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What Can We Learn from Character Education? A Literature Review of Four Prominent Virtues in Engineering Education

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Abstract

The complexity of problems that engineers address requires knowledge, skills, and abilities that extend beyond technical engineering expertise, including teamwork and collaboration, problem-solving, curiosity and lifelong learning, cultural awareness, and ethical decision-making. How do we prepare engineering students to develop these essential capacities? One promising approach is to integrate character education into the undergraduate curriculum. Using an established and commonly used taxonomy advanced by the Jubilee Centre for Character and Virtues at the University of Birmingham, this paper explores the extent to which virtues are already incorporated into engineering education. Four prominent virtues in undergraduate engineering education are detailed in this paper: (1) critical thinking (an intellectual virtue), (2) empathy (a moral virtue), (3) service (a civic virtue), and (4) teamwork (a performance virtue). By conducting a literature review of these four virtues, we gain insight into how engineering educators already infuse virtues into engineering education and identify the gaps and opportunities that exist to enrich undergraduate engineering education through a virtue framework. Although virtues are part of engineering education, our findings reveal that most engineering educators do not explicitly describe these concepts as “virtues” and tend to treat them instead as “skills.” While virtues and skills are developed in similar ways, we identify four distinctions that reveal the added benefits of recasting and cultivating these capacities as virtues: 1) virtues, unlike skills alone, are necessarily ordered to morally good ends, 2) virtues have a motivational component that skills often lack, 3) virtues involve evaluating and addressing potential conflicts among values, and 4) virtues are interconnected and mutually reinforcing in ways that skills often are not. These conceptual distinctions have practical implications for undergraduate engineering education, enabling educators to draw on the pedagogical literature in character education to help students consider their values and develop the most relevant virtues across a four-year curriculum. This more comprehensive and holistic approach empowers students and future engineers to better navigate the complexity of real-world ethical decision-making and develop the virtues needed to serve the greater good.

Introduction

Virtues of character are stable and enduring dispositions that enable us to think, feel, and act in morally good ways for morally good ends [1]-[4]. Although virtues represent stable and enduring dispositions, virtues, like other personality traits [5], can be intentionally taught and cultivated by well-designed pedagogies that draw on relevant theoretical and empirical research [3], [6]-[10]. While virtues are intrinsically good for their own sake, professional practice can be enhanced by virtuous thoughts, feelings, and actions, as has been shown in professions like medicine, law, education, and business [11]-[15]. Within the medical profession, for example, research shows a direct correlation between virtues and improved quality of technical work as it pertains to decision-making within complex nuanced real-world dilemmas [11]. Might we observe similar findings within the engineering profession?

This paper explores this question by considering the relationship between personal and professional skills and engineering practice through the lens of virtue or character education [16]. The approach is further supported by recent research concluding that engineering professionals feel ill-prepared for engineering practice and the ethical issues they face in the workplace, and that engineering students lack growth in ethical decision-making as it relates to professional practice [17]. Character education helps to address this need while providing a way to bolster the development of key engineering education outcomes such as teamwork and collaboration, problem-solving. curiosity and lifelong learning, and cultural awareness [18]-[20]. We believe character education holds significant promise for helping engineers and engineering educators address these educational and professional gaps.

The purpose of this paper is to conduct an initial literature review to understand the current state of engineering education through the lens of character education and to offer a new perspective on the role that virtue education can play in engineering education. Informed by the framework advanced by The Jubilee Centre for Character and Virtues at the University of Birmingham [21], the ***three guiding research questions*** for this paper are:

(RQ1) Which virtues are currently prominent in undergraduate engineering education?
(RQ2) How are such virtues currently embedded within undergraduate engineering curricula?
(RQ3) What can character education contribute to undergraduate engineering education pedagogy and practice?

In answering research question one (RQ1), our literature review revealed ***four prominent virtues in engineering education***, one from each of the four virtue categories of the Jubilee Centre Framework [21]: (1) ***critical thinking*** (an intellectual virtue), (2) ***empathy*** (a moral virtue), (3) ***service*** (a civic virtue), and (4) ***teamwork*** (a performance virtue). These four virtues were selected during the review process because they are both prevalent in the undergraduate engineering education literature and essential to professional engineering practice. In answering research question two (RQ2), we reviewed engineering education literature to identify curricular and extracurricular examples of how each of the four virtues has been incorporated into undergraduate engineering programs. In answering research question three (RQ3), we reviewed scholarship in character education and virtue ethics to identify how a virtue framework can better inform engineering education.

Virtues and Character Education

Scholars and educators have used several virtue frameworks to shape conversations around virtues and character education, but within professional education, one of the most prominent is the Jubilee Centre Framework [21], which identifies four distinct types of virtues (intellectual, moral, civic, and performance), similar to the fourfold typology proposed by Shields [22]. We use the Jubilee Centre Framework (Table 1) because of its clear delineation of four types of virtues as well as its prior application to educational contexts, including professional education [23].

The Jubilee Centre identifies ***intellectual virtues*** as the "character traits necessary for discernment, right action, and the pursuit of knowledge, truth and understanding." ***Moral virtues*** are “character traits that enable us to act well in situations that require an ethical response.” ***Civic virtues*** are “character traits that are necessary for engaged responsible citizenship, contributing to the common good.” Finally, ***performance virtues*** are “character traits that have an instrumental value in enabling the intellectual, moral and civic virtues.” All four types of virtues are interdependent and necessary for comprehensive character education [21],[24].

Table 1: Overview of Jubilee Centre Framework [21],[24]

Intellectual Virtues	Moral Virtues	Civic Virtues	Performance Virtues
Autonomy Critical Thinking Curiosity Judgment Reasoning Reflection Resourcefulness	Compassion (Empathy) Courage Gratitude Honesty Humility Integrity Respect Justice (Equity, Equality)	Citizenship Civility Neighborliness Service Volunteering Community Awareness	Confidence Determination Motivation Perseverance Resilience Teamwork (Collaboration)

It is important to note that several of the “virtues” in the Jubilee Centre Framework (such as “volunteering” or “service”) may be perceived as “behaviors” rather than “virtues,” and some “virtues” (such as “reflection,” “citizenship,” or “critical thinking”) may be perceived as “skills.” A key difference between virtues and behaviors is that virtues are consistent and reliable *dispositions* that lead to particular behaviors, thoughts, or feelings over time and across situations, whereas behaviors need not be consistent over time or across situations [1]. A key difference between virtues and skills is that virtues must be ordered to morally good ends, whereas skills can be ordered to good, bad, or morally neutral ends [2],[4]. While enacting the right behaviors and skills are important to developing and enacting specific virtues, they are not in and of themselves virtues [25]. These distinctions are important to keep in mind in engineering education when considering how to apply the Jubilee Centre Framework to cultivate virtues rather than mere behaviors or skills.

In addition, the divisions between the four categories of virtues need not be rigid. For example, “justice” might be a civic virtue as well as a moral virtue when it involves issues relevant to the civic community, while “humility” may be an intellectual or performance virtue when it enables learning or improves performance. Moreover, while virtues may be conceptually distinct, the virtues are often, in practice, mutually reinforcing and interdependent—an idea that philosophers typically describe as the “unity,” “reciprocity,” or “interconnection” of the virtues [2, pp. 84-100], [26], [27]. Good engineers, for example, need “judgment” or wisdom (an intellectual virtue) to make good moral decisions about how to exercise “courage” (a moral virtue) in particular situations, and they need “courage” to use their “judgment” in a way that is not distorted by fear. Similarly, engineers need intellectual, moral, and performance virtues to practice good “citizenship,” and they need performance virtues such as “perseverance” or “resilience” to exercise intellectual, moral, and civic virtues in the face of difficulties or delays. The proper exercise of each virtue relies on the proper exercise of others. As will be evident later in this paper, these interconnections are central to the relevance and value of a character framework in engineering education.

Methodology

In examining virtues from the Jubilee Centre Framework in engineering education, this section describes our methods in relation to how we approached RQ1 and RQ2.

RQ1 – Which virtues are currently prominent in engineering undergraduate education?

The methodology for the literature review was intentionally inductive and began with a broad search of each of the 27 virtues from the Jubilee Centre Framework within engineering education literature. Web of Science databases as well as Google Scholar were used in the search. Table 2 summarizes the comprehensive set of search terms, each in conjunction with the terms "undergraduate engineering education" and the number of results from these initial searches. The preliminary results revealed that many of these terms were present in engineering education literature, and virtues from all four categories of the Jubilee Centre Framework were well represented in engineering education. Some of the most frequent results were not chosen for this paper due to the use of the terms. For example, "perspective" was most often used in the context of "industry perspective," "equity" in the context of teaching equitably, and "justice" and "equality" in a civic context, not a moral context as defined by the Jubilee Centre Framework. Additionally, in light of the top skills needed of engineering professionals, including problem-solving, teamwork, and cultural awareness [18], [20], we selected critical-thinking (an intellectual virtue), teamwork/collaboration (a performance virtue), and empathy (a moral virtue) to represent each of these skills, respectively. Due to the extensive research on service in engineering education, service (a civic virtue related to community service and service-learning) was chosen as a fourth focal virtue for this paper.

RQ2 - How are such virtues currently embedded within undergraduate engineering curricula?

Upon answering RQ1 and identifying four virtues prominent in engineering education, we continued to critically review the literature to identify empirical studies from 2010 to the present that described pedagogical interventions that explicitly address these selected virtues within undergraduate engineering programs. Of the articles retained, the search criteria were again narrowed to studies published since 2015 and, when possible, to include only studies that used rigorous or validated assessment processes to determine the efficacy of the intervention in strengthening the selected virtue. Table 3 provides an overview of the data collection process for the empirical studies ultimately presented in this paper. Note that the synonymous terms that were retained from the initial search (e.g. "collaboration" in relation to "teamwork") were included in the search process.

Table 2: Summary of keyword search terms occurring with "undergraduate engineering education" and frequency of results in the preliminary literature search.

Intellectual Virtues		**Moral Virtues**	
Search Terms	Number of Results (Google Scholar; Web of Science)	Search Terms	Number of Results (Google Scholar; Web of Science)
perspective	3,300; 188	integrity	724; 14
creativity	1,890; 64	equity	617; 17
reflection	1,600; 67	justice	549; 8
critical thinking	**1,280; 59**	equality	301; 2
reasoning	1,260; 95	**empathy**	**291; 3**
judgment	853; 21	gratitude	270; 2
autonomy	700; 17	fairness	253; 2
curiosity	538; 5	courage	215; 3
wisdom	431; 1	honesty	202; 1
prudence	39; 0	humor	117; 3
intellectual humility	4; 0	humility	77; 1
		kindness	53; 0
		forgiveness	25; 0
		compassion	8; 0
		bravery	6; 1
Civic Virtues		**Performance Virtues**	
Search Terms	Number of Results (Google Scholar; Web of Science)	Search Terms	Number of Results (Google Scholar; Web of Science)
service	**2,960; 89**	motivation	2,730; 187
community service	**324; 20**	**collaboration**	**2,460; 109**
service-learning	**477; 48**	leadership	2,410; 53
social awareness	84; 13	**teamwork**	**2,150; 80**
community awareness	26; 8	determination	770; 26
social intelligence	11; 2	resilience	212; 5
		self-regulation	207; 6
		perseverance	187; 1

Table 3: Overview of the empirical study selection.

Virtue Keyword Search Term (synonyms)	**First Round of Empirical Study Review**	**Final Articles Selected**
Critical Thinking	12	4
Empathy	12	6
Service (service learning; community service)	39	5
Teamwork (collaboration)	9	3

Since the goal of the process was to generate a few recent examples of each virtue in the engineering classroom, the study selection process was not designed to be comprehensive nor to identify exemplars. However, this review lays the foundation for a more rigorous and systematic review in the future. In the following four sections, we present a summary of our literature review and present the following for each of the four selected virtues: (a) definition of the virtue, (b) role of the virtue in engineering education, (c) teaching the virtue in engineering education, and (d) summary paragraph.

Critical Thinking: An Intellectual Virtue

Defining Critical Thinking as a Virtue

Critical thinking represents "the cognitive skills of analysis, interpretation, inference, explanation, evaluation, and of monitoring and correcting one's own reasoning" [28]. Studies have used multiple terms that represent key components of critical thinking: problem-solving [29], [30], inquiry [31]-[34], judgment [11], and argumentation, all of which include an ability to be self-critical [32], [33]. From a virtue standpoint, critical thinking, which the Jubilee Centre Framework lists as one of seven intellectual virtues [21], includes one's motivational disposition to cultivate cognitive skills and use them towards morally good ends [35]-[37].

The Role of Critical Thinking in Engineering Education

Critical thinking and related capacities are widely acknowledged as important in engineering and engineering education [19], [30], [38]. A recent series of 27 studies that surveyed over 14,000 engineers, engineering graduates, and engineering faculty found problem-solving, akin to critical thinking, to be the single most important competency for engineers [39]. Critical thinking is associated with many aspects of ABET Student Outcomes. Not only does it address problem solving and analysis, but the process of argumentation cultivates communication skills that are essential to collaboration. Being self-critical keeps one open-minded to learn and solve problems both alone and in groups. Lastly, the process and spirit of inquiry is a necessary driver in self-directed, lifelong learning [19]. Despite its accepted importance, engineering graduates consistently fall short in critical thinking skills according to employers [29], [39], [40]. According to a 2019 literature review, established effective engineering curricula for cultivating critical thinking remain elusive, and brief duration (one semester or less) is the most common shortcoming to most critical thinking interventions. [30].

Teaching Critical Thinking in Undergraduate Engineering Education

Several literature reviews on critical thinking interventions in undergraduate engineering education have been conducted in recent years and reveal that, while various pedagogical approaches to teaching critical thinking exist (e.g. reflective writing and supplemental discussions), project-based learning appears to be the most studied [29], [30], [41], [42]. Project-based learning presents students with the challenge of solving a real-world problem and is thought to promote critical thinking because of the open-ended nature of the activity [30]. Since project-based learning is often done in teams, students engage in reflective dialogue and weigh various perspectives that further promote critical thinking. Students are also given more ownership over their learning process than they would with traditional course pedagogy, which facilitates positive motivations [29], [42]. Capstone design projects, required of all ABET-accredited programs, is just one example of such open-ended, team-based projects.

Providing real-world scenarios with no right or wrong answers provides an ideal context for students to learn how to apply critical thinking to open-ended problems. Consider a 10-week course in which students were assigned to address a groundwater management issue in their local community [43]. The course instructor facilitated the development of students' critical thinking by scaffolding their learning progression through all six levels of Bloom's Taxonomy (knowledge, comprehension, application, analysis, synthesis, and evaluation). In addition to classroom discussions that were not assessed, open-ended questions about the issue were included in homework, and the midterm and final exams and were assessed for the strength of their argument rather than for correct or incorrect answers. Students also participated in a local town hall meeting and were evaluated on the content and clarity of their argumentation. One finding was that students engaged in more active inquiry at the end of the course [43].

One rare longitudinal study at the University of Louisville's J.B. Speed School of Engineering incorporated critical thinking throughout the four-year undergraduate experience [44], [45]. The critical thinking programming was systematically integrated across participating courses by ensuring the consistent use of a common language and critical thinking framework. Participating faculty were then provided the autonomy to develop curricular materials to operationalize the critical thinking language and theory provided. At least one course per year incorporated an explicit critical thinking approach, and each subsequent year advanced students' mastery learning of critical thinking [45]. To assess student improvement in critical thinking, researchers qualitatively analyzed one assignment from each participating course using a blinded scoring rubric. Two reviewers were assigned to each student artifact, and scores were assigned based on the average of the reviewers' scores. Results showed that students improved significantly in their critical thinking from year 1 to year 4, but there was no control group to provide a point of comparison [45].

Another longer-term intervention explicitly used a problem-based learning approach to promote engineering undergraduates' critical thinking. Farmer and Wilkinson [46] studied chemical engineering students tasked with developing industry recommendations based on copper sampling from various mines and accounting for factors such as environmental effects and economic impact. Despite the promise of the duration and project-based learning pedagogy used, results of students' growth in critical thinking proved inconclusive, possibly due to the lack of rigor in the study design and selection of assessment instruments, along with an over-reliance on student self-reporting [46].

Summary of Critical Thinking and Connection to Engineering Education

Although numerous interventions seek to foster critical thinking in engineering undergraduate education, graduates' ability to apply critical thinking in engineering practice continues to fall short of expectations [39]. Determining the efficacy of such interventions and learning from related research is limited likely due to shortcomings of study design and assessment [29], [30], [46]. Project-based learning that does not offer one correct solution has proven the most popular pedagogical approach [43], [46], while longer duration projects woven throughout the entire four-year undergraduate experience are recommended for cultivating deeper and more enduring habits of critical thinking [30], [44], [45]. In all empirical studies reviewed, there was no explicit or implicit pedagogies that conceptualized the teaching of critical thinking as a virtue.

Empathy: A Moral Virtue

Defining Empathy as a Virtue

The Jubilee Centre Framework lists empathy (i.e. compassion) as one of several moral virtues [21]. Early work on empathy placed a conceptual emphasis on empathy as one's ability to "think and feel oneself into the inner life of another person" [47, p. 482]. Levenson and Ruef describe empathy's conceptual complexity by distilling it into three essential components: an emotional component, where one feels what another person is feeling; a cognitive component, where one can reason and understand what another person is feeling; and a behavioral response component, where one acts with empathy based on the emotional and cognitive understanding of another's experience [48].

The Role of Empathy in Engineering Education

Studies show that individuals with more empathy have a higher capacity in interpersonal relationships, especially with individuals from other cultural and ethnic backgrounds [49], and also generally improved communication [50]. Many recognize the importance that empathy plays in the engineering profession [51]. It is often highlighted as one of a broad range of professional skills for twenty-first-century engineers [52]. In particular, empathy has been shown to improve collaborative teamwork to develop comprehensive design solutions [53] and make ethical decisions [54], therefore addressing related ABET Student Outcomes [19]. However, research suggests that students who choose to study the physical sciences often report lower empathy [55], which makes the intentional development of empathy all the more important in engineering education.

Teaching Empathy in Undergraduate Engineering

There is a growing interest in empathy in engineering education, especially within engineering design projects where clients are integral to the process, and recent initiatives in engineering have incorporated empathy into their curricula via service-learning modules [56], student role-play, and reflections [57]. Such projects are implemented with the goal of fostering user-centered and empathic designs [58], but in general, "the professional skills literature does not provide guidance on how to foster empathy in undergraduate engineering programs" [59, p. 128]. Teaching empathy has been more widely studied in medical professions [60], [61], where many approaches to building empathy have been tested, including creative arts interventions (e.g. creative writing and drama), patient interviews, communication and interpersonal skills training, and experiential learning, with the latter three having the most pronounced impact on empathy development [60], [61]. Integrating peer-support, structured self-reflection, and course-based community service has also been shown to prevent the empathy decline that typically occurs during medical training [62].

An example of service-learning as a tool for teaching empathy is "Project for Sharing" wherein students work with stakeholders to create devices for underserved community members [56]. Student projects included building an infant/child location detector for blind parents and a simple-to-use communication device for deaf-blind children and their teachers. Students were measured on perspective-taking, empathic concern, and personal distress modeled from Davis [63]. Students who were engaged in these projects over multiple semesters showed increased empathy, and students who worked in more depth on the service projects experienced greater increases in empathy [56].

The University of Georgia implemented four empathy modules into “Engineered Systems in Society,” a sophomore course co-taught by a mechanical engineering professor and a social work professor [64]. Students were debriefed by the professors at the end of each class, and at the end of each module, students wrote reflections on their experiences and how they relate to engineering practice. Students learned skills such as affective regulation, nonjudgment, and mirroring via skill exercises and applied exercises. For example, in the first of the four modules, students practiced early communication by eliciting interesting information about their classmates (a skill exercise), and teams of three role-played informing community stakeholders about their food scarcity and sustainability project and then seeking out potential project advisory committee members (an applied exercise). In the third module, students focused on responding and mirroring conversation partners (a skill exercise) and role-played stakeholders in an advisory committee (an applied exercise). Qualitative analysis of students’ reflections revealed that the course helped students to consider the elements of power, distance, and difference between engineers and community stakeholders [65]. Some challenges students encountered included immersing themselves within fictional role-playing scenarios and initiating conversations with other students. The authors concluded that these challenges reflect gaps in the engineering education experience.

One approach to addressing these gaps is to offer interdisciplinary courses, such as the “Engineering Peace” course at the University of San Diego [66], [67]. In the course, mechanical engineering and peace studies students worked together during the semester to design and build a “pro-social,” humanitarian drone and payload with cameras to identify palm weevil infestations, metal detectors to sense un-exploded ordinances in Afghanistan, and heat sensors and alarms to alert densely-packed refugee settlements in Thailand of camp fires. Focus group interviews revealed that engineering students felt they gained a sensitivity to the perspectives of those from other disciplines through their interdisciplinary teamwork. From reflecting on readings to understanding the real-world contexts in which their drones would be used, they were able to identify potentially harmful unintended consequences of their work, leading them to question their role in the creation of these potentially harmful technologies [67].

Summary of Empathy and Connection to Engineering Education

Empathy in engineering education is important for fostering a deeper and more nuanced understanding of all stakeholders for their end design products. It is also key to facilitating effective collaboration among teams, particularly multidisciplinary teams. The most common and effective pedagogical approaches to developing empathy in engineering education appear to be practicing working in diverse teams on real-world applications and reflecting on reading and end-user perspectives and context [56]-[58], [63]-[67]. As with critical thinking, the engineering education studies on empathy reviewed in this section did not discuss empathy as a virtue or explicitly incorporate character education research.

Service: A Civic Virtue

Defining Service as a Virtue

The Jubilee Centre Framework defines the virtue of service as the disposition that motivates impactful action for others' benefit, which could include volunteering, campaigning, and fundraising [23], [68]. Service is one way to practice kindness and citizenship [69], [70], and it can help participants build empathy [71] and engage with surrounding communities [72], [73]. Service in the context of education is often called service-learning [74] and can include after-school programs, community engagement, [75] and community service [60]. Service-learning experiences can be elevated to cultivate a commitment to service as a virtue (i.e. a long-standing disposition) via multi-semester, highly integrated commitments, such as leadership positions [76]. Service has a "double-benefit," benefitting the participants as well as those served [23], [68]. "Double-benefits" for students who participate in service-learning include being more traditionally successful compared to their peers [74]. Research suggests that undergraduate students who participate in service-learning have higher GPAs [77], take more credit hours, and graduate at a higher rate than their peers [78]. These benefits equally impact students with greater financial need [78] as well as non-traditional students [79].

The Role of Service in Engineering Education

Integrating service in engineering via community-centered projects provides students with a unique perspective on what it means to be an engineer [72], [73], [75], increases their professional competencies through its project-based learning and customer-centered design, and gives students opportunities to practice teamwork and communication [72], [73], [75], [80], thus aligning with several ABET Student Outcomes [19]. There is also some indication that project-based service-learning experiences can help students improve their mastery of technical problem-solving [72], [81]. Undergraduate service-learning experiences result in increased student motivation and retention [72], [75],[81]. Despite these benefits, studies suggest that engineering students, compared to other majors, are among the least likely to participate in service-learning [79], and service-learning opportunities are most likely to occur in junior and senior years [72], which makes it more difficult to cultivate a virtue of service over four years.

Teaching Service in Undergraduate Engineering

Engineering educators have a growing practice of integrating service into project-based learning to create service-learning modules [72], [75]. Efforts to integrate and scale service-learning into undergraduate engineering courses are growing, including programs such as the Purdue University Engineering Projects in Community Service Program (EPICS), first-year service-learning at The University of Toronto, and UMass Lowell's Service Learning Integrated throughout a College of Engineering (SLICE) [81]. Several specific examples reveal different approaches to integrating service-learning into undergraduate engineering curricula.

The Purdue (EPICS) program includes multi-year elective courses in which interdisciplinary student groups (around 80% engineering majors) work with community members on sustained, multi-semester projects [75]. These projects focus on Access and Abilities, Education and Outreach, Environment and Sustainability, and Human Services. This robust program, which began at Purdue University in 1995 [82], has expanded to 35 colleges and universities and 73 high schools and middle schools. EPICS graduates report using the project-based skills they gained in EPICS after graduation [83], and over 70% of participants report that the program positively affected their motivation to continue in engineering [75, p. 737]. While many project-based and service-based learning initiatives target graduates or upper-level students, early EPICS participation leads to EPICS having greater impact on retention [75, p. 739].

To engage potential future engineers, one university program has developed a course for first-year mechanical engineering undergraduates that includes a 10-week project where students work in teams of 4-5 to build dancing robots for a robot flash mob for local elementary school students [75]. The elementary students participate as customers, meeting with team members, providing design specifications, and practicing design by creating their own decorative components for the robots. This project integrates project-based learning, teamwork and collaboration, customer-focused design, and service-learning with the intent to increase undergraduates' confidence and motivation to become engineers. At the close of the course, researchers surveyed the engineering students and found that 90% of participants reported that the hands-on creative design process was more fun and interesting than what they experienced in other engineering courses, and nearly two-thirds of students reported the course as a whole increased their confidence in becoming an engineer [75].

Service-learning can also be well integrated into the senior capstone experience. One such example is within the mechanical and industrial engineering department at Southern Illinois University Edwardsville. Their capstone course is designed to address ABET Student Outcomes while also providing students with the real-world experience of service-learning. This semester-long course includes formal lectures, guest lectures by industry professionals, and student project team site visits to provide the foundation needed for the students to identify and address a community need through their service-learning projects. Students spend the majority of the course working in collaborative teams on their selected projects, which included designing (1) assistive technology for ammunition packaging, (2) stocking carts, or (3) smart carts, all for local companies. By the end of the semester, students reported statistically significant increases in confidence in their ability to transfer their skills and knowledge to the workplace. More specifically, they expressed more confidence in how to "create and adapt complex products and services," "apply engineering techniques and design procedures to solve open-ended problems," "generate new ideas for products/services," "adapt existing products/services using engineering techniques," and "apply engineering techniques and skills to solve real-world problems" [84, p. 69].

Summary of Service and Connection to Engineering Education

Students who participate in service can not simply do good but also do well. Studies suggest that participating in service-oriented engineering projects does not detract from students' engineering education but rather enhances it, which aligns with the "double-benefit" model discussed above. The more students serve and become closer to their communities, the more they grasp fundamental engineering concepts and master engineering practices [82]. Female students remain committed to engineering [74], and all students' motivation increases [72], [73], [75], [80]. As for the other virtues, the studies reviewed here did not explore service explicitly as a virtue, but there is an implicit assumption that service is intended towards morally good ends, and there is a clear interrelationship between service, empathy, and teamwork.

Teamwork: A Performance Virtue

Defining Teamwork as a Virtue

Teamwork can be broadly defined as the virtue that enables the coordination of a group of individuals requiring collaborative behaviors towards specified goals [85]. The Jubilee Centre Framework lists teamwork as a performance virtue that has "an instrumental value in enabling intellectual, moral, and civic virtues" [21, p. 5]. In the engineering literature, a number of related terms are used interchangeably with teamwork, including "collaboration" [86], "project-based cooperation" [87], "group work," "project management skills" [88], and "project based learning strategies" [89].

The Role of Teamwork in Engineering Education

Engineering educators and practitioners already recognize the value of being a good team member [20], which is included as an ABET Student Outcome [19]. Research into the interpersonal dynamics of higher-education STEM projects have found that superior collaborative processes are linked to numerous beneficial outcomes such as stronger ties among team members and greater psychological health and self-esteem [90], which has also been demonstrated to lead to greater scholarly productivity [91]. In practice, engineers require interdisciplinary teamwork to face complex problems such as sustainability challenges brought on by global warming, resource depletion, environmental pollution, and multiple threats to resource security [92]. Such challenges further increase the need for engineering graduates to be strong team members [93].

Teaching Teamwork in Undergraduate Engineering

While ABET requires competencies such as teamwork to be addressed, it does not specify how teamwork or collaboration should be taught or how learning outcomes should be measured [19]. A 2013 meta-analysis conducted by Borrego, Karlin, McNair, and Beddoes [94] sought to evaluate the extent to which teamwork is being effectively addressed in engineering education. They found that project-based learning is the predominant pedagogy, but the project assignments lacked the complexity and authenticity needed to develop team skills. Thus, despite the growing emphasis on the importance of teamwork in engineering, there remains a distinct lack of development and clear consensus for how engineering educators are to cultivate teamwork skills most effectively. Outside of engineering, many empirical studies have shown the positive effects of improved team effectiveness through teamwork training in domains ranging from health care [95] to the military [96], [97]. Several examples reveal recent attempts to improve teamwork in undergraduate engineering education.

One example of a pedagogical teamwork intervention can be seen in the computer engineering program at the University of Alicante in Spain where students worked in teams of four to six members simulating a real-life work context with the objective of analyzing and evaluating the performance of different computer architectures [98]. The intervention began with a brief training on leadership and management styles, and all team members signed team contracts that outlined group rules promoting the assumption of each individual's responsibilities and included how possible non-performance within the group should be managed. The experimental method compared participating students with a control group on a number of pre and post measures assessing academic performance, conflict, and individual motivation. The study included a 15-

question survey to assess student's attitudes on how their group functioned based on a number of factors, such as team member involvement, existence of conflicts, communication, and workload distribution. Results showed a significant difference between the two groups. Students in the experimental condition were significantly more motivated than the control group, and the team-member workload was more evenly distributed compared to the control group. Perhaps most importantly, the authors concluded that the team contract led to increased individual accountability among team members [98].

At the University of Zaragoza in Spain, where the entire Industrial Design Engineering Degree is implemented through project-based learning, faculty sought to improve empathy and teamwork competencies of Informatics students. Their approach was to apply human-centered design methods that require teams at the outset to discuss the provided end-user criteria and weigh the perspectives and design ideas of all members before beginning the design process [99]. Three groups were divided into teams of three to five members with each group undergoing a different sequence of a three-day human-centered design training workshop. Outcomes were assessed through observation of team processes, evaluation of end products, and semi-structured, self-report student surveys. In the open-ended, self-report survey question about teamwork, 77% of the participating students indicated improvements in the following areas: working in teams, respecting and being willing to listen to different opinions, demonstrating more confidence in expressing their own ideas, and improved debate and discussion skills. When asked, 94% of the participating students reported that the workshop increased their desire to improve their teamwork skills [99].

Undergraduate engineering students commonly report difficulty working in teams due to team members not all sharing equal responsibility for their respective roles and tasks, and students often do not have the skills to proactively address this challenge [100]. In response to this challenge, one biotechnology engineering program developed a series of workshops over the course of three weeks for first-year engineering undergraduates to learn about and self-reflect on their participation in 14 team membership best practices. Some of the best practices include students' clearly assigning team member roles, practicing active listening, giving and receiving feedback between teammates, having a structure wherein a teammate can be "fired" if not upholding their role, and self-reflection on their own roles as team members. Results from the student self-reflections as well as focus group interviews revealed that these workshops most profoundly impacted students' understanding of diverse perspectives and built trust and respect among teammates [101].

Summary of Teamwork and Connection to Engineering Education

The above examples highlight how engineering educators are already using explicit pedagogies in the classroom to provide students with the opportunity to collaborate in teams and proactively work on being good team members. Project-based learning is core to this process. Some approaches focus on increasing empathy and understanding to promote more open problem-solving dialogue among diverse team members, while some include team contracts to inspire self-accountability as a team member. While teamwork was not presented in these studies as a virtue, it was shown that teamwork increases empathy between and beyond teammates.

The Value of Character Education for Engineering Education

So far, this paper has explored the engineering education literature to answer RQ1 and RQ2. With the relevant virtues and pedagogical interventions identified, we now turn to the final research question:

RQ3 - What can character education contribute to undergraduate engineering education pedagogy and practice?

The selected virtues explored in this paper provide a glimpse into the breadth of relevant roles that virtues might play in engineering education. Critical thinking and teamwork align directly with ABET Student Outcomes, and service and empathy indirectly inspire students to continue to pursue not only engineering but engineering for the greater good. The extent that these capacities are taught provides a strong foundation for extending character education organically in engineering education.

Yet what became apparent from our review is that while these concepts and capacities are relevant to and have been studied in engineering education, there is no explicit mention of them as "virtues" or capacities of "character." Instead, they are implicitly discussed most often as behaviors or skills, without any explicit use of virtue or character language.

In many ways, this is understandable, particularly since some of the virtues surveyed here (such as critical thinking or teamwork) can also be properly understood as skills. Many virtues and skills share a fundamental similarity in how they are developed: through habituation and practice. Like skill, virtue is a fundamentally "developmental" concept: virtue is conceptualized, in part, by how it is developed, and it is developed in ways similar to skills—through reflection, repetition, and habituation over time [1], [2, p. 4], [8], [10]. This is one reason why philosophers have employed a "skill analogy" to explain virtue and its cultivation [2], [10]. The analogy implies that the type of pedagogical interventions used to teach relevant skills could also be used to cultivate virtues, which fits with research suggesting that the capacities identified above are most effectively cultivated when they are embedded across a four-year curriculum that gives students more time and opportunities to practice specific virtues. Such practice helps students habituate dispositions that can become more stable and enduring than shorter interventions might allow.

The analogy between virtues and skills is helpful for engineering education. It implies that many of the pedagogical interventions used to cultivate "skills" can also advance the development of these capacities as "virtues." However, applying a character framework and conceptualizing these four capacities as "virtues" rather than "skills" could provide significant added benefits for engineering education. Four distinctions between skills and virtues are most relevant.

First, skills and virtues can be ordered toward different ends [1, p. 22], [10]. A skill is primarily ordered toward the accomplishment of a given task or the completion of a particular product. If an engineer needs to design a structure, for example, she uses her knowledge and skills to meet the given requirements of the project and complete the task. Skills can be ordered toward a multitude of ends to accomplish morally good, morally bad, or most commonly, morally neutral objectives. By contrast, virtues, by their very nature, are necessarily ordered toward morally good ends. Most often, these ends are further specified with reference to individual and communal flourishing. For an engineer to display the virtue of empathy, for example, she must order her empathy toward the wellbeing and care of another—that which promotes the flourishing of the individual and community. To express empathy for other reasons—for instance, to earn recognition or take advantage of someone's suffering—would not express an underlying virtue. The fact that virtue requires ordering one's thoughts, feelings, and actions to morally good ends has important implications for engineers. Conceptualizing and cultivating these capacities as virtues highlights the need for engineers to evaluate the moral quality of the ends to which they are directing their capacities and, where possible, to orient them toward communal flourishing. A character framework thus better captures the social purposes that define the profession of engineering and highlights the pedagogical need for students to consider their larger purposes when developing these capacities.

This distinction between ends points to a second and related difference between virtues and skills: virtues have a motivational component that skills often lack [1, p. 22], [10]. When an engineer uses her skills to complete a project, her internal and moral motivation may not be considered. She might want to accomplish her task to impress her client or supervisor, get paid, or build her resume; the moral quality of the motivation does not necessarily impact nor diminish the application of her skills. We do not share this example to suggest that moral considerations are not present in engineering education and real-world engineering practice, but to point out that one's motivation is crucial for virtue cultivation. A virtuous behavior does not, on its own, signal an underlying virtuous disposition. The moral quality of the motivation matters for virtue. Consider the following case: an engineer cultivates "teamwork" to give the external impression that she is a collaborative and well-liked coworker for the purposes of achieving a promotion—an example of extrinsic motivation in the engineer's approach to teamwork. By contrast, a virtuous engineer cultivates teamwork to support her coworkers, achieve a collective goal, and create an environment of collective success. The former engineer uses the façade of teamwork for potentially extrinsic, self-interested reasons, whereas the latter engineer cultivates teamwork as a virtue with a morally good motivation. Again, this is not to suggest that intrinsic and morally good motivations are absent in engineering education and real-world engineering practice, but simply to highlight the contrasting views. A character framework encourages engineers to not merely seem good but to also be good through motivations ordered toward morally good ends. As a result, a character framework encourages engineers to be reflective about their motivations and to seek, as much as possible, to order their thoughts, feelings, and actions toward morally good ends. Pedagogically, educating these capacities as virtues rather than skills challenges students to become more aware of their motivations and, when necessary, to reorder their motivations toward morally good ends.

Third, and related, a character framework encourages engineers to understand the nuances and conflicts between different forms of value. When critical thinking is taught solely as a skill, an engineer only needs to understand a narrow conception of value. For example, she may only need to create a design that maximizes economic value while maintaining structural integrity. By contrast, if she is taught critical thinking under a character framework, she must use her critical thinking to also consider other values that relate to communal flourishing, such as environmental, moral, and civic value, which might lead the engineer to see how different types of value can conflict. Maximizing efficiency and economic value, for example, might be in tension with environmental, moral, and civic value that preserves the good of the community or the health of an ecosystem. Although many engineering educators already teach students these nuances, a character framework explicitly draws out these potential conflicts and encourages the use of the virtue of prudence, or practical wisdom, to integrate or reconcile different moral considerations [21], [102]. When applied to engineering education, a character education framework encourages interventions to help students evaluate and assess different forms of value.

Fourth, virtues are understood as interconnected and mutually reinforcing [2, pp. 84-100], [26], whereas skills can be conceptualized and cultivated as discrete capacities without reference to virtues or even other skills. When critical thinking is used discretely as a skill, it can be practiced without ethical deliberation or morally good motivation. A character framework, however, recognizes that the development and exercise of any one virtue relies on the cooperation of others. To embody critical thinking as a virtue ordered toward a morally good end, for example, an engineer must combine her mathematical and scientific knowledge, problem-solving capacities, and analytical capacities with ethical deliberation and decision-making to make good judgments. To do so reliably and well over time, the intellectual virtue of critical thinking will require moral, civic, and performance virtues to determine its proper ends and motivate its proper functioning. It might, for example, require the moral virtue of empathy to understand what is best for diverse stakeholders, the civic virtue of service to direct critical thinking toward ends that promote communal flourishing, and the performance virtue of teamwork to achieve those communal aims. Without the cooperation of these virtues, critical thinking could not be reliably exercised or developed. The interconnection of the virtues has important implications for engineering education. Since virtues cannot be fully developed in isolation from others [2, p. 85-87], engineering educators cannot teach a limited number of virtues or cultivate them in isolation. To develop and practice any of the virtues will require developing and practicing other related virtues. This interconnection thus highlights the need for a more comprehensive and holistic approach to educating character within engineering that seeks to cultivate multiple virtues and to do so across a four-year curriculum in ways that intentionally foster connections between different virtues and capacities.

These differences between virtues and skills are not merely conceptual or semantic. A character framework highlights the practical and pedagogical value of considering the moral quality of one’s ends, cultivating morally good motivations, evaluating different and competing forms of value, and recognizing the ways that different virtues can be interconnected and mutually reinforcing. While none of the empirical studies reviewed explicitly spoke of the four capacities as “virtues,” acknowledging them as such could be critical in designing pedagogy that leads to long-term development of them not simply as skills and behaviors, but as long-standing dispositions directed toward morally good ends. Moreover, identifying them as virtues would enable engineering educators to take advantage of the growing literature in character education to identify relevant pedagogies to cultivate these virtues [3], [8], [9].

Conclusion

This review of four virtues in engineering education has affirmed the undoubted relevance of character in engineering and engineering education, as well as the lack of explicit conceptualization and cultivation of these capacities as "virtues." When capacities are taught as skills rather than more holistic dispositions of character, we miss opportunities to employ more holistic pedagogy to cultivate virtuous engineers. Since virtues and skills are similarly cultivated through habituation and practice, a character education approach could benefit from the current interventions used to teach these skills while also helping students ensure that their particular capacities are 1) ordered to morally good ends, 2) reflect morally good motivations, 3) properly evaluate and address potential conflicts among values, and 4) are interconnected with and reinforced by other relevant virtues. Future studies integrating character education into undergraduate engineering education could help to further advance character education as a promising approach that could not only address the gap in professional skills such as teamwork, problem solving, and cultural awareness, but also improve engineers' technical decision-making and transform ethical decision-making in ways that move beyond rule-based approaches to compliance [16]. When engineers exercise intellectual, moral, civic, and performance virtues consistently and reliably towards morally good ends, they would not only be good, but do good in the world.

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