On Competence and Virtue in Engineering and Computing Education

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***Abstract*— This presents a descriptive analysis of the relationship of competence and virtue for engineering and computing professionals. Rooted in recent developments in competence theory, including the development of the Computing Curricula 2020 (CC2020) guidelines, this work illustrates the relationship between competency-based and virtue-oriented approaches to education. It presents the case for connecting virtue, and the development of virtue, as a necessary aspect for the formation of competent engineering and computing professionals. It suggests a proposed set of engineering and computing (E/C) dispositions drawn from the lifetime learning and computing competency literature that can be used to frame competency-based and/or virtue-oriented E/C education and outlines how dispositions like these serve as a means of bridging competency and virtue as learning goals. The paper concludes with the case for formation in professional virtue is a critical component of engineering and computing education.**

Keywords — Disposition; Virtue Ethics; Competency Development; Engineering Ethics; Computing Ethics

I. INTRODUCTION

"The pursuit of knowledge is a collaboratively conscious, intelligent, rational, deliberate, and methodical effort." [1] As the centerpiece of education, our goal as instructors is to invite our students into joining this pursuit of knowledge, to help them engage collaboratively in the "intelligent, rational, deliberate, and methodical effort" of learning, specifically the knowledge, skills and dispositions expected of persons developing as competent engineering and computing (E/C) professionals [2]. The hope is that we are helping our students develop as competent learners, able to develop the kinds of critical capacities that are required for professional practice [3][4].

The observation is that many of the skills and abilities that form a part of E/C education are better framed as virtues [5]. At its heart, virtue is about engaging in actions for the good, with good intent [5][6]. For supporting a student in the professions, such as Engineering or Computing, this entails facilitating students' development both as a learner and as a professional; developing the virtues of a learner and the virtues expected of an engineering or computing professional.

A. Goodness

Virtue is disposition directed to the good; with respect to virtue, the particular goodness is the differentiator, and provides a basis for enumerating and/or distinguishing particular virtues [7]. Thomas Aquinas maintained that an enumeration of the different types of a given thing must be associated with the definition of that thing itself, hence for virtues, it is the underlaying form of goodness that distinguishes one virtue from another ([8]1.12c). A distinct feature of Aquinas' theory of virtue is that different virtues are about different things, and that a given virtue disposes one to act well in relation to what that virtue is about.

Recognizing that educators have the complicated task of advancing students' sense of moral development and reasoning [9]. Consequently this connection between goodness, and its reflection in personal action as virtue is particularly important to engineering education, where the goal is to support students' ongoing conversion: intellectual, moral and religious [10], and in doing so to help students recognize and value 'engineering' goodness. [5][11]

Goodness in education has numerous voices: Scholar academics believe that the purpose of education is to help children learn the accumulated knowledge of our culture by becoming an initiate in an academic discipline. A social reconstructionist would see the value of a particular education in the growth or ability of the student to contribute to a more just society. Social efficiency advocates frame the value of education in terms of how students are better prepared to function as mature contributing members of society, developing the skills and procedures they will need to be effective contributors, particularly in their area of specialization. A utilitarian twist on this perspective would emphasize the learner's potential earnings and/or contribution to the economy. A learner-centered perspective focuses on the needs, concerns and choices of the individual learner, which shifts the goal of education to supporting the intellectual, social, emotional, and physical growth of the individual in their progress toward mastery [12][13]. This work primarily focuses on the latter perspective.

II. BACKGROUND

Neither competence nor virtue as elements of E/C education are new. While virtue has long been a topic for education, and competence more recently, it is only in recent developments in

virtue ethics and in competency modeling that form the genesis of this exploration.

Virtue ethics has its roots in Aristotle's work more than 2300 years ago emphasizing virtuous living. A good person will make good decisions, so what is important is to become a good person. In the 1200's Thomas Aquinas integrated this philosophy with a Christian worldview, and his perspective would dominate Western philosophical thinking until the advancement of more relativist and utilitarian viewpoints emerged in the 1700's [14][15]. More recently, virtue ethics has seen a resurgence, particularly in its application to E/C education (*e.g.*, [16],[14],[17], [18]).

Competence as an educational term has more recently been proposed as a newer form of outcomes planning or assessment based on competency statements (see [19],[2]). Recent developments on competence theory and modeling [19][20][21] strongly relate the good of competent professionals to their disposition to apply knowledge and skill in contextually-appropriate tasks. Through disposition is established a strong connection between ethical activity and competent engineering with different emphases by the various engineering codes of ethics [22]. These connections, or rather their apparent lack of integration across engineering and computing education curricula is the focus of this work [18][21] [23].

A. Virtue and Virtue Ethics

Virtue ethics as a philosophical system aims at asking the question, what is a good human person? What are the virtues to be developed and the vices to be avoided in becoming a good moral human person? Instead of a list of rules about human behavior, virtue ethics then focuses on the definition of the virtues and vices, the education or discipline necessary to become virtuous, the difficulties encountered and the end to be achieved. [15]

Here, virtue is defined as a well-motivated disposition to act in self- and other-benefitting ways on the basis of knowledge about those actions [16][24]. This emphasis on virtues reflects character development, and more particularly in the connection between the known, choice of the actor in intending the good by their actions, with the assertion that character development as the fundamental basis for human and societal flourishing (*e.g.*, [17], [24]). From an educational perspective, this emphasis on character development shifts the emphasis to a learner-centered perspectives: that character is largely caught through role-modelling and emotional contagion; that the direct teaching of character provides the rationale, language and tools to use in developing character; that its progress, particularly with regard to virtues and the dispositions that effect them, can be measured holistically, not only through self-reports but also with more objective methods. [15] [17] [24] [25] [26]

In the 12th Century Aquinas established four generic ways in which a rational being can be morally good. By examining the underlaying good that distinguishes each virtue from another, these were established as to the cardinal virtues [7][27].

(1) the good of corresponding to reason: *consistens in consideratione rationis* (Prudence),
(2) the good according to right and due: *recti et debiti* (Justice),
(3) the good of restraining the passions *refraenandi passions* (Temperance), and
(4) the good of firmness *firmitas* (Fortitude).

Aquinas regards these four as the paradigmatic character virtues, aspects of goodness that are basic in a certain sense. For example, fortitude is something that helps us live in accordance with reason (prudence), but that does not entail that there is a set of reasons which are unique to courageous actions. Aquinas establishes these four as cardinal virtues, because they each have a separate and distinct goodness criterion. This permits a broader enumeration of virtues, allowing us to expound other virtues that rely upon one of these four as its central good.

For example, one could identify a disposition toward disinterestedness as an aspect of justice. Disinterestedness is a attitude reflecting service to the work itself, with the actor focusing on fulfilling what the work itself demands rather than being dominated by one's own interests such as pay, career advancement, organizational needs or any other interest apart from doing high quality work in service of the customer and/or the public [26]. This is accounted as an aspect of justice in that it reflects the right and due of quality work for another – the customer and/or public.

The concept of 'goodness criterion' raises the question of what makes a given action a virtuous action. Debates continue; Aquinas generally agrees with Aristotelian ethics insofar as he is taken as virtuous dispositions play a significant role in making actions good. Aquinas is also often contrasted with Dun Scotus, who separates the role of the actors' virtuous disposition in ascribing their actions as good. [7] Agreement in these positions in found for identifying moral goodness by stating that virtue is not important for the substance of the act but for the way in which the act is performed, *e.g.*, that virtuous acts may be performed by non-virtuous people. The fact that actions can be good independently of virtue does not rule out the possibility that virtue can contribute further goodness to our acts. This understanding is valuable*, e.g.,* that the way that a virtuous person does them, that is, readily, without any hesitation, with pleasure, and without difficulty. Consequently these cardinal virtues comprise the building blocks for constructing a taxonomy of the virtues [7] and a reasonable means of connecting related virtues. Connecting virtue to professional competence is relatively new exploration [26].

B. Competency & Comptency Modeling

While there are numerous models that have been suggested or are in use for modeling competency in an educational contexts [20], the CC2020 effort spearheaded by the IEEE and ACM established the model in Equation 1 for use in Computing Education [28]. A competency statement can be described as:

$$\textit{Competency} = \textit{Knowledge} + \textit{Skill(s)} + \textit{Disposition(s)}\ \textit{performed in a context or task}$$

Equation 1. Competency Model for Computing Education [20]

At one level, competency modeling is like outcomes descriptions: They aim at describing an educational goal for students. The advantage of a competency-based approach to education is significant. By extending descriptions of what

graduates can do to include both dispositional and contextual expectations, it challenges educators to include more practical situations, more emphasis on disposition development. Competency modeling is difficult to complete at lower levels of Bloom's Taxonomy (see Clear, *et al* [19]) as it significantly extends descriptions of content learning and memorization.

What competency statements do is to provide a richer description of what graduates can do, contextualized to the context or task in which student competence is observed. Consequently, competency challenges educators to better structure how students develop as proficient computing professionals [21][25]. When used as a descriptive framework, it provides richer descriptions of program or student outcomes [19], allowing students, employers, educators or society in general to more easily recognize the purpose and benefits of engineering or computing [28].

III. Connecting Competence and Virtue

Numbers of efforts have championed the importance of contextualization both in competence modeling and in virtue ethics. The CC2020 report [28] and its supporting research [2] [19][25] present tasks as the observable opportunity for demonstrating or assessing competence; Similarly these same (and other) works strongly suggest disposition as the connection to both to competency as it is formed and observed in the learner, and as a key connection to affective domain learning. These two extensions to traditional outcomes modeling and assessment present challenges engineering and computing educators. This work aims to expand a synthesis of these explorations, connecting these understandings of virtue and competence and briefly outline the implications for Engineering and Computing (E/C) education.

A. Competence and Competency Modeling

The use of competency statements shifts the focus of curricula away from describing a body of knowledge in relation to a disciplinary area and channels it toward a more pragmatic description or assessment of student accomplishment and task-based performance [29]. While this is fundamentally an extension of outcomes modeling long established in E/C education, it establishes (or re-establishes) the central role of disposition development as a central need for E/C education.

Similarly, expansions on competence theory and modeling strongly relate the good of competent professionals to their disposition to apply knowledge and skill in contextually appropriate tasks. Through disposition is established a strong connection between ethical activity and competent engineering with different emphases by the various engineering codes of ethics [22]. These connections, or rather their apparent lack of integration across E/C education curricula is the focus of this work [18][21][23].

Curiously, one of the common challenges suggested in the literature surrounding competence education and engineering ethics presented is the issue of *decontextualization* – separating the knowledge and application of a thing from the contextual situation in which that knowledge, skill or affect is applied. This is noted in engineering ethics education (*e.g.,* [14][18]) and in competence development (*e.g.*, [19][20][21]).

Yet recently, numbers of efforts have championed the importance of contextualization both in competence modeling and in virtue ethics. The competency model presented includes tasks as the observable opportunity for demonstrating or assessing competence and disposition as the connection to affective domain learning. These two extensions to traditional outcomes modeling and assessment present challenges E/C educators and suggest more integrative approaches [19][25].

B. Disposition: Bridging from Competency to Virtue

While many of the dispositions presented in Table 1 and Table 2 may be values common to many professions, these concepts are often embodied in 'professional skills' or 'soft skills' descriptions [2][28]. Frezza and Greenly leverage this relationship to explore the relationship between engineering codes of ethics and engineering virtues [26]. Their examination of six engineering and computing codes of ethics suggests that the virtues of prudence, disinterestedness, truthfulness and justice warrant significant inclusion in E/C education. While representative, this work makes no attempt to assert a full breadth of dispositions that might comprise engineering or computing virtue.

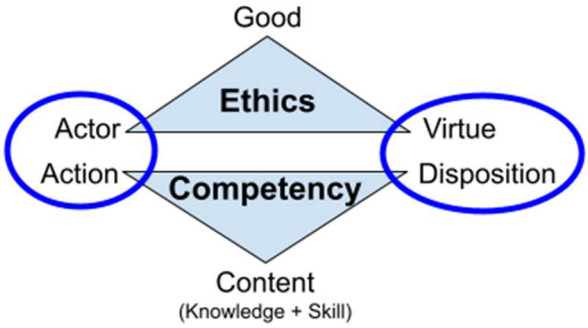

Figure 1. Connecting Competency and Ethics through Enacted Virtue (from [26])

What this work suggests is that competency modelling provides a mechanism for integrating ethics formation in conjunction with technical competency development. Similarly, through the expectation for disposition development and observation, challenges educators to spend more effort on the observation of students' choices and actions, not just the results of their decisions. This aligns with John Dewey's observation that "The self is not something ready-made but something in continuous formation through choice of action" [30]. This in turn connects learning to virtue, in that when dispositions toward the good are included in the goals of E/C education, E/C education would necessarily include virtue formation as a goal.

At question is the reasonable means by which to enumerate E/C virtues correctly. For this purpose, we suggest the application of experience-based moral epistemology. One of the earliest uses of this approach dates to the early 14th Century, when Godfrey of Fontaines employed experience-based moral epistemology in his explorations of prudence as a central moral virtue. His approach focused on leveraging experience as a means of better understanding virtue. Godfrey's argument expanded upon Thomas Aquinas' work, establishing that character virtues are necessarily connected, and yet there are still distinct dispositions with their own essential and defining characteristics. For example, the distinctness of fortitude

(courage) is not undermined by its being connected with the virtue of temperance (moderation). [7]

Table 1. Learner Dispositions and their connection to virtue

Learning Disposition	Parallel Effective Lifelong Learning Inventory (ELLI) [31]	Summary of Good Addressed	Cardinal Virtue
Resilient	Willingness to explore, make mistakes, persevere. ***Resilience & Robustness***	Challenge to activity in serving a higher good	Fortitude
Interdependent	Responsible to manage the balance between being sociable and being private in their learning. ***Relationships/ Interdependence***	Rendering good to self and another	Justice
Reflexive	Values self-awareness and comprehension; Interested in different approaches and becoming more knowledgeable and aware of themselves as learners. ***Strategic Awareness***	Exploring alternatives in support of better actions	Prudence
Creative	Values looking at things in different ways and new possibilities. Receptive to hunches, imagination, and imagery. ***Creativity***	Open-mindedness toward better condition	Prudence
Inquisitive	Energy and a desire to find things out, to get below the surface of things. ***Critical Curiosity***	Open-mindedness toward better condition	Prudence
Connective	Value making meaning: Develop links between what they are learning and what they already know. ***Making Meaning***	Exploring alternatives in support of better actions	Prudence
Endeavoring	Believes that learning itself is learnable; through effort, their minds can improve. ***Growth Orientation***	Moderation of self toward better action	Temperance

With this understanding, Aquinas' postulation that it is the underlaying form of goodness distinguishes one virtue from another becomes valuable; in examining a proposed engineering disposition drawn from experience (*e.g.*, [25]), it is the examination of the underlying good, notwithstanding its necessary connection to prudence[1], by which that disposition could best be identified as a virtue. Because virtues are related to moral intentions and behavior, identifying the underlaying form of goodness that is the target or intention of that disposition serves as a means of exploring the connection between the good of a particular engineering activity and the virtue enacted. By summarizing the good embodied in the intent and action(s) of a disposition, one can follow Aquinas' approach for relating these dispositions as aspects of the cardinal virtues. In doing so, this allows the disposition to remain discipline-relevant, while still providing a framework for agreement, discussion and understanding.

C. Virtues of a Learner

For students to have a deep understanding of their personal goals, professional roles, and their roles in the society, they need to fundamentally understand how they learn. This is particularly important in E/C professions, where lifetime learning is an established value. Consequently, it is important that they integrate their technical learning with social, educational, liberal perspectives on learning. As a virtue-focus challenges students to integrate values and action, in their Effective Lifelong Learning Inventory (ELLI), Shum and Crick [31][32] identify seven dimension of the characteristics of effective learners [33]. Following Godfrey's approach, these experiential aspects of a learner suggest a set of dispositions, values and attitudes that form a key and assessable part of a learning journey.

Table 1 presents a set of learning dispositions developed from the seven core elements of the ELLI. Each of the seven ELLI dimensions are listed in bold at the end of the disposition description. To illustrate the method, four of the seven proposed learner dispositions are expanded below.

Resilient: A mature learner shows a willingness to explore, make mistakes, and persevere. They should be able to face and deal with their "felt discomfort" when facing new challenges. They should be able to define and locate the problem at hand and come up with possible solutions while expanding their understanding(s) of the solutions. This reflects the challenge of applying their learning to serve a higher end, which is consequently an aspect of fortitude.

Inquisitive: A leaner should be aware that knowledge and mastery come from active learning, questioning, and, most importantly, careful examination of mistakes they make in the process. True learners should seek to frame their understanding, to engage in critical curiosity prudentially oriented towards a better condition or solution.

Connective: (see [1]) reflects the Making Meaning dimension of the ELLI. A learner values seeking/examining facts, their understanding, interpretations, and connections while trying to unify their knowledge. A connective learner examines facts and information, on a path toward creating a thematic continuum of meanings, interpretations, and connections. Learners act to clarify and unite while expanding their knowledge. As this serves the good of better learning and better actions, this would be an aspect of virtue of prudence.

Endeavoring: An effective learner is actively engaged in the challenges of growth: reexamining facts, revising their knowledge, and expanding their learning horizons. In seeking knowledge, a learner always keeps on keeping on, acting on the realization that learning requires effort and engagement, valuing that the effort is worthwhile. This requires self-moderation, with a view towards something good, something better. Following Aquinas' model, the endeavoring disposition would be an aspect of virtue of temperance.

The learner dispositions presented in Table 1 are also mapped to the summary good that they support. For example, a

[1] Aquinas asserts "No moral virtue is possible without prudence" in *Quaestio disputata de vertiate* 14:6 [27].

connective disposition supports exploring connections that build meaning, and these meanings expand/improve the value of that which is learned. Consequently, connective disposition would primarily be a facet of prudence. As four of the seven ELLI learning dispositions map to prudence, this analysis suggests that developing prudence is key to helping develop lifelong learners.

D. Virtues of an Engineering or Computing Professional

Similar to learners, identifying a definitive set of E/C virtues is also probably impossible. However, the need for virtue as a key component of E/C education has been strongly supported from multiple sources (*e.g.*, see [14][18][19][20]). It is well acknowledged about the ethical nature of engineering, deeply rooted in the design activity that comprises the conception, design, implementation and operation of technology. Consequently, E/C professionals have a responsibility to develop their ability to develop ethical technology ethically [11][23]. What is less agreed upon is how engineering professionals enact virtue, that is that they act well in relation to the good of a particular engineering activity.

Table 2. Engineering Dispositions and Virtues

Engineering Disposition	Summary of Good Addressed	Cardinal Virtue
Self-directed	Challenge to activity in serving a higher good	Fortitude
Truthful	Challenge to activity in serving a higher good	Fortitude
Proactive	Challenge to activity in serving a higher good	Fortitude
Passionate	Challenge to activity in serving a higher good	Fortitude
Collaborative	Rendering good to another	Justice
Responsive	Rendering good to another	Justice
Disinterested	Rendering good to another	Justice
Responsible	In support of better/best action	Prudence
Meticulous	Exploring alternatives in support of better actions	Prudence
Inventive	Open-mindedness toward better condition	Prudence
Deferential	Engage the experience of others in support of better action	Prudence
Purpose-driven	Moderation of self toward better action	Temperance
Adaptable	Moderation of self toward better action	Temperance

A means of exploring engineering virtues would be to leverage sets of engineering dispositions from E/C education literature (*e.g.,* see [25][26][28]). Using these as foundation for experience-based moral epistemology, one can summarize the good affected by the habitual application of a particular disposition. Such an analysis of a 'summary good' is presented in Table 2.

Identifying E/C dispositions and exploring the various ways in which they help effect good also communicates enacted values (see [25] and [34]). By framing dispositions from values observed enacted, and generally agreed upon by the community they represent a 21st Century application of experience-based moral epistemology for the E/C professions. A set of applicable E/C dispositions brings a significant advantage to education, in that these dispositions represent identifiable affective program goals.

IV. Virtue Development in Support of E/C Competency

At the undergraduate level, E/C students ideally develop both as nascent E/C professionals and as learners. Not surprisingly, developing as a learner (or 'lifetime learner') has been identified as a core competency of many national E/C accreditation commissions such as ABET in the USA. While lifetime learning (*e.g.,* the ELLI model) could be viewed as its own meta-competency (a higher-order competency as suggested in [11],[19],[20]), this virtue-based analysis suggests that both collections of competencies share overlapping dispositions as a foundation for competency.

While many voices may speak for what it means for an E/C student to be 'prudential' or 'temperate', it is not clear that this could be clearly answered. What values are we challenging students to enact? This can be reasonably answered by examining the virtues that underpin representative aspects of discipline-specific competency, specifically their dispositional values (*e.g.,* Table 1 and Table 2), one can derive a cogent meaning of what virtue, particularly Temperance, Justice, Fortitude and Prudence should look for a particular discipline.

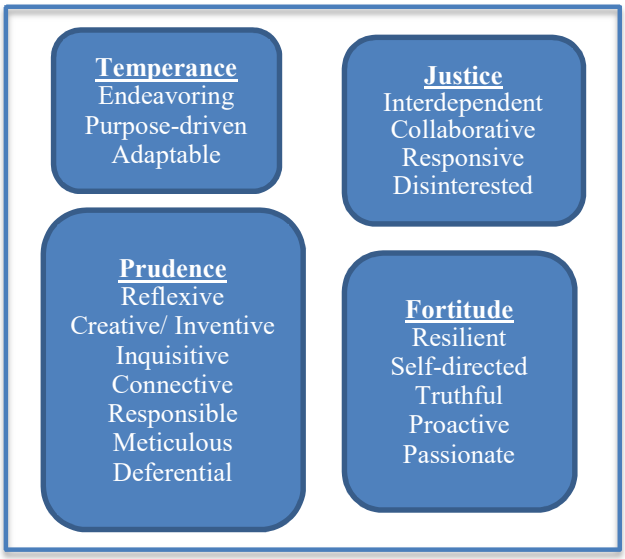

Figure 2. Dispositions Supporting E/C Competency

Figure 2 presents a synthesis of E/C dispositions and their associated virtues derived from Table 1 andTable 2. What this figure represents is a synthesis of values, an 'experienced-based moral epistemology' of what virtue looks like for an E/C student. What Figure 2 presents is a representative set of affective domain learning goals for an E/C undergraduate program. However, no matter how useful, this assertion of program values does little to provide mechanisms by which these virtues could be formed in students. For this, theory on the science of virtue is helpful [24].

A. Virtue Formation and Mastery Development

The STRIVE-4 model for virtue [24] suggests that virtue traits have four major components: knowledge, behavior, emotion/motivation, and disposition. These correspond well to the broader approach to disposition in the recent developments in competence modeling. At the core of the STRIVE-4 research is the extent to which an actor's choices or agency play a role in positive moral behavior; virtue as being cultivated and enacted by choice. Not surprisingly, agency is seen a key constituent of virtue, which parallels the agency recommended in competency development [19].

Virtue development shares the social and contextual nature of competency development, both approaches strongly suggesting that E/C education needs to extend significantly beyond technical and professional content development [11][35]. Combining the challenges of contextual nature of competency development and those of learners, particularly the endeavoring and resilient dispositions of virtuous learners, raises the question if E/C professional formation is really more a form of virtue formation [18]. Intentionality, and identification of intentionality of the individual is key. Learning is different between a mistake made and a mistake knowingly avoided – the ability to recognize the missed value. That avoidance action then becomes the action in future. This is choice, and the desire to choose a different action reflects agency and represents a step toward mastery. Repeated informed choices reflect the development of disposition, and when in conjunction with contextually appropriate application of knowledge and skill, reflects a competency enacted.

Much agreement exists in E/C education about the knowledge and skills wanted in developing engineers (*e.g.*, [19][36][37]). However, the key unification between mastery and virtue is disposition, and embracing the affective domain aspects of disposition development[4] and the social learning implications this embraces[2]. A broader view of E/C virtue, embracing E/C competency and learner dispositions is summarized in Figure 2.

B. Virtue Formation and Mastery Development

The ultimate goal of education is to develop students to be self-learners, keep up with changes, and have the capability and capacity to learn new subjects, and embrace the values that support E/C mastery. The challenges that students face to survive and be successful in overly packed E/C curricula comprised mainly of technical classes assignments, laboratories. Such processes impact the time, and freedom to think openly, critically, and develop a professional appreciation of overarching values of education, of being an engineer, and of being productive and conscience members of the society. More particularly these educational challenges can easily prove counterproductive for the formation of the dispositions that support E/C competency.

Most E/C programs are knowledge-based in their approach with only anecdotal support for competency development [28]. Disposition development, at the heart of competency and virtue development, requires a more holistic approach [1][4]. The power of reflection, collaboration, and actively supporting students on their journey to become learned and productive members of the society is not valued in most E/C programs with packed courses and curricula.

Competency and virtue development is fundamentally moral development, and within the individual this is always about more than cognition. It involves knowing, caring, and acting [9]. Reflexive practice is a common means to approach this type of learning[39][40][41]. One structural means of accomplishing this in a course is through storytelling. The following section reflects the authors' lessons learned embracing storytelling as a means of fostering disposition development in E/C learners.

V. Storytelling and Disposition Development

Evidence of virtue formation is not easily assessed. Students' self-stories (narratives) are an effective source. The following narratives comes from sample transcriptions of 21 students' journals from two courses, "Thoughts to Things" and "How Things Work." Both courses engaged students from the College of Engineering and the College of Design.

- G1: These reflections came from the "From Thoughts to Things" course. The summaries provided are based on 3 groups, each with 4 to 5 students. More than half of students started in engineering and left after 1 or 2 terms for the College of Design.
- G2: This is from a group of 5 students who worked with another group of 4 students in "How things work."
- G3 From a group of 6 students from "How things work," 3 of whom started engineering and the other three directly in design.

The student reflections have been trimmed for brevity and are offered here with permission. They present a brief sample of how the affective, dispositional terms of Table 2 can be identified in student work. What is most compelling in these stories is the description of self-growth; how dispositions developed in the student authors as related by the authors themselves. The transcripts have been annotated with particular learning and E/C professional dispositions (Figure 2) that were reflected in the student text.

Reflexive… Resilience…(G1)

In the beginning, I was afraid. What is technological literacy, and why should I take this? I dropped out of the engineering program and joined design since I did not like the engineering classes and their perspectives. During the first ten days of the class, I felt this class could be a similar experience to my engineering classes. The faculty is in Engineering and Design Colleges but is an engineer. I was not sure if I must be scared or happy with this information. My feelings were very confused and not comfortable at the beginning…

The class started, and everyone chose a team, and we started to work with our teams. The instructor encouraged discussions and reflection and would provide guidance, but more importantly, encouragement to deal with our difficulties, talk about them, articulate them, and reflect on them

[2] Vygotsky [38] asserts learning as a social process in which communication between people is essential, maintaining that productive thinking has its beginnings in the social plane (between people engaged together in activity), and is later internalized within the learner, on their individual plane.

individually and as a team. He would listen to us, encourage us, provide ideas and perspectives, and help us to define our journeys to be more pleasant and enjoyable. It helped that the class did not threaten us with grades. Every day in class, we had to think about problems, a concept, and a process. We would discuss this with the team and reflect on our thoughts, discussion, and learning. The class's attitude was, 'Do not be afraid of making mistakes.'

Endeavoring… Proactive… Collaborative… (G1)

Within a month and into the class, we became fearless. We would ask the instructor to give us our hardest concepts and ideas and let us work on them as a team once we have the confidence to find new perspectives and new ideas. This was true as long as we challenged and supported each other to be critical of our perspectives, we could face the problems that we thought were difficult with whole new perspectives, ideations, and different approaches to find the solution and understand the problem deeper. It needed everyone's collaboration.

Interdependent… Connective… (G2)

We were encouraged to use our Sketchnoting (Visual storytelling and note-taking) *and writing to create our perspectives and bring meanings to our learning… By working in the team, working with other teams, discussing ideating, and reflecting, things gradually became different. We started to listen carefully to each other's ideas... Together they would make more sense. My team and other teams help us see things from a new perspective. Our debates, discussion, reflection, and group reporting gradually changed us. We gradually changed, and it was easier to admit that. We found that we can connect our design learning and perspectives to technological literacy reframing and perspectives. We could understand both of them better. Each of the members (after going through some confusion at the beginning) became a unique storyteller and thinker who had our perspectives but also shared a group and more holistic visions). Surprisingly, we started to find new angles to face new challenges and got more comfortable rethinking and readjusting our ways of questioning and learning new and challenging subjects.*

We found out that while mistakes are inevitable, as a group, our mistakes would start a different set of discussions and activities, and we would come out of them with better perspectives and at a time with better questions and more inclusive perspectives and ideas.

Self-Directed… Endeavoring…(G2)

*We started to ask for new problems… we are not only fearless, but we are curious to face new things, challenge our ideas and perspectives, and even if we do not solve the problem, we are sure that we would have useful ideations, learning, and most importantly we would create great questions. The instructor always said, "*The important thing is never to stop asking questions!*" He told us that it was something Einstein said. We looked for other things that Einstein said and kept more interested in how and what great minds would engage in problems and challenges.*

Reflexive… Adaptive…G2

In the end, do we like the experience and, in many ways, [did it] changed us? Yes, and at times no....but the experience, the learning, the changes of perspectives, the teamwork, the collaborations, the thinking, rethinking, and expanding our ideas were amazing. It would not be possible without the unique setup of the class that was not threatening us with grades but was encouraging us to be fluid, brave, and learn from our mistakes...YES, memories, the process, the struggle, the transformation, and the shared journeys in an open, encouraging environment were our true values.

Adaptive… Inquisitive… (G3)

We all started to get used to being out of our comfort zones. We just kept playing, ideating, thinking, and approaching problems differently. However, we thought that challenge made us see differently and, at the time, made us have a more open-minded approach to finding new angles, even if we were not comfortable... This happened to us when working together.

1. *What are the basics of locomotives and locomotion? We had to think about this from the first days of trains to modern times. We understood the importance of the steam engine and how it worked to create linear motion in trains.*
2. *How do we create power? We started with basic ideas of power generation, how to create electricity in the lab and the city?*
3. *Then we looked at nuclear power. How is that done? What are the dangers and the benefits?*
4. *Finally, were even looked at "how do we detect if a country or a state is developing their nuclear arsenals?"*

Purpose Driven… Adaptive… (G3)

We started to be challenged, had difficulties, and had a very focused perspective. We ended up being better thinkers, better analyzers, and better team players and became confident that we would be able to change our ways of thinking and learning. We will be able to make sense of the most difficult ideas. We changed our ways, perspectives, and "beliefs" that we would not like to explore new ideas. We learned how to learn, relearn, change our approaches, and value diversity of perspectives to create better questions.

Interdependent… (G3)

We all remember the teamwork, the struggles that we shared, the reviews/presentations that we did for our projects and getting feedback from other teams that changed our thinking and made us better thinkers and more critical in our approaches.

A. Engaging and Recognizing Self-Growth

What this students' story relates is set of reflective tales of self-growth [4], and the repeated admission of intentionally embracing numbers of E/C virtues. This rich exemplar shows students not only embracing representative E/C dispositions, but also developing in virtue: embracing the knowledge, behavior and emotion/motivation of related E/C virtues [24]. These reflections expressed the impact of self-transformation, a shaping of value.

Reflection allowed these learners to focus on their experience and connect the processes of learning to their (sometimes new) ways of thinking[41]. To reach metacognition, the process of reflection includes critical thinking (which is a process of thinking about thinking)[4][39]. The culture of reflection and reflecting in constructive process has been encouraged by many scholars[1][4][39][40][41][42]. Reflections are activities that can lead the thinkers into more in

depth engagements with knowledge, experience, and deep thinking.

The framing of learning about the growth of the learner in competence and virtue sets up not just their acknowledgement of professional ethics, but rather their experience of being ethical as learners and nascent professionals. The transcript comes from an environment that allowed these students to safely question and reflect on their dispositional beliefs relative to their future professions (*e.g.,* [4][9][18]). Their words show how they experienced the ethical nature of engineering work. These ethical perspectives presented themselves at all levels of framing questions that connect goodness to action: The good of the product (*e.g.*, *nuclear power*), the good of the process (*e.g.*, '*supported each other to be critical…*') and the good of the person (*e.g.*, '*We gradually changed*…').

VI. Discussion

Competency development is not just a judgement that the work product performs well. It embraces learner intentionality. How did the engineer(s) learn from their (individual and collective) mistakes? In this type of contextual learning there is a difference between a mistake made and a mistake knowingly avoided – the ability to recognize the missed value. That avoidance action then becomes the action in future. Competence, like virtue, embraces these forms of learning, as well as dispositions toward the virtues of temperance and fortitude.

Competence reflects our judgment on the values that we expect of the engineer, reflected through how they go about engineering. Yet it is in the engineers that the connection between the goodness of the engineering in the goodness of the engineer meet. This happens through agency, where the person reflects the values of the engineering and computing profession in how they accomplish, how they apply good engineering. Essential to this exploration is a the three-fold distinction among the *goodness of engineering* as it is conducted, the *goodness of the engineering product*, and the *goodness of the engineer* conceiving, designing, implementing and/or making operational the product.

Herein lay the connection between the nature of competency as learned/developed in engineering and computing degree programs, and what is termed 'virtue ethics.' When considered *in toto*, having this (or any) marker for goodness provides a bridge between ethics and the actual business of professionally conducted engineering, and consequently the development of a competent, professional engineer/computing (E/C) professional. Because of professional values, and particularly their integral part reflected in competencies, 'virtuous' engineering becomes essential to the education of competent engineers. As recommended in Fowers, et al [24], there remains a rich body of research questions to explore how the science of virtue connects to engineering and computing education.

VII. Implications for Engineering Education

At the heart of competency and virtue-based E/C education is to guide E/C students to becoming leaders in problem solving, problem defining, with a professional and ethical understanding of their disciplinary mission. Consequently educators should embrace disposition development to compliment cognitive domain learning, particularly in defending the value of varied learning experiences[3][44]. Educators should actively facilitate student's success by providing constructive, empathetic, systematic, and well-planned process for the students to find who they are, how to learn the subject, and find their ways in owning their education[42]. This requires a different approach, one that embraces more than cognitive learning and the social aspects of learning and value formation (*e.g.,* [1][15][38]).

In engineering, and in other professional fields, one of the challenges is what, and to what level and depth should educators "teach". With content-packed curricula, the pressure in technical classes to cover all the material negatively impacts affective student development, with at least these three potential detriments:

1. The perceived overvaluing of technical content forces students to become mostly technically focused learners. More well-balanced learners will have better understanding of their fields, and their connection to values and the socio-technical and socio-economical aspects of life and their purpose.
2. The burden of learning is individually on the shoulders of the students. The challenge from education perspective is embracing the social (interdependent) nature of learning. The need is for technical material to be collaboratively absorbed/learned with meaningful individual competency development.
3. Grade pressure does not allow most students to engage in shaping and informing their attitudes and values. Disposition development warrants different approaches, challenging students to reflect on their learning with deeper connections to their values and virtues of becoming professionals and lifelong learners.

With these types of detriments, it is significantly harder to form well rounded E/C professionals with the broad characteristics that are desired of educated members of the society, and more particularly impair the ability of an educational program to help students to develop the virtues that are desired for empowered learners and competent E/C professionals. These issues suggest that further study of virtue formation approaches is warranted, particularly with research questions that explore the relationships between the affective aspects of disposition and their impact on student learning.

VIII. Conclusions and Next Steps

This work suggests that competence and virtue in the professions are connected, and that integrating these into the learning goals and program methods requires stepping beyond cognitive approaches to E/C education. Providing complementary perspectives in the process of students' growth, their development of self-efficacies, values, confidence, are significant parts of their journeys toward becoming professional and contributing members of the society and are essential for engineering and computing education. As educators, we hope our students would be successful in creating new ways of solving problems and addressing more important problems in the future for the betterment of humanity. With such a sacred and difficult mission, they need to have a better understanding of their roles as agents of change, with technical, social, and ethical responsibilities and virtues.

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