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LITERATURE REVIEW

A Scoping Literature Review of Engineering Thriving to Rede ne Student Success

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Background: The importance of thriving is well-established, but little is known about thriving for undergraduate engineering students. We introduce *engineering thriving* as the process by which engineering students develop optimal functioning in undergraduate engineering programs. Since thriving is currently underexplored in the engineering education literature, we investigated the larger body of literature on engineering student success.

Purpose: We introduce the concept of *engineering thriving* to synthesize the largely discrete existing bodies of literature on engineering student success to bring together many different perspectives, methodological approaches, and findings that shape our understanding of engineering thriving. Our work on thriving unites disparate lines of research on engineering student success, challenges the assumption that addressing barriers automatically leads to success, and strives to change the way engineering education views student success.

Scope/Method: We used the scoping literature review method to investigate papers on undergraduate engineering student success. Four databases were searched, yielding 726 initial papers that studied separate dimensions of engineering student success, such as academic, personal, cognitive, and behavioral. We integrated the relationships among these dimensions to develop an understanding of engineering thriving. Our final analysis included 68 papers after removing duplicates and applying selection criteria.

Conclusions: Our findings indicate that an engineering student thriving includes multiple dimensions of success, involves cyclical processes of growth and adaptation, and consists of synergistic competencies that should ideally be studied together with as many other competencies as possible. These findings support the conclusion that engineering thriving can be understood as helping students manage constantly changing internal and external factors within the broader engineering education system.

Keywords: thriving; student success; engineering and computing undergraduates; scoping literature review; non-cognitive and affective factors

Introduction

The importance of supporting engineering students beyond the academic outcomes that often define success and dominate current research is well-documented; however, more work is needed to understand what exactly constitutes a successful engineering student beyond academic outcomes. For nearly a decade, various agencies have advocated to attract, educate, retain, and graduate more holistically successful undergraduate engineering students (National Academies of Sciences, Engineering, & Medicine, 2016, 2017; President's Council of Advisors on Science and Technology, 2012). More specifically, The President's Council of Advisors on Science and Technology expressed the need for "transformative and sustainable change in [science, technology, engineering, and mathematics] STEM undergraduate education" by uniting the diverse expertise from academics, professionals, businesses, and foundations to address the predicted shortfall of STEM professionals in the United States (2012, p. 36). Furthermore, the Engineer of 2020 Report by the National Academy of Engineering echoes the need for an engineering curriculum that is both "responsive to the disparate learning styles of different student populations and attractive for all those seeking a full and well-rounded education that prepares a person for a creative and productive life and positions of leadership" (2005, p. 52). In addition, the National Academies of Sciences, Engineering, and Medicine recommended a greater focus on interpersonal and intrapersonal competencies to increase national college completion in STEM disciplines (2017). These reports offer consensus that educating successful engineering students beyond the traditional focus on academic outcomes is of high priority, yet each report presents drastically different visions for what exactly constitutes successful engineering students beyond solely academic outcomes.

To address this need for a more holistic and integrated perspective of engineering student success, we introduce *engineering thriving* as the process by which engineering students develop optimal functioning in undergraduate engineering programs. The disciplines of positive psychology and higher education provide several insights on thriving that guide our conceptualization of engineering thriving. One such insight is the concept of *optimal functioning*, which is defined in positive psychology as "a multi-dimensional and holistic concept [which] includes both hedonic and eudemonic components" (Norrish et al. 2013, p. 149) or, more simply put, includes both "feeling good" and "functioning well" (Huppert & So, 2013, p. 838). In alignment with prior research on general human thriving (Schreiner, 2010; Seligman & Csikszentmihalyi, 2014), we conceptualize engineering thriving as a process of development rather than a binary state (a student is either thriving or not), especially as engineering students grow and change over time. This scoping literature review of engineering thriving integrates studies across disciplinary boundaries to understand the *process* of engineering student thriving.

Another important aspect of engineering thriving is inspired by modern reconceptualizations of Tinto's model in engineering education and higher education, which investigates multiple dimensions of student's institutional integration—such as academic, social, professional, and university (Lee et al. 2018), and multiple dimensions of positive student outcomes—such as academic achievement, self-efficacy, and identity (Reid, 2013). Thus, we expect engineering thriving to include multiple dimensions of students' undergraduate engineering experience and multiple dimensions of desired outcomes for thriving engineering students. Overall, existing research from multiple disciplines guide our conceptualization of engineering thriving as a developmental process toward optimal functioning in multiple dimensions of students' undergraduate engineering experience.

Engineering thriving broadens our understanding of engineering student success beyond the academic outcomes that currently dominate research. Traditionally, engineering student success is measured through academic outcomes such as retention or academic performance, and it is achieved by removing or reducing barriers that lead to failure (Boles & Whelan, 2017; Lohmann & Froyd, 2010). Engineering thriving, in contrast, enables us to include both individual competencies that develop over time and relevant external structural factors (Ge & Berger, 2018). A shift to engineering thriving broadens the traditional definitions of success in engineering education by investigating multiple personal, contextual, academic, and external dimensions that simultaneously contribute to engineering students' overall abilities to succeed.

The foundations of this conceptualization can be found in decades of prior work on human thriving. Several researchers from positive psychology and higher education have investigated the "scientific study of what makes life most worth living" (Peterson et al. 2014, p. 2). In higher education, Schreiner (2010) concluded that a focus on thriving could change the ways higher education views student success:

> Rather than defining success solely as grades and graduation, a focus on thriving encourages a more holistic view of student development that expands to include healthy relationships, sense of community, making a contribution, and proactively coping with life's challenges (p. 10).

Fredrickson (2001) and Fredrickson & Branigan (2005) reached similar conclusions. Their research repeatedly showed that positive emotions are associated with better problem solving, focused attention, and creative thinking, while negative emotions hinder attention and focus. Additional findings indicate that improving students' abilities to thrive also improves their academic performance, retention, engagement, and satisfaction (Durlak et al. 2011; Oades et al. 2011).

The "Engineering" in Engineering Thriving
Some might wonder how engineering thriving, as we present it, differs from similar non-discipline specific thriving. While insights from other disciplines offer important foundational knowledge to support students in engineering, we argue that a conceptualization of thriving developed specifically for undergraduate engineering students will be more applicable and responsive to engineering's unique population, culture, and research. We assume fundamental disciplinary differences derived from the epistemological foundations that form each discipline's identity (Becher, 1994; Donald, 1995). Members of each discipline, including researchers, subscribe to fundamental disciplinary norms and underlying philosophies that shape inquiry and provide boundaries for the discipline's identity. Like any construct studied broadly, disciplinary variance can be lost to generalizations when the focus is no longer on a specific discipline. Thus, we highlight three major differences that differentiate engineering thriving from that of other disciplines—engineering's domain-specific population, culture, and research.

Distinct Population: Undergraduate Engineering Students

Each understanding of thriving is specific to the population from which it was created and may not be reflective of other populations. For example, Norrish and colleagues' framework of flourishing from the discipline of positive education was based on K–12 students from a school in Australia (2013). They acknowledged that more research is needed to explore how positive education translates to other settings (2013, p. 156). In another example, Seligman (2011) introduced a model of human well-being from the discipline of positive psychology that claimed to be universally applicable. Seligman's model has been criticized by Christopher and Hickinbottom (2008), Wright (2013), and Warren and Donaldson (2017), who argued that different cultures and populations have significantly different understandings of well-being and that these contextual differences are integral to any conceptualization of well-being. In these examples, Norrish's (2013) framework of thriving was developed from K–12 students, which drastically differed from Seligman's (2011) model developed from his knowledge of positive psychology research. Similarly, both models likely differ from an understanding of thriving developed from undergraduate engineering students. Crivello et al. (2009) stated, "well-being is a socially contingent, culturally-anchored construct that changes over time, both in terms of individual life course changes as well as changes in socio-cultural context" (p. 53). Researchers have created several understandings of thriving based on studies with 'WEIRD' populations (Western and/or White, Educated, Industrialized, Rich, and Democratic; Schulz et al. 2018), resulting in critiques of their generalizability to other populations (Utseyet al. 2008, p. 207). Some of these theories show promise for extending (e.g., Self-Determination Theory and Positive Time Perspective) to multiple ethnicities and socio-economic status levels in the United States (Froiland et al. 2019; Froiland et al. 2020). However, these models of human thriving from other disciplines, which were not developed specifically for undergraduate engineering students, may not fully apply to this population. Overall, different populations tend to have domain-specific understandings and experiences of thriving, and these understandings of thriving must be re-examined before applying to populations for which they were not specifically developed.

Distinct Culture: Engineering Programs & Institutions

Based on decades of research, engineering culture is also crucial to the discussion of engineering student thriving because culture shapes the assumptions, values, expectations, and behaviors of social units (Geertz, 1973; Rousseau, 1990; Smircich, 1983). Pedrotti noted that culture influences how constructs are defined, manifested, and understood (2014, p. 403). As culture determines which aspects of thriving are valued, it is important to ground our understanding of engineering thriving in the culture of engineering. For example, Perna and Thomas (2008) created their framework of student success based on their review of literature from economics, sociology, psychology, and education. They concluded that "disciplinary perspectives were central to any understanding of student success" (p.10). They reported that different disciplines focus on different aspects of student success with different approaches and theoretical underpinnings, thus resulting in vastly different understandings of the same construct. Similarly, we argue that various disciplinary differences justify a framing of thriving that is more applicable and responsive to the distinct population of undergraduate engineering students.

Although general theories of human thriving have been developed in disciplines such as psychology (Butler & Kern, 2016; Su et al. 2014), some measures developed in psychology do not appear to measure the same theoretical constructs in undergraduate engineering students (Scheidt et al. 2018) and may not directly transfer to this population. Within the discipline of engineering education, engineering education researchers study *engineering* identity uniquely in the engineering culture even though identity research spans several disciplines (Godwin, 2016; Prybutok et al. 2016). Just as engineering education researchers recognize engineering identity as distinct from general research on identity, engineering thriving will likely be distinct from general human thriving. The domain-specificity of engineering thriving is necessary for two reasons: 1) to align with prior research specific to engineering students and 2) to address widespread criticisms of cultural biases in prior research on thriving (see Ho et al. 2014; Pedrotti, 2014). This section situates engineering student thriving in the engineering culture as described in the literature, describes various outcomes of this culture on engineering students, and advocates for the importance of understanding thriving specific to the culture of undergraduate engineering education.

The culture of engineering differs from that of other disciplines. In the context of this paper, engineering culture is defined as "the explicit and implicit customs and behaviors, norms, and values that are normative" in engineering education programs (National Academies of Sciences, Engineering, 2016, p. 60). Veenstra and colleagues pointed out four key differences in the expectations, values, norms, and behaviors of undergraduate engineering education compared with those of literature, science, and arts (LSA) education, and other pre-professional or professional programs (2008). These four main differences include engineering education's:

1. Expectation that engineering graduates are "analytical thinker[s] who can lead people in technology innovation, design and systems thinking" (Veenstra et al. 2009, p. 5). In contrast to engineering, LSA education and other programs differ as they provide students with a broader college education that tends to be less focused on a specific career path, especially during the students' first year.

2. Valuation of courses related to analytical thinking and problem-solving using technology that is higher than those from other disciplines. The engineering curriculum is most demanding for mathematics and science courses during the first year.
3. Expectations for admission into engineering programs tend to include a greater focus on students' success in mathematics and science courses compared to that of other programs.
4. Inclusion of a weeding-out system (Gray et al. 2017; Meyer & Marx, 2014) and the expectation of a future career that is competitive. First-year engineering curricula tend to be very competitive, and the culture of competition contributes to patterns in which engineering students earn lower college GPAs than students in other programs (Veenstra et al. 2009, p. 5–6).

Overall, undergraduate engineering has been described as a culture of "suffering and shared hardship" with a "meritocracy of difficulty" where engineering students are often expected to be (and celebrated for) struggling with their prescribed heavy workloads and generally stressful situation (Godfrey & Parker, 2010, p. 12; Stevens et al. 2007, p. 1). While there is consensus within the literature regarding the hardships and struggles associated with engineering culture, the documented outcomes of this culture are varied.

Outcomes of Engineering Culture on Students

Given the important work on the larger structural and systemic factors shaped by the engineering culture, we also focus on the outcomes of this culture on engineering students as individuals. A series of studies started by O'Leary and Ickovics (1995) found that individuals' response to high-stress situations (or adverse events) typically results in a distribution amongst four types of outcomes: thriving, recovery, survival, or succumbing. As shown in **Figure 1**, many people recover and return to their previous level of functioning after experiencing adverse events. At one tail of the distribution, a small percentage of people experience thriving and function better than before they experienced the adverse event. Similarly, a small percentage of people at the other end of the distribution regress to a state of succumbing and are unable to function properly without intervention. However, most people end up near the middle of the distribution (surviving or recovering), with about the same functioning or worse as before they encountered the adverse event.

Because adverse events refer to both one-time and long-term stressors, **Figure 1** inspired us to explore the idea that perhaps it is also possible for engineering students to thrive after experiencing adverse events related to the current engineering culture. In the context of undergraduate engineering education, an adverse event could be a short-term stressor such as a high-stakes exam. Adverse events could also include repeated long-term stressors such as a weeding-out system that imposes environments of high competition among peers (Veenstra et al. 2009) and hostility toward minoritized groups (Bothwell & McGuire, 2007). Compared to the average U.S. college student, engineering students suffer from lower retention rates (Roy, 2019) and more mental health issues (Lipson et al. 2016; Danowitz & Beddoes, 2018; Jensen & Cross, 2019).

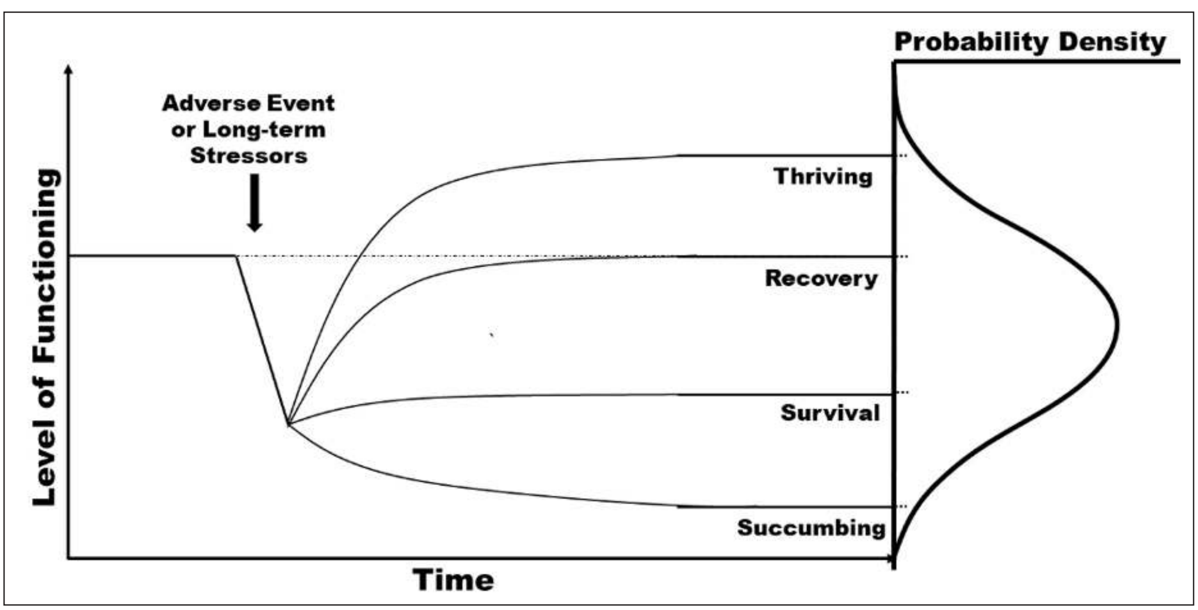

Figure 1: Model of outcomes to adverse events or long-term stressors and distribution of these outcomes, adapted from O'Leary and Ickovics (1995).

While understanding these adverse events is important, prior research has shown that it is an individual's interpretation and response to an adverse event, and not necessarily the adverse event itself, that ultimately determines their outcome (Nelson & Simmons, 2003, 2011). For example, the absence of academic struggles (in the form of failing grades) in engineering classes does not imply the student will be retained in engineering (Ohland et al. 2004). Conversely, the presence of adverse events can provide opportunities to experience a deeper awareness of personal strengths, new ways to relate to others, and a greater appreciation for life (Park, 2010; Tedeschi & Calhoun, 2004). Since experiencing adverse events seems inevitable in engineering's culture of "suffering and shared hardship" (Godfrey & Parker, 2010, p. 12), we investigate the key components of thriving for engineering students that are both individual to students' agency while identifying aspects of the distinct context and situation of the engineering educational system.

Consistent with O'Leary's and Ickovics' (1995) model of outcomes in **Figure 1**, we present two documented cases of engineering students who thrived (in the sense of improved functioning) after experiencing similar adverse events (those associated with engineering culture) that stifled many peers. For example, Foor and colleagues (2007) document Inez's journey as an engineering student who also faced challenges with the engineering culture and had weak high school preparation. Inez felt like an outsider in engineering in multiple aspects—including her socioeconomically disadvantaged background, gender, and multi-minority racial identity (Foor et al. 2007, p. 1). During her time as an undergraduate engineering student, Inez experienced repeated marginalization, active discouragement, and rejection from her peers and professors. As Inez shared her experiences of adverse events in undergraduate engineering, "her voice and manner were cheerful, upbeat, and positive" (p. 113). Rather than surviving her undergraduate engineering experience, Inez spoke of her enjoyment in "doing" engineering and her pride in being able to improve people's lives with engineering (p. 106–107). Similarly, Holly Jr. (2018) documented James' journey as an engineering student who experienced repeated racial hostility, academic struggles, and a lack of belonging. Despite facing many adverse events while pursuing his engineering degrees, James not only graduated but went on to teach inner-city African American boys and encourage them to pursue engineering. For James, the lack of belonging he experienced as an engineering student motivated him to find his own village of people (with many outside engineering) and create the community he did not find in engineering (Holly Jr., 2018). Rather than succumb after developing his heightened awareness of the injustices of institutionalized racism, James discovered his purpose and passion for teaching "by implementing a pedagogy that promotes equity for Black Americans amid inequitable conditions" (Holly, 2018, p. *x*). For James and Inez, the adverse events they experienced as part of the current engineering culture were indisputably challenging and unjust. Yet, they grew from these difficult experiences and used them to strengthen their desire to improve their own lives and those of others. Thus, we advocate for the importance of supporting students' agency development within current systems and structures while also working for cultural and systemic change within the distinct context and situation of the engineering educational system.

Distinct Research: Engineering Education Research

Over the past two decades, domain-specific research around engineering student experiences has increased. Where the previous sections briefly reviewed prior work on domain-specific aspects of engineering students and culture, the review of domain-specific research is the focus of the remainder of this paper. Current research on engineering student success is widespread but often disconnected. This review aggregates perspectives emerging from many disparate studies to bring previously disconnected findings into dialogue with one another. The community of engineering education includes researchers from diverse disciplinary backgrounds, with varied skillsets and levels of expertise that, when united, can elucidate our understanding of a broad array of complexities.

Our outline for the remainder of this paper is as follows. First, we present our research design for the scoping literature review based on Arksey and O'Malley's five-stage framework (2005). As part of our review, we synthesize insights from individual papers on engineering student success to reveal the broader complexities and new properties regarding engineering student thriving. Next, we examine how these dimensions may be connected from theoretical and empirical literature to support engineering student thriving. We synthesize the relationships between these individual perspectives of engineering student success. This literature review provides a broader understanding of the complexities of engineering student success, unites disparate lines of research on engineering student success, reveals new properties by examining the synthesis of all papers, and provides novel insights on supporting holistic engineering student success. Finally, we conclude with a discussion of the broader meaning of our results and their potential implications for future research, practice, and policy.

Methods

Research Design and Purpose

We conducted a scoping literature review to identify the multiple ways engineering student success is operationalized in the literature and to identify gaps in our knowledge of engineering student success. We followed Arksey and O'Malley's (2005) five-stage framework for conducting scoping literature reviews and utilized Levac and colleagues' (2010) recommendations to clarify and enhance each stage. According to Arksey and O'Malley, scoping literature reviews are particularly useful to "examine the extent, range, and nature of research activity… identify research gaps in the existing literature… summarize and disseminate research findings… [and] determine the value of undertaking a full systematic review" (2005, p. 21).

Scoping literature reviews serve a different purpose from systematic literature reviews and, according to Peterson and colleagues, "should not be considered a less rigorous version of systematic reviews" (Peterson et al. 2017, p. 14). While a systematic review can follow the scoping literature review, researchers might also determine that systematic reviews are not needed or feasible after conducting the scoping literature review. Additionally, unlike systematic literature reviews, scoping literature reviews are particularly useful to understand the landscape of topics "where it is difficult to visualize the range of material that might be available" (p. 21). Since engineering student thriving is underexplored in the existing research, it is difficult to visualize the range of material that is available. By its nature, scoping literature reviews conducted on under-explored topics generally yield small numbers of papers and, thus, assessing paper quality is not part of the methodology (Arksey & O'Malley, 2005). However, we selected only peer-reviewed papers as our baseline for quality. Since thriving is not well-defined in engineering education, our review of papers in this study is based on both journal papers and conference proceedings on undergraduate engineering student success.

Stage 1: Identifying the research question

The purpose of this scoping literature review is to unite many disparate perspectives captured in prior research on undergraduate engineering student success so that we can synthesize these perspectives to develop an understanding of engineering thriving. An understanding of engineering thriving can inform strategies to encourage more student thriving and, consequently, challenge elements of the discipline's culture that create barriers for students. Thus, this study was guided by the research question: "What is currently known regarding the competencies that contribute to undergraduate engineering student success?"

While we developed this research question to generate a breadth of literature found in our search, we also created clear scopes of inquiry to inform future stages of our research, such as selection criteria and study relevance (Levac et al. 2010). Following Levac and colleagues' (2010) recommendations, we created a set of search terms relating to undergraduate engineering students' competencies relevant to their success. Consistent with prior work in engineering education and related disciplines, we define *competencies* as combinations of knowledge (understanding concepts and information), skills (proficiencies or expertise, usually developed through training), attitudes (one's thoughts or feelings), abilities (potential for performance, often innate), and other characteristics that reside within individual engineering students and assist them in navigating their undergraduate engineering experience (Cole et al. 2020; Dale & Iles, 1998; National Academies of Sciences, 2012, 2017; Passow & Passow, 2017; van der Klink & Boon, 2002). The National Academies of Sciences, Engineering, and Medicine (2017) created three broader categories of competencies—intrapersonal, interpersonal, and cognitive—to organize the breadth of individual competencies that are documented in research (p. 1). Since competencies are malleable and "ultimately reside within the individual student" (National Academies of Science et al. 2017, p. 34), evidence suggests that they can also be taught, learned, and trained (Borghans, Duckworth et al. 2008; Peterson & Seligman, 2004). In addition to consolidating a list of competencies, we also tracked the relationships among individual competencies to further develop our understanding of engineering thriving. In alignment with our research question, we searched for papers that clearly defined *success*. As we discussed earlier, thriving is relevant only for a given population in a specific context. To situate our review within engineering education, we identified undergraduate engineering students as our target population. Thus, we focus our scoping literature review on studies involving undergraduate engineering student success in the United States (see **Table 1** for justifications).

Stage 2: Identifying relevant studies

Identifying relevant literature is the next step in our scoping literature review process. Arksey and O'Malley stated that "[the] point of scoping the discipline is to be as comprehensive as possible in identifying primary studies (published and unpublished) and reviews suitable for answering the central research question" (2005, p. 23). As such, our goal was to identify a broad range of studies that could help answer our research question. To achieve this goal, we searched a variety of sources, such as databases and reference lists. In consultation with three librarians at our institution, we included four databases: Education Resources Information Center (ERIC) [EBSCO], Scopus, Ei Compendex [Engineering Village], and Professional Development Collection [EBSCO]. Appendix A details the specific search strings, number of papers found in each database, and notes for each database search.

Stage 3: Study selection

To identify relevant documents to address our research question, two of the authors (Ge and Jensen) developed, agreed upon, and revised the list of relevance criteria using the post hoc approach common to scoping reviews (Arksey & O'Malley, 2005). Since there is not a standard definition of engineering student success, we manually filtered the papers that described

Table 1: Selection criteria for determining relevant papers for the final review, with justification for each step.

Selection Criteria	**Justification**
Success is explicitly defined and operationalized in the paper.	This criterion is directly relevant to the research question. The paper must define what success means or looks like for undergraduate engineering students.
The study participants include undergraduate engineering students, which includes computer science students.	This criterion is directly relevant to the research question. Engineering in the context of our study includes all engineering majors and computer science, a major that is included in several Colleges of Engineering (such as Arizona State University and the University of Illinois Urbana-Champaign). However, our definition of engineering excludes engineering technology (ET). ET departments are often not in the College of Engineering, and ET culture differs significantly from engineering, with most ET graduates not considered engineers (Lucietto, 2016). This criterion excludes youth clinics, family enrichment programs, religious services, or 4-H programs. This criterion also excludes studies that do not have results specific to engineering students, such as generalized findings from samples that include non-engineering students.
The paper is published in English.	Due to limited resources for translation, we included only documents published in English.
The location of the study is in the United States.	We restrict study location to the United States to align our study with the visions set forth by U.S. national reports, such as the National Academy of Engineering and the ABET report.
The study is a research study (quantitative, qualitative, or mixed methods) or intervention study.	Since the desired outcome for this scoping study is to develop an understanding of engineering thriving, this criterion excludes descriptions of courses, programs, or activities. This criterion also excludes papers on instrument development, personal opinions (e.g., book reviews), program evaluations, incomplete studies, and literature reviews.
The paper explicitly mentions enabling, positive, or asset-based competencies (including knowledge, skills, abilities, attitudes, and other characteristics that enable a person to perform skillfully, make sound decisions, and take effective action).	This criterion is directly relevant to the research question. This criterion excludes approaches that solely focus on addressing disabling conditions, such as using race/ethnicity or genders as causal variables.
The paper explicitly discusses relationships (both theoretical and empirical) between competencies or between competencies and student success.	This criterion is directly relevant to the research question. Since the purpose of this study is to develop an understanding of engineering thriving, it is crucial to investigate the relationships between competencies (especially those with empirical support).

engineering student success or other positive outcomes. As three of the authors (Ge, Jensen, and Major) independently reviewed the titles and abstracts using our initially agreed upon relevance criteria, we marked some papers for inclusion immediately and others for further review. If the relevance of a paper was unclear from the title and abstract, then the reviewer examined the full text. Then, we revised our criteria by discussing the papers that are still marked for further review, sometimes with input from a fourth reviewer (Berger). Through this iterative process of refining the relevance criteria, we developed the final selection criteria shown in **Table 1**.

A total of 726 papers were initially retrieved from the databases. After removing duplicates, we found 656 unique papers. Using the selection criteria shown in **Table 1**, three reviewers (Ge, Jensen, and Major) conducted the relevance screening process, according to these selection criteria. **Figure 2** depicts this process using a PRISMA flow chart (Moher et al. 2009). To ensure consistency in applying the selection criteria, these reviewers independently applied the selection criteria to the same 100 papers, resulting in an initial 90% agreement on the papers. After a discussion, these reviewers agreed on screening another 5% of the papers. A fourth reviewer (Berger) was brought on to help determine a decision on the final 5% of papers and clarify the selection criteria to its final version in **Table 1**. Then, the main reviewer (Ge) applied the final selection criteria, refined by discussions with the other three reviewers (Jensen, Major, and Berger), to the remaining 556 papers resulting in the 68 papers included in this article for final analysis.

While the majority of the papers in our review are from engineering education publishing venues, we also included papers published in related disciplines that may have compared students from multiple disciplines as long as they presented results specific to undergraduate engineering students. These publication venues include: *The International Journal of*

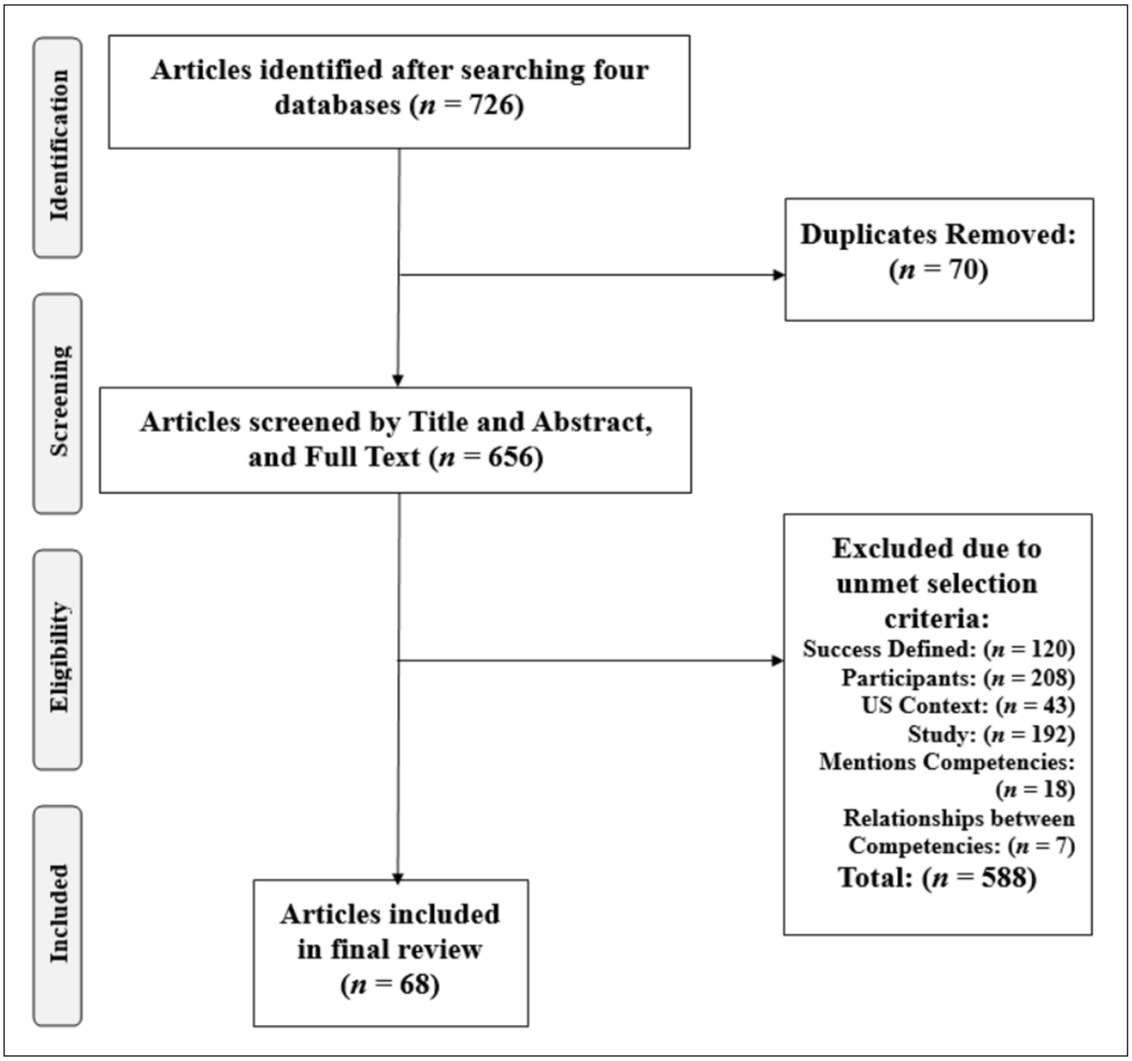

Figure 2: A PRISMA flow chart illustrating the screening process used in this review, as well as the inclusion or exclusion of papers at each step of the screening process.

Science Education (Balgopal et al. 2017; Sorby, 2009), *Journal of Engineering Design Graphics* (Study, 2011), *SIGCSE Bulletin* (Biggers et al. 2009), *Economics of Education Review* (Kokkelenberg & Sinha, 2010), *Interdisciplinary Journal of Problem-Based Learning* (Jones et al. 2013), and *Assessing Writing* (Ostheimer & White, 2005).

Stage 4: Charting the data

We collectively developed the chart of information to extract from the final 68 papers in order to answer the research question. This data charting form was created in a spreadsheet and pre-tested independently by two reviewers (Ge and Jensen) on a small subset of papers. After pretesting, the reviewers (Ge and Jensen) charted a list of information extracted from each paper according to the criteria shown in Appendix B, so long as the information was provided. The main reviewers (Ge and Jensen) met weekly to discuss the charted papers and resolved any conflicts or questions that arose.

Stage 5: Collating, summarizing, and reporting the results

Descriptive Numerical Summary of Findings

A total of 32,595 undergraduate engineering students were studied across the final 68 papers. Across studies, the number of students, demographic characteristics, major, years in school, transfer status, and geographic location varied. Most of studies were quantitative (*n* = 47), followed by mixed methods (*n* = 12), and qualitative (*n* = 9). Several studies used multiple data collection and data analysis methods in the same paper, including: survey studies, which were the most prevalent (*n* = 31) [especially pre-post (*n* = 12)], followed by intervention studies (*n* = 23), institutional or academic record analyses

(n = 10), correlational studies (n = 10), interviews (n = 10), regression or linear modelling (n = 9), observation (n = 5), evaluations (n = 3), case studies (n = 2), audio and or video recording (n = 2), ANOVA (n = 1), think aloud (n = 1), focus groups (n = 1), and journaling (n = 1). Since several studies employed multiple methods of data collection and analysis, the final numbers sum to greater than the total number of papers.

Summarizing Findings from Papers in this Review

Once all the competencies and external factors important to undergraduate engineering student success were charted in our organizational spreadsheet, the researchers created broader categories to understand the hundreds of competencies and external factors that emerged. The researchers mapped all the existing relationships (categorized as inputs, outputs, moderators, mediators, controls, and correlations) into a concept map diagram using the program Cmap Tools©. Once all entries were mapped, the researchers used the Cmap auto-layout function to sort the competencies according to which appeared more often as inputs, outputs, or middle factors (such as moderators, mediators, and controls). This process of auto-sorting revealed general patterns among competencies that helped us group them into broader categories. The detailed version of our concept map diagram included hundreds of competencies and external factors interwoven together in complex relationships. The concept map diagram resembled a complex web that was difficult to understand and interpret without manually creating broader categories.

To understand the hundreds of competencies and external factors that emerged, we created broader categories, informed by the auto-layout function of Cmap, that ultimately helped us synthesize an understanding of the information. Since there was no established understanding of the overall broader picture of engineering student thriving, we adapted the three core categories (intrapersonal, interpersonal, and cognitive) used by the National Academies of Sciences, Engineering, and Medicine to group our competencies (2017, p. 1). To capture all the competencies that emerged from our review, we modified the definition of intrapersonal competencies and created a new category called *behavioral competencies.* Each grouped category of competencies and their definitions is shown in **Table 2**. In addition to the competencies, external factors and outcomes that contribute to undergraduate engineering student success frequently appeared in the literature and were reported to associate strongly with competencies. We define and chart these external factors and outcomes important to engineering student success in **Tables 3** and **4**, respectively.

While each paper in this review provided one or more definitions and measurements of success, several of these definitions and measurements are inconsistent across studies. **Figure 3** compares the percentage of papers that defined success in each category with the percentage of papers that measured them. In **Figure 3**, the *measured* category only includes the outputs measured in the papers, to better align with the definitions of success as outputs, while the *defined* category includes how papers defined success. Most papers provided more than one definition of success, resulting in the total percentage of papers being greater than 100%. Details of each category are established in **Tables 2–4**.

Nearly a quarter of the papers in our review used assessment measures of success that were not congruent with the paper's definitions of success, which is problematic when making comparisons of the findings across studies and drawing generalizable conclusions from the disparate research. We discuss these findings in the next section.

Discussion

This study was guided by the research question: "What is currently known regarding the competencies that contribute to undergraduate engineering student success?" Each of the 68 papers examining undergraduate engineering student success presented one or more definitions and measurements of success that we synthesized to develop our understanding of engineering thriving, which includes new properties that were not captured in any individual study on engineering student success. Engineering thriving is grounded in research on undergraduate engineering students and, thus, is likely more applicable and responsive to this population than understandings of thriving developed from other disciplines. In the following three key findings, we summarize the major properties and differences between engineering student success (as described by individual papers) and engineering student thriving (as revealed by a broader synthesis of all papers in this review).

(1) **Single-axis versus Multidimensional Foci**: Individual papers focused on single-axis findings that result from the specific bounded contexts and populations in each study. Engineering thriving focuses on a synthesis of these single-axis findings to discover multidimensional interactions among engineering students' competencies, context, situation, and academic factors in the broader educational system.

(2) **Sequential versus Cyclical Processes**: Individual papers presented sequential processes consisting of specific inputs that lead to success outcomes for undergraduate engineering students. Engineering thriving focuses on the synthesis of these sequential relationships to discover a cyclical developmental process without apparent inputs that precede outcomes.

Table 2: Competencies that contribute to engineering student success.

Competency and Definition	Competencies Reported by Papers in Our Review
Intrapersonal competencies involve one's relationship with oneself and how one interprets external situations and stimuli.	· Engineering identity · Interpretation of experience and tasks · Engineering motivation/drive · Growth mindset · Subjective task value (interest, attainment value, cost) · Positive future self · Self-efficacy (academic, career, self, work)/confidence (general and academic) · Meaningful learning · Teamwork/collaboration (attitudes) · Impulse control · Concentration · Satisfaction/happiness · Achievement orientation · Goals/self-schema · Empathy · Expectancy of success · Sense of control and decision-making · Creativity · Engagement · Passion/interest · Empowerment (includes sense of control and decision-making in learning) · Societal/global awareness · Multicultural/ethnic awareness · Emotional intelligence (includes self-regard, emotional self-awareness, self-actualization, and interpersonal relationships) · Prosocial goals/values
Interpersonal competencies involve expressing information to others, social skills, as well as interpreting others' messages and responding appropriately.	· Community · Communication · Cultural intelligence · Interpersonal relationships · Mentorship · Relationships (with peers, instructors, advisors) · Care · Support system/network · Leadership skills · Teamwork skills · Belongingness · Professionalism (includes entrepreneurship, ethics, and project management)
Cognitive competencies involve thinking, reasoning, knowledge transfer, and related mental processes.	· Solving engineering problems · Problem solving ability and approach · Critical thinking skills · Metacognitive abilities · Mastery focused learning/deep learning · Scientific writing · Applying knowledge from major · Computing ability · Cognitive ability · Spatial skills and ability
Behavioral competencies involve specific actions and habits in response to situations and stimuli.	· Working ahead of deadlines · Completing assignments · Study habits (alone/groups) · Classroom listening · Organization · Using supplemental instruction (in college) · Attending office hours · Seeking help · Time management · Note taking

Table 3: External factors important to engineering student success.

External Factors Important to Success	Factors Reported by Reviewed Studies
Entry Characteristics involve student characteristics that we do not expect to change within the bounded undergraduate engineering academic experience.	· High school performance (SAT, GPA, ACT) · Country of origin · Citizenship (domestic/international) · Use of supplemental instruction (in high school) · Transfer status · Parents' level of education · Mathematics preparation · Race/ethnicity · Gender · Personality (conscientiousness, introversion, neuroticism) · Residency (in-state/out) · Influence to choose engineering (from teachers, parents, family)
University Resources involve opportunities and assets that the university or program provide to help engineering students succeed.	· First-year engineering courses · Scholarship · Financial aid · Study/living abroad opportunities · Classroom instruction (flipped, traditional, peer led) · Skill development workshops · Project based/service learning opportunities · Internship and co-op opportunities · Living-learning communities · Diversity and inclusion resources/efforts
Context and Situation involve life circumstances and contexts that may trigger students' experiences and responses during the undergraduate engineering experience.	· Course load/credits taken · Study/living abroad experiences · Living in learning community/dorm · Instructor competence · Financial status · Marital status · Age · Year in major · Experience with extracurricular involvements · Interactions with faculty and peers · Employment with matched skillset · Learning style[1]

Table 4: Outcomes important to engineering student success.

Outcome and Definition	Outcomes Reported by Papers in Our Review
Course Grades refer to students' final grade in a technical or required course.	· Mathematics (especially Calculus) · Physics · Computer programming · Science · General chemistry
GPA refers to students' grade point average.	· Measured semesterly · Measured cumulatively from the time students entered the program
Retention refers to whether students persisted either in their specific engineering degree program, the college of engineering, or the university.	· Typically measured annually
Graduation refers to students successfully completion their undergraduate engineering degree.	· Typically binary: Yes/No

(3) **Discrete versus Synergistic Competencies**: Individual papers presented discrete competencies that were uniquely defined in each study, even when multiple papers studied the same competency. Engineering thriving focuses on a synthesis of the multiple definitions for each competency to discover that they function synergistically and ideally should be studied together with as many other competencies as possible.

[1] We included learning styles in our table to accurately represent the papers in our review. However, we acknowledge more recent research findings that indicate students can learn from any style of instruction (Kirschner, 2017; Rohrer & Pashler, 2012).

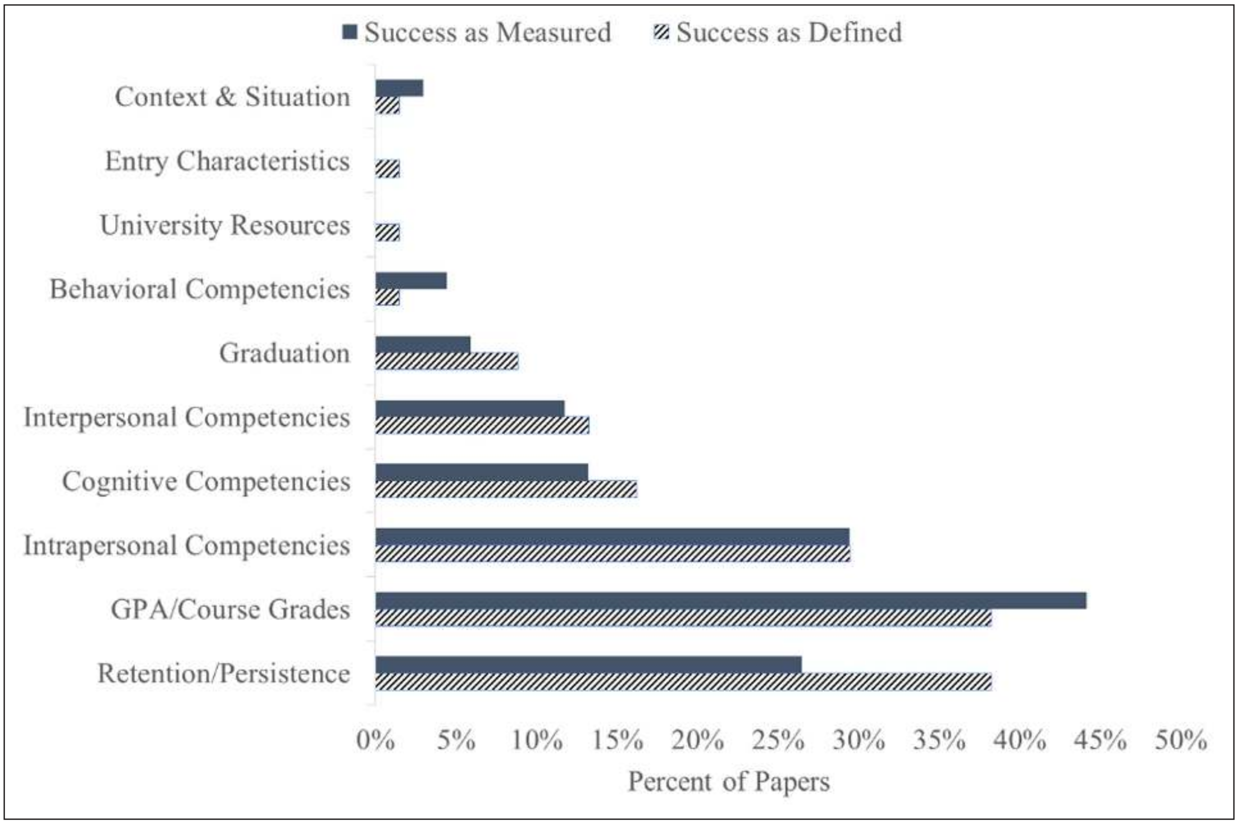

Figure 3: A comparison of the distributions of the measured and defined success factors for the papers in this review, grouped into categories explained in Tables 2 and 3. Indicated by the unequal percentage bars within each category, 24.5% of papers in our review defined and measured success differently.

Success has Single-Axis Foci; Thriving has Multidimensional Foci

In our review, individual papers studied engineering student success with specific competencies in a specific context, and thus, capture only single-axis perspectives of engineering student success. These single-axis findings provide valuable insights in describing the domain-specific experiences of a specific engineering student population within a specific context. A natural consequence of single-axis foci is that the results and impact are bounded by the parameters of individual studies. For example, many papers in our review studied self-efficacy from different contexts. These contexts included cooperative education and internships (Hutchison et al. 2005; Reisberg et al. 2012), successfully completing engineering classwork (Micari & Pazos, 2016), knowledge to solve engineering problems (Wickliff et al. 2017), motivation (Hutchison et al. 2005), teaming (Hutchison et al. 2005), enjoyment (Hutchison et al. 2005), and coping (Concannon & Barrow, 2009). Similarly, Balgopal and colleagues (2017) studied communication in the context of concept negotiation discourse, while Ing and colleagues (2013) studied communication in the context of presenting research findings. In these examples, we illustrate seven different contexts of studying self-efficacy and two different contexts of studying communication. In addition to context-specificity, individual papers in our review solely focused on the experiences of a specific population of undergraduate students. Examples include only Black or African American students (Hughes et al. 2011; Martin et al. 2016), first-year students (Doolen & Biddlecombe, 2014; French et al. 2005; Liu et al. 2015; Mazumder, 2010; Reid & Ferguson, 2011; Wickliff et al. 2017), students from a single engineering discipline (Allen & Peirce-Cottler, 2008; Bledsoe & Flick, 2012; Hotle & Garrow, 2016; Welch et al. 2015), or engineering students taking non-engineering courses, such as general chemistry (Cole et al. 2018; Coletti et al. 2013; Kaeli et al. 2017; Shapiro et al. 2016). Focusing on the distinct experiences of certain demographic groups is tremendously valuable in understanding engineering student success for these groups, and these individual papers in our review provided the foundation for us to synthesize multiple single-axis perspectives on engineering student success.

However, by examining these single-axis perspectives together, we discovered multidimensional perspectives of engineering student thriving that were not captured in any individual paper in our review. **Tables 2–4** summarize these multidimensional perspectives, which result from integrating all the context-specific and population-specific findings into the following broader categories: competencies (interpersonal, intrapersonal, cognitive, and behavioral), academic outcomes (course grades, GPA, retention, and graduation), and external factors (entry characteristics, university resources, context and situation). With these broader categories, we could then investigate new interactions that emerged among engineering students' internal competencies that transcended the boundaries of any specific engineering context or population. Overall, a multidimensional focus of engineering student thriving recognizes that an engineering student's experience of thriving is shaped by interactions among multiple dimensions—such as the students' competencies, context, situation, and academic outcomes—within the broader educational system.

Success Involves Sequential Processes; Thriving Involves Cyclical Processes

In our review, individual papers provided sequential processes with specific inputs that influence how engineering students achieve specific success outcomes that are biased toward academic outcomes. Studying sequential processes is valuable in understanding the predictors of engineering student success, especially given the ten distinct categories of success outcomes that were defined by individual papers in our study (see **Figure 3**). However, as depicted in **Figure 3**, GPA and course grades were by far the most commonly *measured* success outcomes even though they were not the most commonly *defined* success outcomes. These incongruencies result in inconsistent success outcomes that are biased toward academic outcomes. To illustrate, Gu first stated that "improving spatial visualization skills are critical for our engineering students to be successful" (2017, p. 3). However, the author inferred whether students improved in spatial visualization skills by measuring their grades in an engineering graphics course. In this case, Gu (2017) defined engineering student success in terms of spatial visualization skills, but such definition appears incongruent with the measurement of success using course grades. In another example, Dahm et al. (2009) advocated for "the value of instilling metacognition in students" (p. 2). However, rather than measuring students' actual metacognition, they measured students' performance on learning objectives such as "meaningful error analysis [and] formulating appropriate conclusions" as well as attitudes toward teaming (p. 9). Similarly, Allen and Peirce-Cottler (2008) defined success as developing engineering students' professional skills but measured students' end-of-semester evaluations of the course which, by their own acknowledgment, "student evaluations are not necessarily indicative of their learning of professional skills" (p. 8). These examples are among the 24.5% of papers in our review that measured success differently than was originally defined in the same paper (see **Figure 3**). We addressed these incongruencies by mapping only the success outcomes that were measured in each paper, to align better with the actual analysis and findings presented in each paper. However, this decision likely further biased our findings toward academic outcomes.

By synthesizing these sequential processes together, we discovered cyclical processes of engineering thriving with no apparent inputs that precede outcomes. As detailed in the methods section, our initial diagram of aggregated findings from individual papers resulted in a web with hundreds of internal competencies and external factors all interwoven together in cyclical processes that evolve over time. One example of this cyclical process in our review is the relationship between engineering students' persistence/retention (outcome variables) and mathematics/science abilities (internal competencies). Burtner (2005) found that engineering students who persisted in engineering had the highest confidence in their mathematics and science abilities. The reverse relationship has also been documented by Ngambeki, Dalrymple, and Evangelou (2008), who found that greater interest in mathematics and physics predicted Aerospace Engineering students' persistence in the field. These examples illustrate that supporting engineering students to thrive means supporting them to both manage internal competencies (such as mathematics and science ability) and achieve external outcomes (such as retention and persistence). From the perspective of engineering thriving, there is no obvious sequence of whether developing stronger internal competencies results in students achieving more external outcomes, or whether achieving more external outcomes results in students developing more internal competencies. These findings may be due to the dialectic nature of internal and external competencies or the reality that most engineering-related studies were cross-sectional, and thus, unable to determine causality. Which aspect comes first is still unknown, but also unimportant, when we consider engineering thriving as cyclical processes of managing internal competencies and external outcomes that students experience (again and again over time) as they develop to function more optimally in undergraduate engineering. In contrast to the sequential processes described in individual papers on engineering student success, presenting engineering thriving using cyclical processes highlights the importance of not only achieving success outcomes but also the process of engineering student development.

Success Studies Competencies Discretely; Thriving Studies Competencies Together

Within our review, individual papers attributed different definitions for competencies, thus studying individual competencies as discrete from other competencies. Clearly defining competencies is valuable in helping readers understand discrete competencies as presented in each individual paper, especially when other papers study the same competency. A natural consequence of studying discrete competencies distinct to each paper is that several competencies share the same (or similar) name but different meanings across papers. Consider teamwork, for example. Several papers in our review presented six discrete definitions related to teamwork (such as *teamwork, team,* or *teaming*), which we can categorize into broader interpersonal, intrapersonal, or behavioral categories:

- Interpersonal: "support group that raised confidence through interactions" (Hutchison et al. 2005, p. 7); "study group" (McCord & Matusovich, 2017, p. 6).
- Intrapersonal: "attitudes toward teaming skills" (Dahm et al. 2009, p. 1); a component of work-self efficacy involving the "non-technical and social skills necessary to achieve success in the workplace" (Reisberg et al. 2012, p. 7).
- Behavioral: "work well in a team" (Hutchison et al. 2005, p. 7); "team performance" (Leicht et al. 2009, p. 1361).

These six different definitions related to teamwork illustrate the fundamentally different meanings that individual papers attributed to competencies which share the same (or similar) name. As such, the different definitions individual papers provided are essential to help readers understand the meaning of each competency named in that study. To avoid the confusion and superficial redundancy of having each competency listed in multiple broader categories, **Table 2** only depicts each competency in one broader category that most definitions indicated, or we determined to be the best fit.

By aggregating multiple discrete definitions of competencies that share the same name, we discovered that all individual competencies are connected to four overlapping broader categories and should ideally be studied together within an individual student. As seen in the teamwork example above, aggregated definitions of competencies span multiple broader categories. By examining all discrete definitions of competencies together, we found that individual competencies are studied across four overlapping broader categories—interpersonal, intrapersonal, cognitive, and behavioral (see **Table 2**). When we examined broader categories of competencies together at the level of engineering thriving, we discovered that competencies were highly connected and functioned as pieces of the same broader system. These findings are consistent with prior research on engineering thriving interventions, which suggest that internal competencies work together to influence a student's experience of undergraduate engineering and, thus, should be studied together with as many other competencies as possible (Ge et al. 2019). Just as all components of a system must work synergistically for optimal functioning, the broader perspective of engineering thriving suggests that students' competencies should ideally be studied together.

While we acknowledge the resource constraints of studying all competencies together in a single study, a few papers in our review presented valuable steps toward this ideal. For example, one paper we reviewed consisted of a cluster analysis that examined the combined outcomes of several competencies grouped together (Young & Knight, 2015). Other papers in our study examined overarching competencies comprised of multiple other competencies. For example, Leicht and colleagues (2009) defined emotional intelligence to include self-regard, emotional self-awareness, and self-actualization (intrapersonal competencies) in addition to interpersonal relationships (interpersonal competency). Finally, Mazzurco et al. (2012) measured cultural intelligence to include metacognitive, cognitive, motivational, and behavioral subscales. By studying competencies together (with as many other competencies as possible) in these papers, the researchers made valuable steps toward understanding the ways in which this web of competencies interact within individual engineering students to support their thriving.

Implications and Broader Impact

View Engineering Thriving as a Continuous Process of Development

We caution against the misconception that thriving is binary, especially when one wonders whether a student is thriving. While individual papers in our review presented engineering student success as a set of discrete outcomes, these individual perspectives (on its own) do not capture the nature of engineering thriving. While success outcomes usually include clear thresholds to determine whether a student is successful, engineering thriving advocates for the perspective of engineering students engaging in a continuous process of development. Thus, rather than wondering whether a student is thriving, we suggest wondering how to support the student's continuous development.

With the perspective of continuous development, we find positive competencies need to be deliberately cultivated and applied in multiple dimensions of the undergraduate engineering system for students to thrive. The more students practice positive competencies, the more they will be reinforced. However, we also recognize that this cycle also works in reverse. In this case, as opportunities to develop positive competencies are ignored, the harder it becomes for students to utilize said competencies to thrive, especially in adverse events. Since students' abilities to thrive in college strongly relate to their abilities to thrive after college (Gallup Consulting, 2016), more thriving engineering students are likely to result in more thriving engineers whose work contributes to the well-being of society.

Multiple Approaches to Intervene on Any Single Competency

As a result of our review, we found that competencies span multiple categories even though individual papers study them discretely, suggesting that there are also multiple approaches to intervene on any single competency. Recall that the papers in our review examined teamwork from the perspective of an interpersonal, intrapersonal, or behavioral competency. Given these three contexts for understanding teamwork, interventions on teamwork can take on any of the three approaches. For example, an interpersonal approach toward improving engineering student teamwork could focus on improving the group relationships of existing teams by providing role models. Alternatively, an intrapersonal approach could focus on reframing engineering students' attitudes, thoughts, and beliefs around teamwork. Finally, a behavioral approach could focus on identifying and teaching behavior patterns to improve engineering students' team performance. Just as we found in our review that competencies often span multiple categories, we recommend integrating multiple approaches to improve the effectiveness of interventions.

Increase Partnerships to Support Thriving Programs and Interventions

The multidimensional nature of engineering thriving highlights the importance of increasing partnerships between professionals who teach, support, advise, mentor, or work with engineering students to create a culture in engineering that promotes thriving. These partnerships could result in new programs or interventions that support academic, personal, behavioral, and cognitive dimensions of student thriving. Based on our review, some discrete examples of these partnerships include:

- Collaborating with a community or client for engineering students to apply their skills in a project-based service-learning course. Examples include Engineering Projects in Community Service (Purdue University) or Service-Learning Integrated throughout the College of Engineering (University of Massachusetts Lowell; Cooper & Kotys-Schwartz, 2013).
- Uniting with the National Science Foundation's Scholarships in Science, Technology, Engineering, and Math (S-STEM) program to provide financial support for incoming engineering students to participate in a first- to second-year bridge program. The bridge program also collaborated with engineering upper-level and graduate students to mentor undergraduate engineering students in mathematics courses, strengthen relationships with other students, and model study skills (Ricks et al. 2014).
- Joining forces with diverse student organizations for engineering students to develop professional and leadership skills, access engineering role models, and create a family-like support system. Examples of these organizations include the National Society of Black Engineers and the Society of Hispanic Professional Engineers (Martin et al. 2016).
- Teaming up with other academic organizations. An example of such is the partnership between the University of Virginia and Technische Universität Dortmund to create "a transnational engineering course" to improve engineering students' global competency (Wold & Moore, 2013, p. 5).

Developing these kinds of support programs and partnerships is necessary to support multiple dimensions of engineering students' thriving, and thus, to increase the number of properly trained professionals. Since engineering thriving is a constant process of development, these partnerships are crucial toward creating a culture in engineering that is conducive to thriving across multiple dimensions.

Limitations and Future Work

First, we caution that the broad view of engineering thriving should be tempered by the understanding that broader dynamics affect the extent to which internal competencies are related to students' ability to thrive. The larger socioeconomic structures, policies, and structures of organizations all influence the culture of an engineering program, yet these broader dynamics are often implicit in individual studies in our review. For example, recent research suggests that generation gaps in understanding the value of technology can affect satisfaction and performance in engineering (Cho & Cho, 2019). Thus, our synthesis is only based on the explicit findings of the papers in our review and does not capture the broader societal influences, such as generational gaps in thinking, that are implicit in the results reported by individual studies. Thus, future work on engineering thriving can benefit from studying and explicitly reporting the impact of these broader societal and structural factors that influence engineering thriving.

Since our findings are limited to the existing peer-reviewed literature on undergraduate engineering students, future work could investigate the different understandings of competencies in engineering and non-engineering disciplines. We argue that the distinct engineering culture, population, and research impacts how student success is studied in engineering and the emphasis on certain competencies as derived from the papers in our review that differ from understandings of thriving in non-engineering disciplines. Several competencies that did not show up in the papers in our review have been well-researched in other disciplines and considered important competencies for human thriving. In positive psychology, for example, happiness is a competency that can be developed through gratitude journaling (Froiland, 2018), reduced materialistic outlook (Kasser et al. 2014), and increased mindfulness (Langer, 2014). Additionally, emotional intelligence has also been described to include the ability to understand the feelings and intents of others (Froiland & Davison, 2020), which differed from the way it was described for engineering students (Leicht et al. 2009). These competencies offer promising directions for future research on engineering student thriving. In addition, studies show that many positive psychology interventions delivered to college students outside of the course format have promoted happiness and other aspects of psychological well-being (Lyubomirsky et al. 2005). These competencies are robust motivational factors that promote strong academic engagement and learning while also promoting psychological well-being (Froiland & Davison, 2016). Overall, many competencies from other disciplines may be worth exploring for engineering students, especially if they improve traditionally desired outcomes in engineering education (such as students' academic success and persistence) as well as a more holistic sense of thriving.

Given the current scarcity and disconnected set of literature findings in our review, we recommend future work on engineering thriving to involve collaborating with staff members, instructors, advisors, and others with experience teaching, supporting, advising, mentoring, or working directly with undergraduate engineering students. While a systematic literature review can follow the scoping literature review, we determined that a Delphi study including experts in many of these roles would be more appropriate to refine our understanding of engineering thriving. Our understanding of engineering thriving can be improved by consulting people whose voices might not be captured in the current literature on undergraduate student success, such as instructors, staff, and academic advisors.

Conclusion

Undergraduate engineering students dedicate several years of time, energy, money, and physical and mental resources to participate in engineering programs under the assumption and trust that these programs will prepare them to thrive in an engineering career. This assumption needs to be evaluated when considering the impact of engineering education. Findings from previous research suggest that fostering successful engineering students requires more than just resolving their problems, weaknesses, and struggles related to academic achievement. Thus, in this article, we focused our search of literature regarding engineering student success on including positive competencies that contribute to both academic and personal success to complement the discipline's traditional focus on academic competencies.

In this paper, we utilized a scoping literature review with the goal of broadening our understanding of undergraduate engineering student success beyond the traditional academic factors. This review summarized existing research on engineering success and synthesized these findings into an understanding of engineering thriving that informs future studies. In the pursuit of supporting more thriving engineering students, this synthesis brings together cognitive, interpersonal, intrapersonal, and behavioral competencies that support valued outcomes for engineering students.

Our synthesis of papers does not suggest that solely focusing on positive competencies is the solution towards promoting engineering student success. Just as solely focusing on addressing the barriers that lead to engineering student failures does not automatically lead to success, solely focusing on positive competencies, while ignoring the barriers, will also not automatically lead to optimal performance. Thus, insights from our synthesis are meant to complement, rather than replace, the traditional goals in engineering education to support more thriving engineers whose work contributes to the well-being of society.

Additional Files

The additional files for this article can be found as follows:

- **Appendix A.** Date of Search: August 31, 2018. https://s3-eu-west-1.amazonaws.com/ubiquity-partner-network/vtpubs/journal/see/see-2-2-9-s1.pdf
- **Appendix B.** Information Charted from Each Paper. https://s3-eu-west-1.amazonaws.com/ubiquity-partner-network/vtpubs/journal/see/see-2-2-9-s1.pdf

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Competing Interests

The authors have no competing interests to declare.

Author Contributions

Julianna Ge managed this project by leading the scoping literature review process, data acquisition and analysis, triangulating findings with other authors, drafting the manuscript and revising it based on multiple rounds of feedback from coauthors, reviewers, and editors.

Justin C. Major contributed to data acquisition, reviewed articles included in the study, triangulated findings with Julianna, shaped the interpretation of results, and reviewed multiple drafts of the manuscript.

Ed Berger contributed to the conception of this scoping literature review, reviewed multiple drafts of the manuscript, shaped the interpretation of results, and triangulated findings with Julianna for studies that were interpreted differently between other coauthors who reviewed them.

Allison Godwin contributed to designing this scoping literature review, reviewed multiple drafts of the manuscript, provided references for the manuscript, and shaped the interpretation of results.

Karin Jensen contributed to the data acquisition and interpretation by reviewing articles included in the study, triangulating findings with Julianna, and reviewed multiple drafts of the manuscript.

John Chen contributed intellectually through suggesting alternative models to represent engineering thriving and reviewed multiple drafts of the manuscript.

John Mark Froiland served as the positive psychology expert for the team and contributed to the manuscript draft, provided references for the manuscript, and reviewed multiple drafts of the manuscript.

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