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Adopting Competency Mindful of Professionalism in Baccalaureate Computing Curricula

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Abstract

While in this 21st century computing artefacts regularly influence the exercise of judgement and decision-making, computing baccalaureates remain largely absorbed in the "what" and the "how" of computation with a limited emphasis on the "why." Computing is reshaping social structures and interrelationships through waves of innovation and disruption that span the micro and macro scales of human activity. The "why" demands more attention than ever. While laying a foundation for the graduates' livelihood remains essential, computing educating must also nurture a professionalism mindful of the social impacts and consequences of their handiwork. The Computing Curricula 2020 Project (CC2020) proposes a baccalaureate philosophy that expands and emphasizes computing proficiency aligned with career paths in industry while promoting a curricular architecture that explicitly nurtures behaviors indicative of ethical and social responsibility. The instrument of CC2020's initiative is competency, a model of knowledge skillfully applied in task while disposed to an ethic of professionalism. Although competency is a familiar term in a variety of clinical and vocational contexts, only recently have computing curricula explored its relevance to baccalaureate education. A competency articulates (1) a task made actionable by combining elements of (2) knowledge, (3) skills, and (4) dispositions. CC2020's conception of competency defines a disposition as an inclination toward principled behavior that conditions choices and frames the subsequent assessment of conduct in professional practice. This paper outlines CC2020's rationale and strategy for integrating competency in curricula and reflects upon the significance of the transformative potential of competency on baccalaureate computing education.

Keywords: Competency, Computing, Baccalaureate Curriculum, Knowledge, Skills, Disposition, Assessment

1. INTRODUCTION

For at least the last five decades the predominant model for describing baccalaureate computing curriculum guidelines has focused on the "what" of computing technology and the "how" of applying that technology to "solving" problems. Those problems are always framed by the context of application in some social domain (e.g. business, medicine, engineering, or government). During the last half century of computing's evolution as an academic discipline that model of "what" and "how" has served well by aiming very often at one-for-one augmentation of humanly performed

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computation. In that role artefacts of computing act primarily as mechanical prostheses applied to computational endeavors. Until just recently computing curricula have been framed almost exclusively within that paradigm as knowledge and skills (Shackelford, R., McGettrick, A., Sloan, R., Topi, H., Davies, G., Kamali, R., Cross, J., Impagliazzo, J., LeBlanc, R., & Lunt, B., 2005; Topi, 2017b; IT2017, 2017).

As computing advances in the 21st century, the consequent complexity, significance, and social impact of the applications to which computing technology is now applied have compounded immensely. More and more often computing applications are instrumental in decision making. In some cases, they are responsible for delivering the default or at least the initial decision in time-sensitive, quality-of-life circumstances. In other cases, they shape the interpretation of information that guides economic behavior and governmental policy. For that reason, computing professionals and their education must attend to a more comprehensive appreciation of the consequences of their design choices. Creating artefacts that may, nay will, impact society far and wide requires educated computing practitioners who exercise their knowledge and skills with a clear understanding of their purpose and a sense of due diligence and responsibility for the implications of their handiwork. As professionals their conduct should honor and reflect ethics and social responsibility.

The Computing Curricula 2020 Project (CC2020) is an international coalition of computing societies led by ACM and IEEE in a four-year project to catalog and assess the worldwide state of baccalaureate computing education. (See www.cc2020.net.) Key to CC2020's mission is architecting a transition from the traditional model for computing curriculum specification (KA-KU-LO: knowledge areas, knowledge units, and learning outcomes) to a richer, more expansive model of baccalaureate education attuned to entry into the computing professions. The instrument of CC2020's mission is competency, a model of knowledge skillfully applied in task and disposed to an ethic of professionalism. CC2020's commitment to competency acknowledges an urgency to accommodate career preparedness as intrinsic to baccalaureate student learning aligned with standards of professional practice. In this regard, CC2020's attentiveness to disposition's role in competency is analogous to that of various clinical and vocational communities (Heath, 1998, Johns, 1995).

This paper outlines three key areas of consideration that illustrate the breadth of concerns with which CC2020's commitment to competency aligns. 1) The most common pursuit of baccalaureate studies in computing education is undertaken as preparation for livelihood, a job. 2) Complementarily, employers seeking to fill job openings have a rightful interest in knowing what capabilities can be expected in graduates of a particular baccalaureate program. 3) The caliber of a practicing professional is an amalgam of technological acumen, empathy, and the efficacy of their services or products gauged by their clients in a particular societal context: individually, in community, or across society. The sections below explore these key areas of concern and explain how the CC2020 model of competency addresses each. The discourse concludes with some summary observations of CC2020's competency mission and the role of competency in comparing and visualizing computing curricula. In a final reflection, the authors assert the imperative for a comprehensive investment in competency-based computing education in the face of the unabating expansion and impact of computing on society.

2. A FIFTY-YEAR LEGACY OF COMPUTING CURRICULUM GUIDELINES

Over the past five decades professional computing societies have developed guidelines to chart a course for computing education in baccalaureate degree-granting institutions. To some extent, these guidelines categorize the various communities of practicing professionals (Longenecker, Feinstein & Babb, 2013). Sub-disciplines of computing have generally evolved independently creating diverse areas of computing, de facto silos. Although most subdisciplines share significant concepts of theory, technology, methodology, and professional practice, they have not always adopted the same vocabulary or taxonomy.

The traditional sub-disciplines of computing are codified in the series of baccalaureate level, curriculum guidelines published under the sponsorship of ACM and IEEE with various partners (including AIS and EDSIG). Among these are: Computer Engineering (2004, 2016), Computer Science (2001, 2008, 2013), Information Systems (1997, 2002, 2006, 2010), Information Technology (2008, 2017), Software Engineering (2004, 2014), and Cybersecurity (2017). (All the guidelines are available at www.acm.org/education/curricula-recommendations.) Efforts are underway as of this writing for new and/or updated

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sub-discipline guidelines in the areas of data science, artificial intelligence, and information systems.

3. COMPETENCY ALIGNED WITH VOCATION

Consistently curriculum guidelines for computing education have first and foremost identified areas of knowledge composed of facts based upon scientific derivation and proof ascribed to a technically-rational epistemology (Waguespack, 2019, p. 31). A fact-based epistemology ("knowing what") naturally appeals to objective, categorical assessment: *true* or *false*, *right* or *wrong*. Knowledge-centric curricula align with a technically-rational model of pedagogy (Simon, 1996). Other knowledge ("knowing how") emerges from professional practice where experience has demonstrated techniques reasonably effective for achieving practicable objectives in software/systems development or support. As a practice-based epistemology ("knowing how") it tends to be more effectively approached as skill assessed subjectively in situational performance: *effective* or *ineffective*, *reliable* or *unreliable*. The juxtaposition of learning founded upon an epistemology that is fact-based as opposed to one that is practice-based might be described as the breadth and depth dimensions of "knowing."

Computing curricula aspire to prescribe the breadth *and* depth of "knowing." Generally, the breadth aspect delineates the scope of knowledge topics to be learned while the depth aspect entails a grasp or command of engaging that learning in a task in order to achieve intended outcomes. Typically, those outcomes reflect degrees of sophistication in "knowing how" to engage "knowing what" which in turn are commensurate with standards of skilled practice. This concept, *degree of sophistication*, as a product of learning is well studied in education research; the most widely respected theory in this regard is rooted in Bloom's taxonomy (Bloom & Krathwohl, 1956; Dave, 1970; Harrow, 1972; Krathwohl, Bloom & Bertram, 1973; Wiggins, McTighe & Ebrary, 2005). The most recent evolution of this theory is Bloom's (Revised) Taxonomy (Anderson & Krathwohl, 2001).

Bloom's levels of cognitive process depict a quality of "knowing how" fused with "knowing what." Each of the six levels of Bloom's articulates an accumulated adeptness for engaging knowledge. Each level is labeled with an action verb that exemplifies a degree of sophistication in engaging knowledge: *remember*, *understand*, *apply*, *analyze*, *evaluate*, *create*. Appendix A lists a set of synonyms for each action verb. Each of those six lists enumerates verbs that connote the command or grasp of relevance, the skillfulness ("knowing how") necessary to effectively engage ("knowing what") in achieving a specific task. Thus, Bloom's levels articulate the interwoven effect of knowledge and skill, two observable aspects of competency, that fuse in the performance of a task. These two aspects interweave a framework of design and assessment in computing pedagogy that underpins both instruction and learning. However, while the cognitive domain proposed by Bloom has achieved substantial currency, the affective domain and in particular, the motivational dimension, has not received commensurate attention. It is in the combination of the cognitive and the affective that competencies should be defined, experienced, and assessed with respect to professional practice.

Learning outcomes have become a standard approach for gauging student learning (USDoE, 2018). However, learning outcomes are often difficult to specify above the lower levels of Bloom's (i.e. remembering or understanding) and therefore may not explicitly draw out sophisticated performance. CC2020's adoption of competency reflects the premise that observable degrees of professionalism require commensurate degrees of sophistication in task performance. This entails engaging knowledge in specific tasks both for purposes of instruction as well as assessment to leverage the affective domain and expose the motivation that leads to choices reflective of professional behavior. And thus, competency enfolds more than the bodies of isolated knowledge and skills that have dominated our educational terrain as it also incorporates a third, affective aspect of practice that is "knowing why."

4. COMPETENCY ALIGNED WITH EMPLOYMENT AND INDUSTRY

While the knowledge and skill aspects of competency serve the purposes of designing pedagogy and educating professional computing practitioners, they also provide a framework for communication and collaboration between academia and industry. It is well-reported that there is a burgeoning demand for technology-savvy job applicants as computing's role in commerce, government, and society in general continues to expand. The job advertisements are replete with openings for applicants possessing a variety of computing skills. Employers frequently identify specific technologies or general knowledge areas (e.g. networking, cloud computing, systems analysis, and database). It is however, the capacity to apply their knowledge of these technologies,

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the skill factor, that represents the value of the graduate that is foremost in the employers' minds. This is clearly evidenced by the corresponding requirements for years-of-experience as a proxy term for practical, demonstrated skill. Employers are seeking individuals who can apply their knowledge of computing technology in specific, commercial tasks and with a level of prudence evidencing a professional insight.

CC2020's definition of competency offers the potential for mutually consistent specifications of practitioner competency: relating attributes possessed by an applicant to those required by an employer. To the extent that specification standardization is achieved between curricular competency and employer job description there can be significant mutual benefit. Institutions of computing education can clearly describe their graduates' capabilities while employers can clearly communicate their functional job requirements. In such a circumstance the computing educators would have the opportunity to weigh their pedagogy against industry needs. Congruently, human resource activities in industry could identify likely institutional sources of qualified graduates as prospective applicants.

Competency offers a contextualized model through which communication of practitioner capabilities of graduates can be realized. This in turn better serves the coordination and collaboration among institutions of computing education along with the human resource activities of industry. Furthermore, this model may better facilitate advising prospective students who wish to align their studies with clearly described employment opportunities. All the while such a collaboration can influence curricula in educational programs by providing a better understanding of job markets they may wish to serve. In any case, specific competency descriptors offer a facilitating bridge in the dialog between academia and industry locally, nationally, and internationally.

The explicit fusion of knowledge and skills adopted in CC2020 emphasizes the role of practice in the process of demonstrating "knowing" (Wiggins, 2005, 2011). Enhancing the existing learning outcomes approach, which has been a prominent feature of curricular description, competency's fusion of knowledge and skills advocates for an explicit goal of crystalizing the dimensions of practical professional capability in curriculum description. The intrinsic role of task in both pedagogy and assessment provides a natural opportunity for an explicit articulation of the interdependence of curriculum and employability.

5. COMPETENCY ALIGNED WITH THE BROADER COMMUNITIES OF PROFESSION AND SOCIETY

"Rather than just entrée to a job, a baccalaureate degree should be the launchpad to a career!"
(Anonymous admissions officer)

From a vocational standpoint a baccalaureate computing degree, as a baseline, should focus on instilling the knowledge and skills that will qualify graduates for gainful employment. But equally important (many employers would say "more so") to become professionally mature, those graduates also need to internalize a professional mindset. That involves an informed attentiveness to the task context that includes the ethical and cultural considerations necessary to apply their knowledge and skills in service to their community. The description and formation of that mindset underpins our discourse on the concept of disposition.

Human behavior emerges not only formed by knowledge and skills but also influenced by intellectual, social, and moral predilections or tendencies that reveal themselves under certain conditions (Perkins & Tishman, 2006). Hence as a component of a competency description, a disposition addresses a "readiness to act overtly in a specific fashion whenever opportunity is presented" (Dewey, 1926). This could be summarized as an *enacted* value, skill and knowledge applied in a particular setting because the agent (actor) manifests that value through their action. In this interpretation of volition, the actor is always judging both the need for action, and the better action to perform or not perform. In the context of a computing competency, this should always involve the purposeful application of computing knowledge; knowledge judged to be reasonable in that particular situation informed by a conscious intent. In a fine-grained scope of competency, the substance of a disposition might focus upon conditions of the feasibility, efficacy, or correctness of practice. In a broader domain, the theme of disposition may be more reflective of an overarching attitude toward professional or social conduct. It is this latter orientation that the CC2020 project is encouraging as the aspect of character in the model of computing competency: knowledge, skills, and dispositions (Frezza, Daniels, Pears, Cajander, Kann, Amanpreet, McDermott, Peters, Sabin, Wallace, C., 2018). CC2020's aspiration is to enable and encourage curriculum designers to reflect upon the mindset they believe should imbue their graduates' behavior as a competent professional. Curriculum designers should

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be forthright in reflecting upon their culture of instruction and learning, the profession(s) their program envisages, the enfolding social context of computing practice, and hopefully, the faculty and administration's overarching commitment to ethics and social responsibility. Designing and engaging computing artefacts should entail an attitude of professionalism that is conscious of the responsibility to contribute to society's well-being through an agency as individuals, professionals, and organizations. (Appendix B lists candidate dispositions relevant to professional conduct.)

6. THE PERMEATING AND EMERGENT NATURE OF DISPOSITION

The meta-language of competency, "knowing what," "knowing how," and "knowing why," criss-crosses domains of scientific fact, practiced behavior, and cultural norms. Scientific (technically-rational) fact and practiced behavior lend themselves to a categorical assessment: true or false, present or absent, consistent or inconsistent, it works or it doesn't. Dispositions enfold intellectual, social, and moral predilections or tendencies that influence behaviors that do not lend themselves as easily to a categorical assessment. These predilections reflect value judgements that are not amenable to scientific proof. Values may differ or be held differently among individuals or cultures. And, value judgements are also often mutable over time - affected by the experience of practice! Vickers has described the confluent influence of dispositions as the agency of *Appreciative Systems* (Vickers, 1983; Checkland, 1986).

An appreciative system is a complex and emergent agency of choice in behavior situated in a social context. A [practitioner's] appreciative system cues what facts to attend to in any particular experience while that same experience results in a learning effect that informs, reinforces and/or refines the [practitioner's] apprehension of value and significance, thus altering that appreciative system. (Waguespack, 2019, p 27)

Dispositions motivate or incline the practitioner's discernment and skillful engagement of knowledge to demonstrate a desired character or quality in the task's completion. Specific to the task at hand dispositions exert a modifying or controlling influence on a practitioner's choices by proposing or projecting a desirable quality onto the outcome. A disposition's agency in competency complements a practitioner's capabilities to discern a task as "*professionally accomplished*" rather than only "*completed*."

In the context of describing competencies, dispositions can be thought of as mediating professionally applied knowledge and skills. Here mediation could be thought of as the "extent that it accounts for the relation between the predictor and the criterion" (Baron and Kenny, 1986) in that dispositions connect the 'better' or 'correct' application of knowledge and skill to the context in which they are applied. Dispositions coupled to fine-grained competencies will likely adhere to objective aspects of quality (e.g. correctness or accuracy). Examples might be exacting conformance to guidelines, protocols, or any number of quantifiable parameters. Characteristics associated with more complex competencies (e.g. systems with direct human interface, artefacts intended for convenience or intuitive simplicity) will likely adhere to more subjective and thus more client-centric interpretations of quality (e.g. convenience, reliability, transparency, intuitiveness, user-friendliness).

In the broader cultural domains, dispositions may assert positions regarding virtually any desirable quality that motivates human behavior (e.g. ethics, integrity, empathy, accountability, honesty, respectfulness). But in the end, the import of disposition is ultimately realized through individual persons applying their knowledge and skills, through their behavior – individuals leveraging their intellect through responsible decisions and actions (Gray, 2015). In this applied context, dispositions incline enacted virtues that reflect the values expressed by the actor through their choices, decisions, and actions (Annas, 2011).

The concept of enacted virtues forms a basis for crafting language for describing dispositions that mediate the knowledge and skills of competency. A rich set of examples can be found in (Gray, 2015) in an examination of Virtue Ethics and their relationship to the ethical commitment of Information System workers in trusted positions. Gray's work explores four virtue ethics information systems security (ISS) constructs: *Astuteness, Conviction, Rectitude* and *Self-Discipline*. (Gray, 2015). Consider Astuteness.

Astuteness: Skill in making assessments and in the application of professional knowledge, experience, understanding, common sense, or insight in regards to information system security. (Gray, 2015, p.66).

Gray (Gray, 2015) presents ISS Astuteness as a construct derived from the more general virtue of prudence. In a proper sense, Astuteness is what would be called a "neutral virtue" (Annas, 2011)

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because as a disposition, it is necessarily consequential in its application. The cycle of assessment and application implied by disposition will vary with the interpretation of "goodness" in differing situations. While this may raise a question of aptness in the use of the term 'virtue', this makes Astuteness an excellent disposition in the critical study of ISS competency. Similarly, generalizing beyond the ISS-specific skills and knowledge being applied, astuteness could be equally applied to many professional computing contexts.

In summation, a disposition as an intrinsic component of competency represents both an opportunity and a challenge for curriculum designers: the opportunity to clearly express institutional and programmatic values, and the challenge to eschew "apple pie" and "motherhood," indistinct platitudes that are difficult to operationalize in the description/assessment of competency and/or the related pedagogy. Ascribing a disposition to a competency rightfully demands a clear institutional commitment to self-reflection and a sober examination of institutional mission, goals, and objectives to reach the clarity that enables its effective integration in curriculum design and the agency of pedagogy. Appendix C represents one approach to naming desirable professional attributes and dispositions for educators with example guidance for assessing a degree of accord or compliance to each element. In the realm of professional societies, the ACM Code of Ethics and Professional Responsibilities offers prime examples of overarching dispositions for the computing profession (ACM, 2018). (See Appendix D for a synopsis of the ACM Code.)

7. ANCILLARY COMPETENCIES

Although the disciplinary context of this discourse is dedicated to articulating computing curricula, computing topics alone will not suffice to prepare graduates for practice as professionals. Indeed, computing competencies distinguish computing professionals among professionals, but there are many competencies other than computing that are elemental to most professions. These shared competencies well deserve careful delineation in computing programs as they are integral to comprehending and succeeding in the full scope of challenges endemic to professional practice.

There are competencies foundational to professional conduct that are apposite to the individual (e.g., basic academic literacy in: mathematics, physical sciences, language, and social sciences; effective communication in written, spoken, and presentational mediums; self-management of time, decorum, protocols; and many others.). Although in depth study in any of these areas of competency may be appropriate in particular programs, basic ancillary competencies might reasonably be expected to be learned through primary or secondary education prior to baccalaureate studies. Regardless, these elements of personally manifested competency are essential to achieving success in professional culture. Ancillary competencies require notice and a degree of stipulation in the baccalaureate curriculum.

8. COMPETENCY IN COLLABORATION WITH APPLICATION DOMAIN DISCIPLINES

The grammar of competency comprises four constructs: a) tasks, b) knowledge, c) skills, and d) dispositions. Competency is always manifest situated in the context of a task, a purposeful and skilled application of knowledge mediated by dispositions. Like competency, context is a "telescopic" concept – it may be observed micro or macro. Every computing artefact resides within some social context; that is, each serves some human intension of an individual or of a community (and often of both!). The features or characteristics of that social context are emphatically relevant to the choices the computing professional is faced with to be adjudged as appropriate or not. To make appropriate choices a professional must possess both ancillary and application domain competencies that complement those that are specifically computing. To benefit prospective students, employers, legislators, and the citizen electorate, computing curriculum guidelines should be as explicit as possible about the ancillary and application domain competencies promulgated programmatically.

Although computing programs variously focused exclusively on technology for software development (i.e. coding bootcamps and academies) have proliferated over the last decade (Waguespack, Babb & Yates, 2018), it should be normative for baccalaureate programs in computing to include requirements for application domain competencies that inform the prospective professional's domain of practice. Cultural or societal contexts may also suggest appropriate competencies: governmental, not-for-profit, nonprofit, domestic, international, etc.

Among the common application domains are business (Topi, 2017a, 2017b), medicine, engineering, transportation, entertainment, etc. There are many subdisciplines; some are Computing + x and others are x + Computing where "x's" position indicates whether "x" the primary disciplinary focus or it is computing's application domain. For example, the computing subdiscipline of information systems itself has numerous derivatives, x-IS programs, (e.g. accounting information systems, marketing-IS, finance-IS, medical-IS, …). Each of these x-IS programs is a discipline in its own right augmented with computing. Any delineated domain of application entails particulars of knowledge, skills, and perhaps, distinctive dispositions instrumental to making informed, astute choices that skillfully apply knowledge in artefact design and engagement.

9. DIGITIZING COMPETENCIES

The evolution of computing education chronicles the emergent diversity of computing disciplines by identifying the relevant tasks and their nominal domains of practice (i.e. computer science, information systems, software engineering, computer engineering, information technology, and lately cybersecurity and data science). Each of these disciplines is evolving to more thoroughly study a domain of practice in computing. This natural proliferation of computing subdisciplines and domain-oriented programs has both benefitted and challenged curriculum developers. This subdividing of focus has expanded and spread the impact of computing into almost every area of human interest. Among the challenges accompanying this expanding impact is the proliferation and the divergence of vocabulary and taxonomy. This phenomenon is exacerbated by the necessary translation of terms across subdisciplines, cultures, and native languages.

CC2020 cannot fully reconcile these derivative dialects in this project. However, CC2020 is committed to an online toolset that graphically represents and compares curricula. This automation offers an opportunity to advance the normalization of disciplinary terminology (Waguespack & Babb, 2019). CC2020 is prototyping automation to gather and digitize the knowledge and skills specifications of extant curricula in order to populate a repository of terms and synonyms that will support the study of current curricula and facilitate authoring future curricular specifications that will include competency. The curating of computing terminology and taxonomy is a key capability in the feature suite of this repository. Table 1 synopsizes the CDKST, a set theoretic model, that underpins the repository's design (Waguespack & Babb, 2019). See Appendix E that recounts the derivation of CDKST that supports the repository of digitized competency entries (Waguespack & Babb, 2019).

The competency repository relies on taxonomies of knowledge and skill concepts semitonically ordered to populate a competency-based definition of curriculum that enables a graphical representation in cartesian space. Semiotic theory stipulates an organization formed by relationships of concomitance among concepts (i.e. synonymy, adjacency and sequence) (Liu, 2000; Stamper, 1973, 1991).

Table 1 - CDKST Model of Curriculum

C competency, demonstrable capability
T task, a purposeful action in context
$K_i \in \mathbf{K}$ knowledge elements: "what"
$S_j \in \mathbf{S}$ level of skilled application: "how"
$D_k \in \mathbf{D}$ disposition, enacted value: "why"

T = task
$\mathbf{T} \dashrightarrow \{(K_i,S_j) \mid K_i \in \mathbf{K}, S_j \in \mathbf{S}\}$
knowledge used at a level of skill

[A task is skillfully applied knowledge engaged in a purposeful act.]

C = competency
$\mathbf{C} \dashrightarrow \{(\Sigma(K_i,S_j) \mid (K_i,S_j) \in \mathbf{T}), D_k \in \mathbf{D}\}$
[Competency is a demonstrable capacity to skillfully apply knowledge that achieves a valued outcome in a situated task mediated by dispositions.]

E = educational program
$\mathbf{E} \dashrightarrow \{C_i\}$
[An educational program is the cumulation of competencies that comprise it.]

B = baccalaureate degree
$\mathbf{B}_e \dashrightarrow \{\Sigma(C_i) \mid C_i \in E\}$
[A baccalaureate is the cumulation of the assessments constituting an educational program.]

J = job description
$\mathbf{J} \dashrightarrow \{C_i\}$
[A job description is the cumulation of competencies defining that job's responsibilities.]

JP = job permit
$\mathbf{JP}_j \dashrightarrow \{\Sigma(C_i) \mid C_i \in \mathbf{J}\}$
[A job permit is the cumulation of competencies assessed that certify job competency.]

P = profession
$\mathbf{P} \dashrightarrow \{J_i\}$
[A profession is the cumulation of job competencies that define it.]

L = professional license
$\mathbf{L}_p \dashrightarrow \{\Sigma(J_i) \mid J_i \in \mathbf{P}\}$
[A professional license is the cumulation of assessed job competency that certifies a profession.]

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Figure 1 represents in concept the repository's CDKST-based structure.

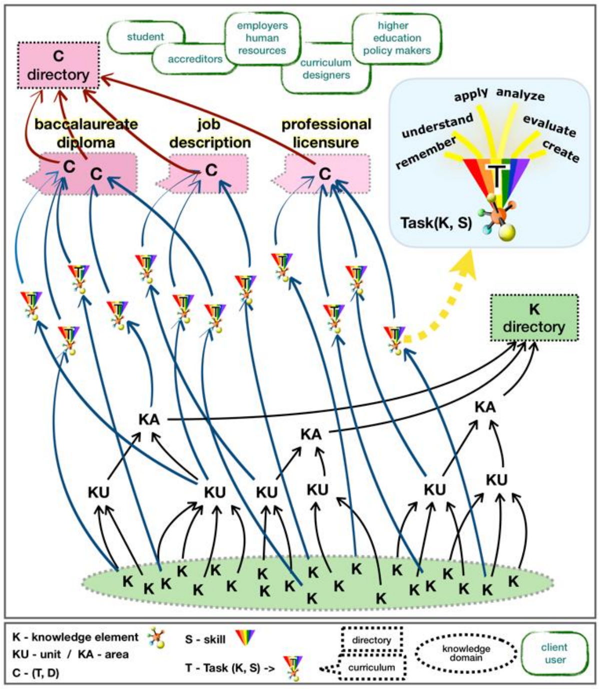

Figure 1 – CDKST Curriculum Framework

10. Summary

This paper explores the rationale and motivation for CC2020's commitment to craft and promulgate a model of competency for describing baccalaureate computing curricula. CDKST's purpose is to frame a synthetic understanding of the objective and subjective aspects of competencies that are situated in the imperatives and compulsions of professional practice. The CDKST modeling framework delineates the embedded elements of action – tasks, skills, knowledge, and dispositions – to facilitate our systematic understanding of competencies in the professional practice of computing. The repository is a natural consequence of adopting CDKST as a platform for analysis and formulation of curricular designs. CC2020's competency initiative represents a significant departure from and extensive benefits beyond the traditional KA-KU-LO model focused almost exclusively on knowledge and skill.

We recognize the serious investment that a comprehensive adoption of competency entails in curriculum design. However, we are confident that the resulting benefits will fully eclipse the cost of resources and labor required. Visualization, comparability, and interoperability even contemplated individually are game changing capabilities for advancing computing curriculum design.

11. Reflection

The genesis of this discourse has been the quest for a computation-friendly model that supports comparison and visualization of competency-based curriculum descriptions. That quest has rendered definitions, models, and elements for digitization. But coincident in this quest, has been the renewed acknowledgement of computing's agency as a formative force in the evolution of civilization in the 21st century. That agency is characterized by the intrinsically disruptive nature of computing as an alchemy of invention. Computing's history has disrupted the nature of information. Computing's future promises to disrupt the nature of judgement. Competency and the essential agency of disposition are crucial to the trajectory of computing's impact on the future of society. Thus, in reflection, we herein retrace the path through this discourse, examining the steps with a critical eye on the future of computing that argues in favor of competency as the quintessential building block for baccalaureate curriculum description.

We articulate a philosophical, ontological, and epistemological orientation for comprehending computing curricula founded upon a competency model defined by Computing Curricula 2020. This conclusion is guided by the substantive and indelible impact of computing as a discipline chronicled in decades of curricular reflection and theorizing.

Computing, as a leverage of human ingenuity, has proven to be as irreversibly disruptive as was the harness of fire and water, the advent of agriculture, the crafting of tools from the elements of the earth, and the mastery of natural phenomena and resources to power our machines. In this spirit, we consider competency as it envelops, in a formulation balancing action-taking, problem-solving, problem-setting, and repertoire development, the requisite and normative aspects of an essential element of our world: the yields of computing.

Computing's history is a trajectory of emergent tasks and skills that chronicles a saga of pioneering, discovery, and boundary testing. As such, the further computing extends facets of human endeavor, the deeper is our collective understanding of computing as a phenomenon unto itself; a discipline worthy of research, academic organization, professionalization, advocacy, and regulation.

With that gravity of computing's impacts in mind, we espouse a competency framework to further the maturation of understanding the nature of

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computing commensurate with its impact on human activity. Further and beyond articulating "why," a competency model should widen the channels of concern that focus on "ought." Enshrined in the "ought" is a responsibility to normalize and shape the mindfulness of the purveyors of computing's impacts.

The future ushered in by computing rests in the stewardship of the computing academy and the professional societies who moderate the search for answers to these questions:

a) what "could" (and could not) be done with computing's capabilities,
b) what "ought" (and ought not) be done with computing,
c) who will wield the competency to assist in reckoning between these poles, and
d) who is the computing professional who accedes to the mantle of continuously seeking the "why" in balance with the "can we, should we, ought we" in search of the solutions to which computing is suited to facilitate?

A competency model can help. No unified curriculum model could provide a one-size-fits-all prescription for the balance required, but perhaps a competency-oriented framework can serve as a compass.

If the academy serves at the pleasure of its stakeholders and constituents, as a nexus of disciplinary research, knowledge, and pedagogy, then let the academy act as a resource for the general development of the human condition. Aligning a computing curriculum framework with competency is an opportunity that may assist in the maturation of the computing disciplines; and dispose them to accept and promote the need for leadership and responsibility to steward the continued professionalization of the computing disciplines.

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Appendix A – Revised Bloom's Taxonomy Action Verbs Along the Cognitive Process Dimension

(Anderson & Krathwohl, 2001)

Definitions	I. Remembering	II. Understanding	III. Applying	IV. Analyzing	V. Evaluating	VI. Creating
Bloom's Definition	Exhibit memory of previously learned materials by recalling facts, terms, basic concepts, and answers.	Demonstrate understanding of facts and ideas by organizing, comparing, translating, interpreting, giving descriptions, and stating main ideas.	Solve problems to new situations by applying acquired knowledge, facts, techniques and rules in a different way.	Examine and break information into parts by identifying motives or causes. Make inferences and find evidence to support generalizations.	Present and defend opinions by making judgments about information, validity of ideas, or quality of work based on a set of criteria.	Compile information together in a different way by combining elements in a new pattern or proposing alternative solutions.
Verbs	• Choose • Define • Find • How • Label • List • Match • Name • Omit • Recall • Relate • Select • Show • Spell • Tell • What • When • Where • Which • Who • Why	• Classify • Compare • Contrast • Demonstrate • Explain • Extend • Illustrate • Infer • Interpret • Outline • Relate • Rephrase • Show • Summarize • Translate	• Apply • Build • Choose • Construct • Develop • Experiment • Identify • Interview • Make use of • Model • Organize • Plan • Select • Solve • Utilize	• Analyze • Assume • Categorize • Classify • Compare • Conclusion • Contrast • Discover • Dissect • Distinguish • Divide • Examine • Function • Inference • Inspect • List • Motive • Relationships • Simplify • Survey • Take part in • Test for • Theme	• Agree • Appraise • Assess • Award • Choose • Compare • Conclude • Criteria • Criticize • Decide • Deduct • Defend • Determine • Disprove • Estimate • Evaluate • Explain • Importance • Influence • Interpret • Judge • Justify • Mark • Measure • Opinion • Perceive • Prioritize • Prove • Rate • Recommend • Rule on • Select • Support • Value	• Adapt • Build • Change • Choose • Combine • Compile • Compose • Construct • Create • Delete • Design • Develop • Discuss • Elaborate • Estimate • Formulate • Happen • Imagine • Improve • Invent • Make up • Maximize • Minimize • Modify • Original • Originate • Plan • Predict • Propose • Solution • Solve • Suppose • Test • Theory

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Appendix B – Candidate Dispositions

Disposition	*Elaboration*
Proactive	*With Initiative* (Nwokeji, Stachel, & Holmes, 2019) / *Self-Starter* (Clear, 2017) Shows independence. Ability to assess and start activities independently without needing to be told what to do. Willing to take the lead, not waiting for others to start activities or wait for instructions.
Self-Directed	*Self-motivated* (Clear, 2017) / *Self-Directed* (Nwokeji et al., 2019) Demonstrates determination to sustain efforts to continue tasks. Direction from others is not required to continue a task toward its desired ends.
Passionate	*With Passion* (Nwokeji et al., 2019), (Clear, 2017) / *Conviction* (Gray, 2015) Strongly committed to and enthusiastic about the realization of the task or goal. Makes the compelling case for the success and benefits of task, project, team or means of achieving goals.
Purpose-Driven	*Purposefully engaged / Purposefulness* (Nwokeji et al., 2019), (Clear, 2017) Goal-directed, intentionally acting and committed to achieve organizational and project goals. Reflects an attitude towards the organizational goals served by decisions, work or work products. *e.g.,* Business acumen.
Professional	*With Professionalism* / *Work ethic* (Nwokeji et al., 2019) Reflecting qualities connected with trained and skilled people: Acting honestly, with integrity, commitment, determination and dedication to what is required to achieve a task.
Responsible	*With Judgement* / *Discretion* (Nwokeji et al., 2019) / *Responsible* (Clear, 2017) / *Rectitude* (Grey, 2015) Reflect on conditions and concerns, then acting according to what is appropriate to the situation. Making responsible assessments and taking actions using professional knowledge, experience, understanding and common sense. E.g., Responsibility, Professional astuteness (Grey, 2015).
Adaptable	*Adaptable* (Nwokeji et al., 2019) / *Flexible* (Clear, 2017) / *Agile* (Weber, 2017) Ability or willingness to adjust approach in response to changing conditions or needs.
Collaborative	*Collaborative* (Weber, 2017) / *Team Player* (Clear, 2017) / *Influencing* (Nwokeji et al., 2019) Willingness to work with others; engaging appropriate involvement of other persons and organizations helpful to the task. Striving to be respectful and productive in achieving a common goal.
Responsive	*Responsive* (Weber, 2017) / *Respectful* (Clear, 2017) Reacting quickly and positively. Respecting the timing needs for communication and actions needed to achieve the goals of the work.
Meticulous	*Attentive to Detail* (Weber, 2017), (Nwokeji et al., 2019) Achieves thoroughness and accuracy when accomplishing a task through concern for relevant details.

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Appendix C – Professional Attributes and Dispositions Scale

University of Vermont
Department of Education Secondary Education Program
[http://www.uvm.edu/~mrazza/forms/attdis.pdf (current September 12, 2019)]

Attribute / Scale	1	2	3	4
PROFESSIONAL ABILITY				
Collegiality	Unable to work successfully with others	Hesitant, Reluctant to share ideas and materials	Seeks out others and is able to work successfully with others	Actively engages others, shares ideas, works well with others
Professional Ethics and Demeanor	Lacks awareness of school policies and practices	Follows school policy and practices; maintains confidentiality	Maintains high ethical and professional standards. Maintains professional appearance	Utilizes and contributes to professional organizations
Reliability Dependability	Sometimes fails to complete assigned tasks or duties	Sometimes needs to be reminded to attend to assigned tasks or duties	Responsible: Attends to assigned tasks or duties without prompting	Self-starter: Perceives needs and attends to them immediately
Interpersonal Relationships	Thoughtless: Insensitive to others' feelings & opinions	Limited sensitivity and diplomacy	Perceives what to do or say in order to maintain good relations with others & responds accordingly	Highly sensitive to others' feelings & opinions: Diplomatic
Collaboration & Teamwork	Works alone to design, develop, deliver and assess instruction, without reference to others teaching at the same subject	Aware of other parts of the school curriculum and other learning in the experience of the students	Recognizes the influence of other teachers on professional practice and cooperation with others carrying out plans	Evidence of team leadership and fellowship in the development and implementation of curriculum instruction
Attendance			Is present and engaged	Provides additional personal time
Punctuality			Always on time	Frequently arrives early
REFLECTIVE PRACTICE				
Response to Feedback	Defensive: Unreceptive to feedback	Receptive: doesn't implement suggestions	Receptive: adjusts performance accordingly	Solicits suggestions & feedback from others
Desire to Improve Teaching Performance	Makes no effort to improve teaching performance	Voices desire to improve teaching performance, effort not observable	Demonstrates efforts to improve teaching performance	Continually seeks new and better ways of teaching

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Appendix D – A Summary of the ACM Code of Ethics and Professional Responsibility

(ACM 2018, retrieved from, summarized and current July 15, 2019)

1. General Ethical Principles
   - 1.1. Contribute to society and to human well-being, acknowledging that all people are stakeholders in computing.
   - 1.2. Avoid harm.
   - 1.3. Be honest and trustworthy.
   - 1.4. Be fair and take action not to discriminate.
   - 1.5. Respect the work required to produce new ideas, inventions, creative works, and computing artifacts.
   - 1.6. Respect privacy.
   - 1.7. Honor confidentiality.
2. Professional Responsibilities
   - 2.1. Strive to achieve high quality in both the processes and products of professional work.
   - 2.2. Maintain high standards of professional competence, conduct, and ethical practice.
   - 2.3. Know and respect existing rules pertaining to professional work.
   - 2.4. Accept and provide appropriate professional review.
   - 2.5. Give comprehensive and thorough evaluations of computer systems and their impacts, including analysis of possible risks.
   - 2.6. Perform work only in areas of competence.
   - 2.7. Foster public awareness and understanding of computing, related technologies, and their consequences.
   - 2.8. Access computing and communication resources only when authorized or when compelled by the public good.
   - 2.9. Design and implement systems that are robustly and usably secure.
3. Professional Leadership Principles
   - 3.1. Ensure that the public good is the central concern during all professional computing work.
   - 3.2. Articulate, encourage acceptance of, and evaluate fulfillment of social responsibilities by members of the organization or group.
   - 3.3. Manage personnel and resources to enhance the quality of working life.
   - 3.4. Articulate, apply, and support policies and processes that reflect the principles of the Code.
   - 3.5. Create opportunities for members of the organization or group to grow as professionals.
   - 3.6. Use care when modifying or retiring systems.
   - 3.7. Recognize and take special care of systems that become integrated into the infrastructure of society.
4. Compliance with the Code
   - 4.1. Uphold, promote, and respect the principles of the Code.
   - 4.2. Treat violations of the Code as inconsistent with membership in the ACM.

Appendix E - CDKST Curriculum Framework

(adapted from Waguespack & Babb, 2019)

Competency-Dispositions-Knowledge-Skills-Task

In the following set theoretic representation, *Competency-Dispositions-Knowledge-Skills-Task* (CDKST), we adopt three grounding propositions to conceptualize curriculum: 1) learning is acquiring knowledge elements arranged taxonomically that enable satisfactorily performing relevant tasks; 2) the concept of "skill" is a degree of mastery of a knowledge element modulated by dispositions to achieve a valued outcome, and 3) a disposition denotes a value that motivates applying knowledge while designating the quality of knowing commensurate with a standard of desired performance.

A knowledge element, $K_i \in \mathbf{K}$, is a factual concept supported by science and/or professional practice that underpins a vocabulary of objects, behaviors, and relationships as the domain of interest in a discourse (be it curriculum, task, job, or profession). $S_j \in \mathbf{S}$, a skill attribute, denotes the *quality of knowing* that an accomplished learner must possess to satisfactorily apply a knowledge element in a circumstance of performance. In this sense it is the capacity to demonstrate a degree of *cognitive command* over that knowledge. In this conceptualization cognitive command is represented by Bloom's (revised) taxonomy of learning objectives: remember, understand, apply, analyze, evaluate, and create. A disposition, $D_K \in \mathbf{D}$, represents an inclination, commitment, or motivation, toward an aspect of desired behavior in practice that reflects the attitude deemed critical to satisfaction in a circumstance or context. Task, **T**, is a situated instance of engaging knowledge with a degree of mastery. **C**, competency is a demonstrated sufficiency in a task with appropriate dispositions. **C** in effect defines both the nature of the competency and the criteria of assessment that certifies in a specific task instance.

T = task
$\mathbf{T} \dashrightarrow \{(K_i,S_j) \mid K_i \in \mathbf{K}, S_j \in \mathbf{S}\}$ knowledge used at a level of skill

[A task is skillfully applied knowledge engaged in a purposeful act.]

Task, **T**, is *knowledge applied* in a "live" context to accomplish a designated purpose. **T** represents a *specification* of capability that curriculum is obligated to inculcate in the accomplished learner.

A task is the application of specific knowledge to a situation at hand. Note that tasks may be of varying complexity in terms of the range of knowledge elements engaged. Individual knowledge elements may participate in a variety of tasks. A task may be a collection of constituent tasks within which each knowledge element is applied with a distinct skill. As a collective, the task's satisfactory accomplishment demonstrates a sufficiency of knowing in the doing.

C = competency
$\mathbf{C} \dashrightarrow \{(\Sigma(K_i,S_j) \mid (K_i,S_j) \in \mathbf{T}), D_k \in \mathbf{D}\}$

[Competency is a demonstrable capacity to skillfully apply knowledge that achieves a valued outcome in a situated task mediated by dispositions.]

Competency, **C**, is the capacity to accomplish a task by applying knowledge and skills framed by one or more dispositions. This is the goal sought by a competency-based perspective on curricular design. This forms a focus for assessment as each competency represents both a requirement and the instrument of certification to assure the learner's successful performance – success denoted by the satisfactory outcome of applying the knowledge in accord or compliant with the articulated dispositions. It is reasonable to expect that a system of competency specifications would form a telescopic or hierarchical arrangement of modularized task complexity and thus, would lead to an incremental or progressive process of learning and experience accumulation that would subsequently justify advancement to more elaborate, intricate, or difficult tasks or higher degrees of desired performance.

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E = educational program

$\mathbf{E} \dashrightarrow \{C_i\}$

[An educational program is the cumulation of competencies that comprise it.]

B = baccalaureate degree

$\mathbf{B}_e \dashrightarrow \{\Sigma(C_i) \mid C_i \in \mathbf{E}\}$

[A baccalaureate is the cumulation of the assessments constituting an educational program.]

E, is a composition of competencies relevant to (or defining) a professional or academic course of study, a curriculum. A baccalaureate degree, **B**, is granted by an authorized institution. In fact, the list of competencies may be the vary testimony to the focus of an intended career direction shaping an academic program's intension. This would be the construct for comparing educational programs, assessing guideline or accreditation compliance, or prototyping distinct perspectives on the larger domain of knowledge such as across subdomains of *computing*!

J = job description

$\mathbf{J} \dashrightarrow \{C_i\}$

[A job description is the cumulation of competencies that stipulate the responsibilities of that job.]

JP = job permit

$\mathbf{JP}_j \dashrightarrow \{\Sigma(C_i) \mid C_i \in \mathbf{J}\}$

[A job permit is the cumulation of assessed competencies that certify job competency.]

In its own fashion, a particular job description is in effect a "mini-curriculum" as it prescribes performance requirements that usually distinguish the desired attributes of the applicant or employee. The particulars of the organization, the industry, or the marketplace would shape both the collection of knowledge elements, skills, and the dispositions of their application, thus, aligning with a particular vocation.

P = profession

$\mathbf{P} \dashrightarrow \{J_i\}$

[A profession is the cumulation of competencies that stipulates the range of relevant jobs.]

L = professional license

$\mathbf{L}_p \dashrightarrow \{\Sigma(J_i) \mid J_i \in \mathbf{P}\}$

[A professional license is the cumulation of assessed competencies ranging over the jobs of a profession.]

In this last aggregation, professional societies and governmental agencies specify collections of competencies that qualify a legal standing as a licensed professional (e.g. professional engineer, medical doctor, physician's assistant, nurse, a member of the bar, barber, cosmetologist, etc.).

The CDKST model does not attempt to shape or bound the dimensions of pedagogy as that requires integration with the cultural context within which it must be applied. However, pedagogy must align with the designated dispositions modulating the *quality of performance* the student must demonstrate as competency in context.