credibility, the main reviewer (Gesun) met with two other reviewers to triangulate themes and resolve any discrepancies. When necessary, the main reviewer (Gesun) member-checked with experts to ensure accurate interpretations of their feedback [46]. For transparency, the main reviewer (Gesun) kept an audit trail of records for all raw data, codes, and notes from discussions that justified how and why key decisions were made at each step of the Delphi process.

Overall, these three rounds of the Delphi study allowed the experts to elucidate the most important components of engineering student thriving, the relationships among these components, and the assumptions (often tacit) regarding engineering thriving. This structured process of communication facilitated group communication dynamics necessary for the experts in our study to reach a consensus regarding a complete, accurate, concise, clear, and useful model of engineering thriving.

4. Results

4.1 Summary of Expert Feedback

Recall that we define engineering thriving as the process by which undergraduate engineering students develop and refine competencies that allow them to function optimally in their academic, social, and personal experiences in engineering programs. After three rounds of the Delphi process, our experts achieved consensus on the five model criteria: completeness, conciseness, clarity, accuracy, and utility. Table 2 depicts a summary of the expert feedback on these five criteria for each of the three rounds of the Delphi process.

4.2 Overview of Consensus Model of Engineering Thriving

Fig. 1 depicts the model of engineering thriving and Appendices A–C contains the detailed lists provided by our experts. As shown in Fig. 1, the cyclical structure of the model of engineering thriving indicates an ongoing process of managing changes in students' internal competencies, which affect their external outcomes, which affect their internal competencies. This model accounts for the relationships among seemingly diverse internal competencies, external outcomes, and cultural/systemic factors.

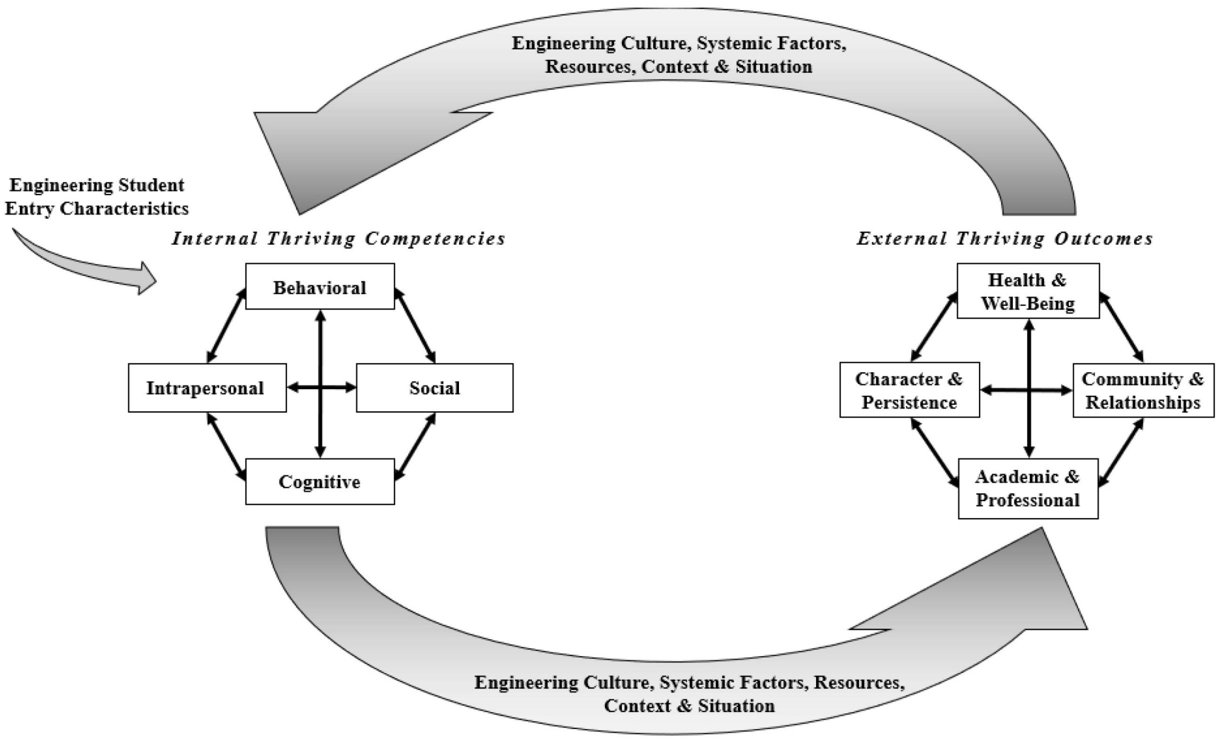

Fig. 1. Model of engineering thriving based on consensus from experts.

The relationships between internal competencies and external outcomes are mediated by the engineering culture, systemic factors, resources, context, and situation. Since engineering thriving is considered a process (rather than a binary state), it is not required for students to have all the "Internal Thriving Competencies" listed in Appendix A to exhibit "External Thriving Outcomes" in Appendix B. Similarly, it is also not required that students exhibit all "External Thriving Outcomes" in Appendix B to consider a student thriving. Finally, the model of engineering thriving is bounded by the context and timeframe of undergraduate engineering programs. Thus, general thriving (such as an adult with a professional career) is not the same as engineering student thriving.

Prior literature provides valuable insights to our understanding of engineering thriving, by largely focusing on understanding the effects of various cognitive competencies on engineering students' academic outcomes [18]. Contrary to the literature, our experts overwhelmingly defined thriving in terms of non-cognitive competencies and non-academic outcomes. Fig. 1 depicts the consensus model of engineering thriving that illustrates the following four key components:

(1) the categories of internal thriving competencies relevant to engineering student thriving;
(2) the categories of external thriving outcomes of engineering student thriving;
(3) the categories of engineering culture, systemic factors, resources, context and situation that affect engineering student thriving;
(4) the relationships between components of the model.

The rectangles in Fig. 1. represent the categories of internal thriving competencies and external thriving outcomes. During the first round of the survey, we collected experts' definitions of thriving and the most important competencies that they believed contribute to thriving. The double arrows connecting the rectangles depict that these categories are interrelated and, in alignment with prior work, likely function synergistically to affect engineering students [47]. These broader categories were created by synthesizing the list of competencies and outcomes provided by experts. Appendices A–C list these specific competencies and outcomes.

The two large gradient arrows in Fig. 1 represent various aspects of engineering culture, systemic factors, resources, context and situations that impact the relationships between students' internal thriving competencies and external thriving outcomes. The gradient indicates the continually changing impact of these factors throughout the process of engineering thriving. These factors can influence two students with similar internal thriving competencies to achieve vastly different external thriving outcomes. As a practical example, two students with similar levels of motivation and cognitive ability could end up experiencing different levels of connection or retention outcomes. Appendix C includes potential influencers on these differential outcomes, including cultural and systemic factors such as engineering culture, implicit biases, and stereotypes. Similarly, these same cultural and systemic factors may also influence two students with similar academic performance (external thriving outcomes) to have vastly different experiences of inclusivity or work ethic (internal thriving competencies).

The arrow in Fig. 1 labeled "Engineering Student Entry Characteristics" represents the student's input profile and prior experiences when they enter an undergraduate engineering program. Despite the model of engineering thriving being bounded by the context and timeframe of undergraduate engineering programs, engineering students' entry characteristics was identified by our experts to have significant influence on engineering students' experiences. As a practical example, engineering student's high school performance and country of origin are not expected to change due to the student's experience in an undergraduate engineering program. Thus, the solid color for this arrow indicates that entry characteristics are not expected to change due to the students' enrollment in an undergraduate engineering program.

4.3 Internal Thriving Competencies

Recall that we defined competencies as "the knowledge, skills, abilities, attitudes, and other characteristics that enable a person to perform skillfully (i.e., to make sound decisions and take effective action) in complex and uncertain situations such as professional work, civic engagement, and personal life" [12, p. 476], and they "ultimately reside within the individual student" [13, p. 3]. Appendix A contains a detailed list of specific competencies that belong in each of the following categories:

- Behavioral competencies: Specific actions and habits in response to situations and stimuli.
- Cognitive competencies: Thinking, reasoning, knowledge transfer, and related mental processes.
- Intrapersonal competencies: One's relationship with oneself and how one interprets external situations and stimuli.
- Social competencies: Clearly conveying information to others and interpreting others' messages and responding appropriately.

Only the individual has direct and immediate control over their own internal thriving competencies, as these experiences are intrinsic. Our experts described internal thriving competencies as having an "active" effect within students. Consistent across our literature review and expert feedback is the notion that multiple internal thriving competencies are inter-related and simultaneously affect the engineering student. For example, students with many positive behavioral competencies, such as help-seeking and caring for others, are also likely to have stronger social skills. Thus, we provide multiple categories of internal thriving competencies to acknowledge a holistic perspective on engineering student development.

4.4 Engineering Culture, Systemic Factors, Resources, Context and Situation

Environmental, contextual, and systemic factors are defined as the personal and university contexts, situations, resources and cultures that impact engineering students' internal competencies and external outcomes. In Fig. 1, these factors are depicted as arrows. Appendix C contains a detailed list of specific factors that belong in each of the following categories:

- Cultural and Systemic Factors: Deeper ingrained "root causes" that influence students' opportunities and abilities to thrive while part of the undergraduate engineering system.
- University Resources: The capital, assets, affordances, and environmental factors within the university or program that affect the engineering student's access to support and enrichment opportunities.
- Personal Context & Situation: Significant life circumstances that can influence students' interpretations and responses during their undergraduate engineering experience.
- Engineering Student Entry Characteristics: The student's input profile and prior experiences when they enter an undergraduate engineering program that are not expected to change during their time in an undergraduate engineering program and may influence their experiences during their undergraduate engineering experience.

The engineering program or institution has the most control over the university resources and engineering culture that mediate the relationship between engineering students' internal thriving competencies and external thriving outcomes. Experts defined cultural and systemic factors broadly, ranging from engineering departments to institutions. Recall that the engineering culture has been described in terms of hardship, suffering, and chilly climates, and that these cultural and systemic factors shape which competencies are considered strengths. Thus, the elements listed in this component are of direct concern for engineering programs and institutions. For example, one expert referred to the engineering programs and institutions as having the responsibility to create "systemic conditions of justice, specifically procedural and distributive forms of justice at all levels of the [engineering] system (personal, interpersonal, organizational, societal, historical)." Given the importance of these cultural and systemic factors in impacting engineering student thriving, this model provides several key components of direct concern for engineering programs and institutions. We discuss these components and opportunities for intentional change in the Implications section.

4.5 External Thriving Outcomes

External outcomes are defined as the results and impacts of the use of internal competencies under favorable contexts, situations, and systemic factors. Similar to internal thriving competencies, external thriving outcomes are neither mutually exclusive nor collectively exhaustive categories. Rather, they are multidimensional and synergistic. For example, students who cultivate strong health and well-being are likely to also find improvements in community and relationships and academic performance [47]. In this sense, the external thriving outcomes can display what one expert described as "success begets success":

> "The best internship opportunities fall to students with high GPAs, and once you have experience, success begets success and motivates authentic classroom learning."

Appendix B contains a detailed list of specific outcomes that belong in each of the following categories:

- Community & Relationships: Creating and maintaining positive connections and belonging to a supportive network of individuals within the engineering education system.
- Health & Well-Being: Building and maintaining a state of multidimensional well-being that supports undergraduate engineering students to balance and function successfully in their responsibilities within their engineering program and personal life.
- Character & Persistence: The positive character traits, capacities, and virtues that result from continuously developing, strengthening, and applying internal thriving competencies.
- Academic & Professional: Achieving educational goals towards an undergraduate engineering degree and professional career.

The locus of control for external thriving outcomes is neither central to the student nor the engineering program or institution. Even engineering programs with the best resources, contexts, and culture cannot guarantee that all their engineering students will graduate with all external thriving outcomes, such as high grades, strong community and relationships, positive health, and excellent character. As one reviewer mentioned, sometimes "success begets success" and the students with high GPAs (one external thriving outcome) tend to land internships (another external outcome).

Other times, however, the presence of one external outcome (such as GPA) does not beget the presence of other external outcomes (such as retention). For example, prior research found that significant numbers of engineering students leave engineering despite having passing GPAs [48]. This example illustrates that just because a student has a good GPA (one thriving outcome) does not imply that the student will retain or graduate with an engineering degree (another thriving outcome). Since engineering thriving is not a binary state (e.g., thriving versus not thriving), we recommend against evaluating engineering students, programs, or institutions based solely on these external thriving outcomes for engineering students.

Since external thriving outcomes are not directly malleable, we recommend evaluating students based on their growth in various internal thriving competencies. Similarly, we encourage interventions to target engineering students' internal thriving competencies (see section 4.3) and the engineering context, situation, or culture (see section 4.4). Since engineering student thriving is a continuous process of development, this list of external thriving outcomes is best used as a guide for positive holistic student development. We further discuss specific examples of these interventions in the Implications section.

5. Discussion

5.1 Analysis of Delphi Responses

Recall the research question guiding this study: To what extent do experts agree on the completeness, conciseness, clarity, accuracy, and utility of the model on engineering thriving? As shown in Table 2, the experts achieved consensus on all five criteria in three rounds. In examining the experts' reactions to the model of engineering thriving, we present the highlights of their feedback for each criterion and summarize modifications to the model leading to consensus.

5.2 Completeness

To evaluate the model's completeness, we asked our experts if any components of the model or tables in Appendix A–C needed to be added. Surprisingly, only 36% of our experts indicated that the literature-derived model seemed complete in Round 1. Our experts overwhelmingly agreed that the model needed to include more non-cognitive competencies and non-academic outcomes. Most experts indicated a need to add to the model more non-academic outcomes, environmental factors (such as life events, family, interactions with admin, advisors), and positive health outcomes (mental, physical, emotional, financial). While the categories of internal thriving competencies echo those from the literature, these additions to the external thriving outcomes deviated significantly from our literature review findings.

In response to expert feedback in Round 1, we modified the model to include three categories of non-academic outcomes. These categories included various positive health outcomes in a "Health and Wellbeing" category, environmental factors in a "Community & Relationships" category, and one more non-academic outcome "Character & Persistence." We also created the tables in Appendix B and C to capture the list of specific examples that the experts offered within these categories. Although the individually listed elements in Appendices A–C are not explicitly part of Fig. 1, they were crucial for the experts to see their specific feedback incorporated in modifications on the model of engineering thriving without cluttering the visual representation of the model itself.

Once we addressed these experts' feedback in Round 1, 64% of experts indicated that the model in Round 2 seemed complete, and several experts offered further additions to improve the model's completeness. Our experts were overall satisfied with the additions to external outcomes and encouraged adding the importance of influential root causes like systemic factors and engineering culture that may mediate the relationships between internal thriving competencies and external thriving outcomes. Recall one expert noted the importance of adding "the systemic conditions of justice, specifically procedural and distributive forms of justice at all levels of the system (personal, interpersonal, organizational, societal, historical)." This expert references the concepts of justice by Duff et al. [49], which describes distributive justice – with regards to fairness in distributing responsibilities, rights, privileges, and burdens – and procedural justice – which refers to fair and inclusive processes that promote trust, respect, control, and empowerment between people who interact in the system. The following examples represent additional feedback from our experts that illustrate the importance of additional mediating factors:

> "Context & Situation can have a much, much larger number of variables than any of the other categories and have a greater number of smaller changes that

happen throughout a student's college career. The definition says "life experiences" which I would take to mean personal context & situation (jobs, family situations & requirements, life events, etc.) but the examples also include school-focused context & situations like course load and instructor competence. I would break this down into at least two separate categories (both affected by and feeding into the system), one for personal context & situation (life events, family responsibilities, work, etc.) and one for university context & situation (e.g., course load, extra-curriculars, instructor competence, internship/research, etc.). I would make the difference explicit as the personal context & situation is very student-specific while the university context & situation contains variables that are directly related to university resources and offerings."

"By focusing on the details of student internal competencies and student external outcomes, the systemic conditions which are arguably at least as influential as what is pictured, cannot be addressed. One can only address the symptoms rather than root causes."

In response to our experts' feedback, we added "Engineering Culture, Systemic Factors, Resources, Context & Situation" to the two larger arrows to represent that the internal thriving competencies and external thriving outcomes are mediated by these factors. That is, they directly acknowledge the role of "the system" in shaping conditions that can lead students with similar internal competencies to vastly different external outcomes, and vice versa. For example, several engineering students are admitted for their strong cognitive competencies, yet they result in vastly different academic performance based on their abilities to navigate the engineering culture or structures at their institution. We also added Appendix C to capture the list of specific examples that the experts offered within these categories. While several papers in our literature review acknowledged the influence of many of these elements [18], our experts' feedback vastly expanded the "Context & Situation" section from our literature review findings.

With these additions, the experts reached consensus on the model's completeness in Round 3 and offered suggestions for future work. One expert suggested building upon two well-known cyclical development models, such as the model of the socio-constructivist Vygotsky cycle [50] and Macmurray's cycle of withdrawal and return [51]. Studying the underlying structures and applications of these models will help us reflect upon strategies to apply the model of engineering thriving in various contexts as described in our future work section.

5.3 Conciseness

To evaluate the model's conciseness, we asked our experts if any components of the model or tables in Appendix A–C need to be deleted or merged to make the model more parsimonious. In Round 1, the majority of experts indicated that the academic outcomes in the model should be merged or reduced to make space for more non-academic outcomes. Contrary to our findings from the literature, which prioritized engineering students' academic outcomes [18], many experts expressed the need to reduce the prominence of academic outcomes in the model. This increased focus on non-academic outcomes may be a consequence of our experts' diversity of roles. In response, we merged course grades, GPA, retention, graduation into a single broader category of "Academic & Professional" outcomes.

By Round 2, conciseness became the first criterion to achieve expert consensus and the only criterion for which a few experts even expressed being *too* concise. Several experts pointed out that the model might be too concise because the broader categories did not contain details of the expert's individual contributions in the model. To address feedback that the model might be "too concise," we expanded the tables in Appendix A–C to include the experts' individual contributions and added more text descriptions to the model explaining each broader category. This process established a delicate balance between including more details in the model and tables in Appendix A–C without deviating from the purpose of the model to depict a simplified and big picture understanding of a complex phenomenon. With these changes, the experts maintained consensus and presented no major reservations in Round 3.

5.4 Clarity

To evaluate the model's clarity, we asked our experts if any components of the model or tables in Appendix A–C need to be relabeled to clarify what the components were and what they meant. While 57% of our experts indicated the model was clear in Round 1, the experts' collective understanding of individual internal thriving competencies seemed to differ. For example, different experts sometimes provided different perspectives of the same term, resulting in inconsistent use of terms and definitions. Consider the following descriptions of "teamwork" from ten experts:

- "work in teams – effectively listen to others, take and apply advice/knowledge, lead and/or follow when needed to accomplish tasks"
- "Team oriented – understand that two+ heads think better than one."
- "Interpersonal skills-working well with others in teams"
- "teamwork: ability to function (in a number of

roles) within a team of people to achieve desired goals or outcomes of the collective''

- ''Teamwork – Ability to address team conflicts and complete tasks in groups''
- ''Ability to work well with others''
- ''collaboration and teamwork''
- ''team skills: the ability to peacefully work with others''
- ''can work with others''
- ''effective team member''

In response, we clarified these different perspectives by combining similar ideas from experts into a single term. The final list of terms is included in Appendix A.

Interestingly, some experts also provided terms that we did not find in our literature search. These terms, such as ''hoop jumping'' and ''brain rodeo'' were considered very important internal thriving competencies to one expert but seemed unclear to others, as illustrated by one expert's feedback:

> ''I think the use of the terms 'hoop jumping' and 'brain rodeo' are unclear. I think I know what is meant by 'hoop jumping', but I have never even heard the term 'brain rodeo'.''

Finding clear shared understandings of individual terms was at times challenging with our experts' varied backgrounds and expertise. This kind of challenge is well-documented in other Delphi studies [52] and is considered a result of language and curriculum differences from experts coming together from different backgrounds and engineering communities. In alignment with the Delphi study's purpose, we captured and represented all feedback from our experts in Appendix A–C, unless there was consensus to remove or modify feedback from a prior round.

When evaluating the model's clarity, our experts posed some insightful questions and concerns that did not lead to actionable changes to the model. This type of feedback was particularly interesting and reflective of the engagement of our experts. We present two examples of this type of feedback:

> ''Unclear. It's hard for me to interpret what the relationships among these specific factors might be.''
>
> ''The time scale should be clarified. If this is an iterative process how and where does it happen within the journey that an engineering student takes from entering an engineering program to when they graduate?''

These two examples indicate that some experts believed changes were necessary, yet the feedback did not provide specific changes to improve the clarity of the model. While we appreciate our experts' insights into missing elements of the model, this type of feedback did not result in any clear actionable changes to the model.

To address this feedback and improve the clarity of our model, we created the model of engineering thriving to focus on the broader categories that emerged and the interactions between these broader categories. In Appendices A–C, we acknowledge the variation in the descriptions of thriving competencies amongst our experts. The purpose of our model is not to focus on different understandings of individual competencies that not all experts understood. Instead, we focused on depicting the shared understandings from our experts regarding the big-picture functioning of the model. Thus, our model depicts broader categories whose interactions and relationships seem to be common across many engineering disciplines and types of engineering programs. Identifying these broader relationships also forms a starting point for understanding engineering thriving in engineering programs and how these categories might change over time. The model also highlights major categories that are of direct concern for engineering students and those who work to support their thriving.

With these changes, 70% of experts indicated in Round 2 that the model was clear, and most of the experts in the other 30% noted that ''engineering'' and ''thriving'' needed to be clearer in the visual representation of the model of engineering thriving. While it was clear that ''thriving'' in the ''engineering'' context had been intentionally embedded into the study and process, our visual model could have displayed our intentional efforts more clearly. In response, we relabeled the larger arrows to explicitly include ''engineering'' to clarify that the context of this model is within the engineering system. Similarly, we relabeled ''Internal Processes'' and ''External Outcomes'' to include ''Thriving'' to clarify that these are only components relevant to thriving.

Thriving refers to positive supports that build thriving, which we hypothesize as a different set of competencies and contexts than those that prevent failure. Engineering students participate in the entire breadth of human experiences, from suffering, hardship, and succumbing through connection, health, and optimal functioning. The barriers that inflict ''suffering and shared hardship'' in engineering students are well-explored [1], while fewer research studies have focused on what causes them to ''thrive,'' or even what thriving means in the context of engineering. Thus, the model of engineering thriving focuses on categories that improve students' functioning, rather than barriers that reduce students' functioning.

In addition, a few experts also wanted clarity regarding how to identify if an engineering student is thriving, and whether a student would need to have all four aspects of internal competencies in order to exhibit external outcomes. This feedback highlighted the importance of clarifying our definition of engineering thriving, which we indicated is a *process* of developing more internal thriving competencies and external thriving outcomes.

Given that engineering thriving is a process rather than a binary state (thriving versus not thriving), it is not required for a student to have all the competencies listed in Appendix A to exhibit "external thriving outcomes." In fact, the bullet points listed under "external thriving outcomes" represent experts' ideas of the characteristics of thriving engineering students and meant to provide a guide to better support engineering students' holistic development.

In response, we explicitly redesigned the two large bidirectional arrows to clearly represent the cyclical process of thriving to avoid depicting engineering thriving as a binary state (thriving or not). Similarly, we caution against using external thriving outcomes to label whether engineering students are thriving or not.

With these clarifications, the experts reached consensus on the model's clarity in Round 3, and a few experts offered helpful suggestions for future work. For example, one expert offered a user interface suggestion to improve the clarity of the model if published online.

> "The model, if implemented on a website could open a text window with explanation when the cursor hovers on top of a box. Reading prior comments, I also guess that some respondents were viewing through a smart phone which will make details much more difficult to see than on desktop computer."

5.5 Accuracy

To evaluate the model's accuracy, we asked our experts if any of the relationships between components (arrows) in the model need to be added, deleted, or redirected. In Round 1, only 38% of our experts indicated that the literature-derived model seemed accurate. Unexpectedly, most of the feedback for accuracy evaluated the word "accuracy" rather than the arrows in our model. The experts pointed out that no model can accurately represent reality and suggested ways to test the model for validity. In response to experts' feedback, we acknowledged their accuracy in pointing out that our model is not a fully accurate representation of thriving for engineering students and redirected the question to focus more on the relationships between categories in our model.

With this reframing of the term "accuracy," 67% of experts indicated in Round 2 that the model was accurate, and those who disagreed suggested changes to the relationships between broader categories in our model. For example, one expert suggested that a nested model with concentric circles of "internal thriving competencies" in the middle might be more accurate since the internal and external seem more together than apart. After discussing the option of using a nested model, we decided that the large rounded arrows to circle between "Internal Thriving Processes" and "External Thriving Outcomes" best highlight the cyclical process of thriving and the process of managing changes in students' internal and external environment. Nested models do not depict this fundamental property of thriving of continuously cycling between internal processes and external outcomes.

Another expert suggested modifying the arrows to present the nature of changing relationships between components. In response, we added the gradient on the large arrows to symbolize change, as the process of thriving requires managing constant change. On the other hand, we shaded the arrow labeled "Engineering Student Entry Characteristics" a solid color to indicate that entry characteristics are not expected to change during the student's journey as part of an undergraduate engineering program.

With these additions, the experts reached consensus on the model's accuracy in Round 3, and a few experts offered helpful suggestions for future work. For example, one expert suggested exploring and clarifying the role of various engineering cultural and systemic factors in mediating the relationship between internal thriving competencies and external thriving outcomes. We discuss exploring this direction in our future work section.

> "I think that you want to be explicit on the elements of 'engineering cultures' and 'systemic factors' so that you can create a 'same/opposite' or '+/–' dynamic relationship with thriving."

5.6 Utility

To evaluate the model's utility, we asked our experts to identify which changes will make the model more useful for them to understand thriving for undergraduate engineering students. In Round 1, 64% of experts agreed that the model was useful, making usefulness the criterion with the highest agreement. While most experts determined that the model seemed useful, some experts suggested including more details regarding potential interventions, causal interactions, and outcome metrics. The following feedback illustrates these suggestions:

> "I think a table of interventions and explicit examples of causal interactions indicated by the arrows would make it more clear and useful."

> ". . .it would be great if there were metrics for some of the external outcome – the table is helpful and someone with a qualitative analysis background may be able to

> study growth in these areas but I don't have that background. . ."

Similar to our response to the clarity criterion, we acknowledged our experts' engagement, and their feedback extended beyond the scope of the Delphi study. Delphi studies are designed to capture the existing knowledge of our experts. Since the purpose of the model is to represent what the experts already knew, we considered these suggestions as excellent opportunities for future work.

In Round 2, 70% of experts agreed that the model seemed useful, while many of the other 30% commented that they were unsure how to apply the model in practice. Since the experts provided no specific changes to the model, we encouraged experts to offer specific changes to the model that would improve its utility. The following comments from experts illustrate this feedback.

> "Useful but at this point not actionable."

> "It's a good starting point. It's [sic] utility won't be demonstrated until people use it."

> "Clearly this model is a starting point for future work and identifying for whom this model will be useful will be important, e.g., faculty, advisors, staff. I'm also curious HOW and WHERE this model will be useful, particularly from a developmental perspective."

> "I'm curious to see what are the possible applications of this model and how and who would use this model."

The experts reached consensus on the model's utility in Round 3, stating that they were not able to offer suggestions to make the model more useful. However, they continued to comment that they were unsure how to use the model in their work. In the next section, we offer ideas for interventions and other ways to apply the engineering thriving model in practice.

6. Contributions and Implications for Engineering Education

This study contributes to research and practice in engineering education in several noteworthy ways. First, we identified and reported a list of several competencies that holistically describe engineering student thriving. This model provides a platform for various stakeholders in the engineering education system to communicate expertise, share ideas, and develop a shared language related to engineering thriving.

Second, the model of engineering thriving established a shared language regarding (1) the most important internal competencies relevant to engineering student thriving, (2) the most important external outcomes of engineering student thriving, and (3) the overarching relationships between internal competencies and external outcomes. This shared language can facilitate applications of this model by addressing the types of competencies, external outcomes, and cultural/structural factors that need to be cultivated, developed, and evaluated to support engineering students to thrive.

Third, the model of engineering thriving, as with all models, simplifies a broad and complex phenomenon such that it can now be better understood and supported. While each component of the model of engineering thriving has unique properties, students are constantly affected by all components of the model. For example, our preliminary findings show that teaching engineering students to improve their internal thriving competencies also helped them improve their grades and social interactions [47]. In other words, components of engineering thriving work together in complex and intricate ways, and the model captures some of these relationships.

In the following sections, we present various applications of the model of engineering for engineering programs, institutions, and students. Since this model was determined to be complete, accurate, concise, clear, and useful, this model can be applied to inform targeted interventions, new partnerships, and future research to support engineering student thriving.

6.1 Applications for Engineering Programs and Institutions

On the broader engineering program or institution level, the model can be used to systemically discuss, generate, and study thriving-related processes in engineering. Since the relationships between competencies and outcomes were identified by literature and refined by experts in the field, this model can also serve as a starting point to guide the design of engineering thriving training, intervention, and certification programs. One example applying the model of engineering thriving could result in certification programs, such as the analogous effort in the process used to develop human resource development (HRD) certification programs from McLagan and Sudadolnik's model of HRD [53]. As shown in Appendix C, engineering programs and institutions have the most control over the university resources they provide to students. The list of university resources provides a guideline for universities to focus on opportunities considered high priorities for engineering student thriving.

Overall, cultivating a culture and system conducive to thriving in engineering programs and institutions requires the collective investment from all members of the system. Engineering professors, staff, advisers, and others with experience teaching, supporting, advising, mentoring, or working directly with undergraduate engineering students are individually and collectively responsible for shaping the cultural and systemic factors of the engineering program and institution. These members shape the long-term culture of engineering programs.

Understanding that changing institutional cultures and systems takes time, intervention researchers will be wise to adapt their interventions to prevailing norms in engineering. For instance, experts in engineering mentioned competencies related to psychological wellbeing, including the following: Positivity, Gratitude, Mental Health, Mindfulness, Supportive Networks, Emotional Intelligence, Interest, and Kindness. Research-based positive psychology interventions to promote these competencies include, gratitude journaling, sharing positive events with others, actively-constructively responding to the positive events of others, practicing creative kindness, and seeing the novelty and purpose in each learning opportunity [8, 54]. Some engineering professors and students may need additional training on the science behind these positive practices before they are ready to embrace sharing their positive experiences with others instead of only sharing their struggles. Similarly, engineering's culture of "suffering and shared hardship" may require an adjustment period for more engineers to experience flow [1]. According to Csikszentmihalyi, flow is defined as "a state in which people are so involved in an activity that nothing else seems to matter; the experience is so enjoyable that people will continue to do it even at great cost, for the sheer sake of doing it" [55, p. 4]. Flow is accompanied by peak performance, high levels of intrinsic motivation, high levels of enjoyment, and getting more done in less time [56], all of which can contribute to engineering student thriving. The student or engineering professor who experiences flow might make engineering work seem "easy." The characteristics of flow directly contrast with engineering's culture of hardship and chilly climate for women and minoritized groups [1, 22, 57]. It is important to celebrate and encourage engineering students who are productive and joyful due to flow, to mitigate cultural expectations that they should be enduring more pain. This perspective is especially important for minoritized students, who may have exacerbated difficulties in experiencing flow due to raced, classed, and gendered elements of the current engineering culture. By understanding the key components of thriving in engineering, engineering departments and institutions can support the holistic development of engineering students.

6.2 Applications for Engineering Students

Since internal thriving competencies ultimately reside within individual students, supporting these internal competencies requires an element of active instruction with engineering students. Since external thriving outcomes are not directly malleable and do not account for the students' context and situation, we recommend against evaluating engineering students, programs, or institutions based solely on external thriving outcomes for engineering students. One way to identify if an engineering student is thriving could be through a self-assessment (such as a checklist or scorecard). Engineering programs can use the results of students' self-assessments to provide targeted resources to support personal differences in student thriving.

Interventions from positive psychology offer insights for teaching how to cultivate internal thriving competencies to general college student populations. Prior research suggests that interventions delivered as courses have been effective in teaching thriving competencies to college students [8, 58]. In fact, a positive psychology intervention that taught students how to practice gratitude, mindfulness, autonomy and relatedness, supportive communication, sharing positive events, and creative kindness led to strong effects on lifetime gratitude and positive emotions toward learning [8]. This intervention worked especially well for minoritized students and those with high levels of attendance [8].

For engineering students, preliminary results for the first engineering thriving course suggested that engineering students started reporting more positive external thriving outcomes in response to formal instruction in various internal thriving competencies [47]. Furthermore, in the first engineering workshop on thriving at the American Society for Engineering Education, faculty and graduate students responded with a great deal of excitement about learning interventions that promote mindfulness, autonomy supportive communication with students, gratitude, and other interventions to promote thriving that are not typically part of engineering programs [59].

7. Conclusions and Future Work

This Delphi process investigates the cognitive, interpersonal, intrapersonal, academic, environmental, and socio-cultural dimensions related to thriving for undergraduate engineering students. By capturing these multiple dimensions of engineering thriving in a simplified model, members of the engineering education community (e.g., researchers, instructors, staff, administration) can better understand the concept and process of engineering thriving. However, changing the current culture and norms in the education of engineers will not occur without the collective investment from all members of our community. Investing in engineering thriving yields the same desired external outcomes as those associated with addressing barriers, which include strong academic and professional skills, close relationships and community, positive health and well-being, and upstanding character and persistence. Overall, engineering thriving might offer the critical, yet underexplored, perspectives to support more undergraduate engineering students to reach their highest potential in engineering school and beyond.

In the next steps of improving the model of engineering thriving, we plan to test the model with data from undergraduate engineering students, recognizing that students may hold different perspectives of engineering thriving than those expressed by the experts in this study. Specifically, we plan to use structural equation modeling to explore the extent to which various engineering cultural and systemic factors mediate the relationship between internal thriving competencies and external thriving outcomes. Furthermore, to address experts' question of evaluating the model's usefulness, future work includes evaluating the utility of the model within the context of many engineering classrooms. Understanding the applications of Vygotsky's and Macmurray's models will be helpful in applying our model in engineering classrooms. With these steps, we can contribute a clearly defined, well tested, and readily applicable model of engineering thriving to attract, retain, support, and graduate more thriving engineers to help even more people thrive in society.

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References

1. E. Godfrey and L. Parker, Mapping the cultural landscape in engineering education, *Journal of Engineering Education*, **99**(1), pp. 5–22, 2010.
2. R. Stevens, D. Amos, A Jocuns and L. Garrison, Engineering as Lifestyle and a Meritocracy of Difficulty: Two Pervasive Beliefs Among Engineering Students and Their Possible Effects, 2007.
3. L. K. Morris and L. G. Daniel, Perceptions of a chilly climate: Differences in traditional and non-traditional majors for women, *Research in Higher Education*, **49**(3), pp. 256–273, May 2008.
4. E. Seymour and A.-B. Hunter, *Talking about leaving revisited*, Springer, 2019.
5. L. A. Schreiner, The 'Thriving Quotient': A new vision for student success, *About Campus*, **15**(2), pp. 2–10, 2010.
6. M. E. P. Seligman, R. M. Ernst, J. Gillham, K. Reivich and M. Linkins, Positive education: Positive psychology and classroom interventions, *Oxford Review of Education*, **35**(3), pp. 293–311, Jun. 2009.
7. J. Norrish, P. Williams, M. O'Connor and J. Robinson, An applied framework for positive education, *International Journal of Wellbeing*, **3**(2), pp. 147–161, 2013.
8. J. M. Froiland, Promoting gratitude and positive feelings about learning among young adults, *Journal of Adult Development*, **25**(4), pp. 251–258, 2018.
9. F. A. Huppert and T. T. C. So, Flourishing Across Europe: Application of a New Conceptual Framework for Defining Well-Being, *Social Indicators Research*, **110**(3), pp. 837–861, 2013.
10. V. Huta and A. S. Waterman, Eudaimonia and its distinction from hedonia: Developing a classification and terminology for understanding conceptual and operational definitions, *Journal of Happiness Studies*, **15**(6), pp. 1425–1456, 2014.
11. R. M. Ryan, V. Huta and E. L. Deci, Living well: A self-determination theory perspective on eudaimonia, *Journal of Happiness Studies*, **9**(1), pp. 139–170, 2008.
12. H. J. Passow and C. H. Passow, What Competencies Should Undergraduate Engineering Programs Emphasize? A Systematic Review, *Journal of Engineering Education*, **106**(3), pp. 475–526, Jul. 2017.
13. National Academies of Sciences Engineering and Medicine, *Supporting students' college success: the role of assessment of intrapersonal and interpersonal competencies*, DC: The National Academies Press, 2017.
14. E. H. Schein, *Organizational culture and leadership*, 4th ed., vol. 2. John Wiley & Sons, 2010.
15. J. T. Pedrotti, Taking culture into account with positive psychological interventions, in *The Wiley Blackwell Handbook of Positive Psychological Interventions*, A. C. Parks and S. M. Schueller, Eds. Hoboken, NJ, pp. 403–415, 2014.
16. A. Godwin, The Development of a Measure of Engineering Identity, in *American Society for Engineering Education Annual Conference & Exposition*, p. 16, 2016.
17. A. Prybutok, A. Patrick, M. Borrego, C. Seepersad and M. Kirisits, Cross-sectional survey study of undergraduate engineering identity, in *American Society for Engineering Education Annual Conference*, 2016.
18. J. Gesun, J. Major, E. J. Berger, A. Godwin, K. Jensen, J. Chen and J. M. Froiland. A Scoping Literature Review of Engineering Thriving to Redefine Student Success. *Studies in Engineering Education*, **2**(2), pp. 19–41, 2021.
19. C. P. Veenstra, E. L. Dey and G. D. Herrin, Is Modeling of Freshman Engineering Success Different from Modeling of Non-Engineering Success?, *Journal of Engineering Education*, **97**(4), pp. 467–479, 2008.
20. K. L. Tonso, The Impact of Cultural Norms on Women, *Journal of Engineering Education*, **85**(3), pp. 217–225, Jul. 1996.
21. V. O'Leary and J. Ickovics, Resilience and thriving in response to challenge: an opportunity for a paradigm shift in women's health., *Womens Health*, **1**(2), pp. 121–142, 1995.

22. E. A. Cech and T. J. Waidzunas, Navigating the heteronormativity of engineering: The experiences of lesbian, gay, and bisexual students, *Engineering Studies*, **3**(1), pp. 1–24, 2011.
23. R. Hughes, Gender conception and the chilly road to female undergraduates' persistence in science and engineering fields, *Journal of Women and Minorities in Science and Engineering*, 18(3), pp. 215–234, 2012.
24. M. W. Ohland, S. D. Sheppard, G. Lichtenstein, O. Eris, D. Chachra and R. A. Layton, Persistence, Engagement, and Migration in Engineering Programs, *Journal of Engineering Education*, **97**(3), pp. 259–278, Jul. 2008.
25. E. Seymour and N. M. Hewitt, *Talking about leaving: why undergraduates leave the sciences*, Westview Press, 1997.
26. G. M. Anderson, J. C. Sun and M. Alfonso, Effectiveness of Statewide Articulation Agreements on the Probability of Transfer: A Preliminary Policy Analysis, *The Review of Higher Education*, **29**(3), pp. 261–291, 2006.
27. National Research Council, *Expanding Underrepresented Minority Participation: America's Science and Technology Talent at the Crossroads*, Washington, DC: National Academies Press, 2011.
28. J. A. Durlak, R. P. Weissberg, A. B. Dymnicki, R. D. Taylor and K. B. Schellinger, The impact of enhancing students' social and emotional learning: A meta-analysis of school-based universal interventions, *Child Development*, **82**(1), pp. 405–432, 2011.
29. L. G. Oades, P. Robinson and S. Green, Positive education: Creating flourishing students, staff and schools, *InPsych | Australian Psychological Society*, **33**(2), pp. 16–17, 2011.
30. J. M. Froiland and M. L. Davison, The longitudinal influences of peers, parents, motivation, and mathematics course-taking on high school math achievement, *Learning and Individual Differences*, **50**, pp. 252–259, Aug. 2016.
31. S. Suldo, A. Thalji and J. Ferron, Longitudinal academic outcomes predicted by early adolescents' subjective well-being, psychopathology, and mental health status yielded from a dual factor model, *Journal of Positive Psychology*, **6**(1), pp. 17–30, 2011.
32. A. J. Howell, Flourishing: Achievement-related correlates of students' well-being, *Journal of Positive Psychology*, **4**(1), pp. 1–13, 2009.
33. B. L. Fredrickson, The role of positive emotions in positive psychology. The broaden-and-build theory of positive emotions, *American Psychology*, **56**(3), Mar. 2001.
34. B. L. Fredrickson and C. Branigan, Positive emotions broaden the scope of attention and thought-action repertoires, *Cognition and Emotion*, **19**(3), pp. 313–332, Mar. 2005.
35. Gallup-Purdue Index Report, Washington D.C., 2016.
36. A. H. Van De Ven and A. L. Delbecq, The effectiveness of nominal, Delphi, and interacting group decision making processes, *Academy of Management Journal*, **17**(4), pp. 605–621, 1974.
37. M. J. Clayton, Delphi: a technique to harness expert opinion for critical decision-making tasks in education, *Educ. Psychol.*, **17**(4), pp. 373–386, 1997.
38. H. A. Linstone and M. Turoff, *The delphi method*, Addison-Wesley Reading, MA, 1975.
39. J. D. Geier, The Delphi survey methodology: An approach to determine training needs, in *Conference on Software Engineering Education*, pp. 387–402, 1995.
40. D. J. Hardy, A. P. O'Brien, C. J. Gaskin, A. J. O'Brien, E. Morrison-Ngatai, G. Skews, T. Ryan and N. McNulty, Practical application of the Delphi technique in a bicultural mental health nursing study in New Zealand, *Journal of Advance Nursing*, **46**(1), pp. 95–109, 2004.
41. O. Lindqvist, G. Lundquist, A. Dickman, J. Bukki, U. Lunder, C. L. Hagelin, B. H. Rasmussen, S. Sauter, C. Tishelman and C. J. Fürst, Four essential drugs needed for quality care of the dying: a Delphi-study based international expert consensus opinion, *Journal of Palliative Medicine*, **16**(1), pp. 38–43, 2013.
42. J. Fawcett, Criteria for evaluation of theory, *Nursing Science Quarterly*, **18**(2), pp. 131–135, 2005.
43. S. B. Bacharach, Organizational theories: Some criteria for evaluation, *Academy of Management Review*, **14**(4), pp. 496–515, 1989.
44. F. N. Kerlinger, Foundations of Behavioral Research (Holt, Rinehart Winston, New York, NY), 1986.
45. V. Braun and V. Clarke, Using thematic analysis in psychology, *Qualitative Research in Psychology*, **3**(2), pp. 77–101, 2006.
46. Y. S. Lincoln and E. G. Guba, But is it rigorous? Trustworthiness and authenticity in naturalistic evaluation, *New Directions for Program Evaluation*, **1986**(30), pp. 73–84, 1986.
47. J. S. Ge, E. J. Berger, J. Major and J. M. Froiland, Teaching undergraduate engineering students gratitude, meaning, and Mindfulness, in *American Society for Engineering Education Annual Conference & Exposition*, 2019.
48. M. W. Ohland, Guili Zhang, B. Thorndyke and T. J. Anderson, Grade-point average, changes of major, and majors selected by students leaving engineering, pp. 114–119, 2004.
49. J. Duff, C. Rubenstein and I. Prilleltensky, Wellness and fairness: Two core values for humanistic psychology, *Humanistic Psychology*, **44**(2), p. 127, 2016.
50. A. Cheville, Transformative experiences: Scaffolding design learning through the Vygotsky cycle, *International Journal of Engineering Education*, **26**(4), pp. 760–770, 2010.
51. A. Cheville, A Philosophical Perspective on ABET's Proposed Changes to Criterion 3, in *2016 ASEE Annual Conference & Exposition*, 2016.
52. K. Goldman, P. Gross, C. Heeren, G. L. Herman, L. Kaczmarczyk, M. C. Loui and C. Zilles, Setting the scope of concept inventories for introductory computing subjects, *ACM Transactions on Computing Education*, **10**(2), pp. 1–29, 2010.
53. P. McLagen and D. Suhadolnik, Models for HRD practice: The research report, Alexandria, VA, 1989.
54. S. L. Gable, H. T. Reis, E. A. Impett and E. R. Asher, What do you do when things go right? The intrapersonal and interpersonal benefits of sharing positive events, *Journal of Personality and Social Psychology*, **87**(2), p. 228, 2004.
55. M. Czikszentmihalyi, *Flow: The psychology of optimal experience*. New York, NY: Harper & Row, 1990.
56. M. E. P. Seligman and M. Csikszentmihalyi, Positive psychology: An introduction, in *Flow and the foundations of positive psychology*, Springer, pp. 279–298, 2014.
57. D. Malicky, A literature review on the under-representation of women in undergraduate engineering: Ability, self-efficacy, and the 'chilly climate,' pp. 10647–10669, 2003.
58. K. K. Maybury, The Influence of a Positive Psychology Course on Student Well-Being, *Teach. Psychol.*, **40**(1), pp. 62–65, Jan. 2013.
59. J. Gesun, K. Jensen, J. M. Froiland, M. Huerta and K. Neeley, Thriving in Engineering: Strength-Based Approaches to Promote Positive Well-being. Workshop presented at the ASEE Annual Conference and Exposition, Tampa, FL, 2019.

Appendix A. Table of Internal Thriving Competencies

Category & Definition	Competencies Reported by Experts
Behavioral competencies: Specific actions and habits in response to situations and stimuli.	• Time management • Study skills • Help-seeking/Resourcefulness • Help giving/Caring/Serving others • Self-care/Stress management • Goal Setting/Orientation • Achieving goals/Taking action • Strong work ethic • Responsibility • Self-regulation/Discipline • Navigating a rich array of educational opportunities
Cognitive competencies: Thinking, reasoning, knowledge transfer, and related mental processes.	• Metacognition • Reflection • Problem solving/Abstraction • Analytical And critical thinking • Knowledge- technical and non-technical • Information literacy • Tinkering • Process oriented • Design thinking • Visualization • Understanding global/environmental/system context/systems thinking • Synthesis • Learning/self-learning/lifelong learning • Integrative learning
Intrapersonal competencies: One's relationship with oneself and how one interprets external situations and stimuli.	• Positivity/Gratitude • Creativity • Meaning/Purpose/Holistic intelligence • Curiosity • Growth Mindset • Mindfulness/Presence • Self-Awareness/Sense of self • Sense of Empowerment • Emotional competence and control • Perspective taking • Comfort with uncertainty/Complexity/Ambiguity • Confidence • Self-respect • Interest • Motivation • Open mindedness • Integrity • Adaptable • Resilience
Social competencies: Expressing information to others, social skills, as well as interpreting others' messages and responding appropriately.	• Social Skills • Teamwork • Emotional intelligence • Conflict resolution • Professional skills • Inclusivity • Personable/Approachable • Respect for people from different backgrounds • Communication/Listening skills • Networking skills • Empathy

Appendix B. Table of External Thriving Outcomes

External Outcome & Definition	External Outcomes Reported by Experts
Community & Relationships: Creating and maintaining positive connections and belonging to a supportive network of individuals within the engineering education system.	• Strong and stable supportive networks • People that undergraduates are in contact with: faculty, staff, instructors, teachers, admin, advisers, campus resources (health and mental health) • Family • Non-competitive community • Academic support • Social support/Recognition • Friendship/personal relationships • Interact positively with peers and faculty • Supporting/Helping/Serving others • Give back or apply that knowledge to community • Cultural and religious groups
Health & Well-Being: Building and maintaining a state of multidimensional well-being that supports undergraduate engineering students to balance and function successfully in their responsibilities within their engineering program and personal life.	• School/Life balance • Mental health • Environmental health • Physical health • Financial health • Intellectual health • Having hobbies/leisure interests • Extracurricular activities
Character & Persistence: The positive character traits, capacities, and virtues that result from continuously developing, strengthening, and applying internal thriving competencies.	• Creative engineering solutions/designs • Persistence/Grit/Tenacity • Calm Under Pressure • Wisdom • Authenticity • Emotional maturity • Spirituality • Ethical judgment/Morality • Leadership • Kindness • Service • Courage
Academic & Professional: Achieving educational goals towards an undergraduate engineering degree and professional career.	• Ability to satisfy academic requirements. Students must be able to succeed in their classes including the classes in their major and core curriculum classes • Course grade/cumulative grade point average • Retention in engineering program • Graduation from engineering program • Professional conduct • Job/viable career plan • Vocational fit

Appendix C. Table of Engineering Culture, Systemic Factors, Resources, Context & Situation

Factor & Definition	Factors Reported by Experts
Personal Context & Situation: Significant life circumstances that can influence students' interpretations and responses during their undergraduate engineering experience.	• Significant life events/changes • Family responsibilities, situations, and requirements • Work/Job commitments, paid or unpaid • Societal influences • Financial influences • Familiarity with engineering culture • Personal implicit biases • Student financial situation (e.g., loans) • Private tutoring

Engineering Student Entry Characteristics: The student's input profile and prior experiences when they enter an undergraduate engineering program that are not expected to change during their time in an undergraduate engineering program and may influence their experiences during their undergraduate engineering experience.	• Having a solid high school background • Influential people (such as family and friends) to enroll in undergraduate engineering program • Entry knowledge • Entry competencies • Gender • Race/ethnicity • Disability-health status • Socioeconomic background • Country of origin • Transfer status • High school performance • Visa status • Cultural capital
Cultural and Systemic Factors: Deeper ingrained "root causes" that influence students' opportunities and abilities to thrive while part of the undergraduate engineering system.	• Systemic conditions of justice: procedural (equitable processes) and distributive (fair allocations of burdens, privilege, rights, and responsibilities) • Diversity in knowledge-constitutive interests (different forms of knowledge and knowing) • Inclusive and diverse environment • Engineering culture/Climate • Perception of non-students in the system (e.g., engineering faculty, staff, administration caring) • Grade Point Average Requirements/Prerequisites • Privilege • Power • Implicit biases inherent in the engineering system/Stereotypes • Any systemic or structural influences that differentially affect students • Campus/Administrative policies and rules
University Resources: The capital, assets, affordances, and environmental factors within the university or program that affect the engineering student's access to support and enrichment opportunities.	• Professional opportunities • Academic opportunities • Academic advising • Appropriate campus resources (office hours, tutoring, counseling, etc.) to answer questions students have • Informal learning opportunities • Course load • Availability of extracurricular opportunities • Instructor competence • Internship • Research • Career services • Scholarships • Financial aid • Mental health resources • Learning communities (cohort, classmates, etc.) • Service opportunities • Resources for student organizations • Recreation • Physical accessibility to spaces

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