From Knowledge-based to Competency-based Computing Education: Future Directions

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Abstract*—Competency is often associated with proficiency, expertise, capability, and performance. Professional schools such as those in dentistry and medicine generally require the practice of skills and knowledge within human environments for someone to become a competent professional in their respective fields. In computing, competency is a relatively new concept. For decades, computing curricula focused on knowledge. However, competency is much more than knowledge. The ACM/IEEE Computing Curricula 2020 (CC2020) project identifies competency as a combination of knowledge, skills, and human dispositions, in context or task. That is, knowledge alone is not enough to produce a competent graduate from a computing program. Industry expects graduates to perform competently from the first day of employment. While computing educators have been sharing computing knowledge for decades, can they do it better under the rubric of competency? The authors leverage on the current activities of the CC2020 project, their personal experiences, and outcomes from current research on computing competency and related topics. Future directions and strategies for transforming the current paradigm of knowledge-based learning toward a broad acceptance of competency-based learning are an important part of this work. The authors recommend several steps needed to achieve such a transformation over time. While universities are not training grounds for industry needs, it would be a mistake to ignore such influence within the rubric of competency-based learning. This work will be of interest to all computing and engineering educators.

Keywords—CC2020, competency-based learning, knowledge-based learning, computing education, engineering education

I. INTRODUCTION

In today's world, there is an ever-increasing emphasis on competence and performance, especially in the workplace. Competency, an ancient concept going back for millennia, often associates with proficiency, expertise, capability, and performance [1] [2]. Professional schools such as those in medicine, education, law, and architecture generally require the practice of skills and knowledge within human environments before certification as a competent professional in their respective fields. In the field of computing, and somewhat in the engineering field, competency is a relatively new concept. [3] For decades, computing curricula have focused primarily on knowledge – content with topics teachers should cover (*know-what,* but often including a *know-how* or skill focus). However, competency is much more than content knowledge which alone is not enough to produce a competent graduate from a computing program [4]. In a modern world where most (sometimes all) computing graduates seek positions in the workplace rather than pursuing graduate studies [5], technical skills and human dispositions are important elements to complement knowledge. Industry (often unreasonably) expects graduates to perform competently from the first day they are employed.

The primary focus of this paper is to move beyond a simple knowledge-based education and demonstrate the need to move to a holistic competency-based teaching and learning to build professional competencies and produce graduates who can perform as competent professionals and members of society. It explores questions as follows:

- Why do we need to move from knowledge-based education to competency-based education?
- What are the elements of a competency-based model?
- How can stakeholders participate and benefit from this new model?
- While computing teachers have been sharing computing knowledge for six decades, can they do it better under the rubric of competency?

To help answer these questions, the authors leverage on the current activities of the CC2020 project. [6] They also assert their personal experiences and utilize outcomes from current research on computing competency and related topics. This work also explores the literature on the transfer of computing skills and human dispositions and the conveying of knowledge in the context of competency. These activities are not trivial and authors in earlier works have discussed some of these issues.

Education is not just about content knowledge. In his exposition, Habermas (cited in Carr & Kemmis) [7] expounds three knowledge interests and different scientific paradigms. Broadly speaking, from Habermas' Marxist perspective, these can be considered as instrumental (the interest of carrying out work); practical (the need to communicate with others to perform work); and emancipatory (there must be more to life than work!). In the same way, society should expect an educated graduate to have a well-rounded education that enables them to appreciate and see the value of the arts, cultural pursuits, sport, literature, and human caring as innate aspects of what makes us human in a world worth living.

Future directions and strategies for transforming the current paradigm of knowledge-based learning toward a broad acceptance of a holistic competency-based learning are an important part of this work. The authors recommend several steps to achieve such a transformation over time. Among these strategies is the ability to engage business and industry in the learning process since most computing graduates enter the workplace as professionals in computing or other fields.

While universities are not training grounds for industry needs, it would be a mistake to ignore such influence within the rubric of competency-based learning. This work will be of immense interest to all computing and engineering educators.

II. Background

In today's world, there are many interpretations of the word "competency" as applied in a variety of contexts. To demystify these notions, the authors first present some background on this topic.

A. Knowledge and Competency over Millennia

Knowledge has been a human quest from the beginning of humankind. The early writings of Socrates and Plato provide testimony to that claim. Likewise, competency is not a novel idea. The concept goes back to centuries and millennia. The construction of the Giza Pyramids or the Roman Colosseum are examples of structures designed and engineered by competent professionals of the time.

Competency is a person-centered concept that requires demonstration of human behavior together with skills and knowledge. Knowledge is a cerebral activity and knowledge-based learning implies activities to acquire greater knowledge. The idea of competency can transcend knowledge and become a foundational idea on which to base academic program designs. That is, competency can become an effective bridge between the deliverables by academia and its consumption by learners and society at large. As Magnusson (1990) stated, *"CBE [Competency Based Education] can be characterized as being an amalgamation of the work of several leading learning theorists: It contains elements of programmed instruction, clearly specified behavioral objectives, hierarchical methods of knowledge acquisition, and social learning techniques"* [2]. Thus, it is logical to foster competency-based learning instead of knowledge-split based learning, particularly at the university level.

B. Competency and its Meaning

A general dictionary meaning defines competence as "the quality or state of having sufficient knowledge, judgment, skill, or strength" [8]. The use of this word always occurs in a context. Being competent in law does not mean someone is competent in medicine. A useful overview of competency occurs in the Harvard University Competency Dictionary [9]. This resource offers the following definition and explanation.

> *Competencies, in the most general terms, are "things" that an individual must demonstrate to be effective in a job, role, function, task, or duty. These "things" include job-relevant behavior (what a person says or does that results in good or poor performance), motivation (how a person feels about a job, organization, or geographic location), and technical knowledge/skills (what a person knows/demonstrates regarding facts, technologies, a profession, procedures, a job, an organization, etc.). Competencies are identified through the study of jobs and roles.*

Thus, from this definition, competency identifies closely with job-related behavior and performance.

C. The Competency Movement and Prior Lessons

Andrew Gonczi [10] observed that "a competency-based approach" had emerged by the early 1990s as a key educational policy in the English-speaking world. Since the early 1980s, the related notion of "mastery" had been adopted for computing curricula for diploma level programs within the New Zealand Institutes of Technology and Polytechnic sector as a new approach to teaching and learning [11]. This approach fostered the teaching, learning, and assessment of knowledge and skills as well as human abilities with the expectation that students would be able to perform tasks at a level that would enable them to perform effectively as practitioners. The computer science curricula report (CS2013) shows recent and similar notions of performance such as: "We use three levels of mastery, defined as: familiarity, usage, and assessment" [12].

While CS2013 has adopted these levels of performance or '*mastery*' of a learning outcome, Gonczi [10] had distinguished three conceptions or models of competency as performance: 1) the task-based or behaviorist model – essentially a *reductionist approach*; 2) the measurement of general attributes and critical thinking - the *generic approach*; 3) the professional ability to perform professional tasks – an *integrative approach*.

In contrast, Eraut [13] viewed competency not so much from a performance viewpoint, but from the more innate perspective of personal characteristics, where "*professional capability…* is defined as *what* a <u>*person*</u> *can think or do that* is *relevant to the* <u>*work*</u> *of a particular profession."* From both origins of professionalism, the necessity of a broadly integrated set of skills and attributes applied appropriately in a professional setting are critical aspects of any broad form of professional competence.

The competency movement of the 1990s became entrenched by political forces and zealotry. The simplistic approach to the assessment of highly granular tasks encouraged by the *reductionist* approach led to it falling out of favor as its weaknesses in dealing with complexity and holistic activities became apparent. The continuing challenges faced by educators in comprehending and designing professionally applicable tasks and assessing them will be a key challenge in retaining a broad *integrative* conception for competency.

D. Professional Viewpoints on Competency and Knowledge

Competency has always been an underlying mainstay in the professions. In medicine or dentistry, for example, those knowledgeable about book learning or attaining perfect scores on medical or dental examinations do not automatically make good doctors or dentists. The practice of these professions requires intense internship activities to acquire and perfect the needed skills along with the human ability or disposition to become a professional in these fields. [10] Almost all governments require doctors and dentists to have a license to *practice* their professions.

The same applies to airline pilots, lawyers, professional engineers, and other true professionals. They require more than knowledge. They require verifiable skills and related human dispositions in addition to knowledge in the context of their professions. Not all countries require these professionals to complete a graduate qualification. Professionals must attain a level of competency to practice in their designated fields, often developed within their baccalaureate degree program.

III. Current Competency Paradigms

As observed, the concept of competency is nothing new. For millennia, people acquired knowledge, skills, and dispositions as apprentices and students from their masters or teachers. In recent times, the notion of competency has become more formalized

A. Curricular Paradigms

Computing curriculum models have all historically had their innate limitations and perspectives. In a recent ICER conference paper [14], three perspectives on framing "computational thinking" have been put forward: skill and competence building; creative expression and participation; or and social justice and ethics.

Melrose [15], as well as Clear and Young [16], gave similar framings for curriculum models for computing from a teaching and research perspective. They outlined three broad paradigms: the functional, the transactional, and the critical. They also defined the self-assessment instrument used to distinguish these paradigms, thus enabling participants in workshops to understand their teaching approaches measured against each paradigm as explained below.

Functional: Based on settings in the present that are reproducible, and often considered as being practical. This is what industry or society needs now for that person to take up that job; it is task and skills-based for a specific occupation. Since content is most important, the methodology often involves set lectures and teacher-directed demonstrations, workshops, or laboratories.

Transactional: Based on the needs of individual students or groups who happen to be taking a course. The teaching methodology often involves the facilitation of group discussion. That is, the process values people and student-centered experiential learning.

Critical: Based on predictions of future needs, where learning to learn is important and developing critical thinkers is a goal. The methodology often involves a teacher asking critical questions, shaking previously held beliefs, querying current systems, and acting as the change agent. [16]

Historically, computing curricula, when set against these paradigms or perspectives, can be seen as largely "skill and competence building" (where "competence" here is about limited skill building) [13] or "functional" in approach [16]. A holistic approach to competency enables a broader conception of the curriculum.

B. Curricula Movements Toward Competency

The Association for Computing Machinery (ACM) has published two points of view surrounding competency in computing curricula reports related to information technology and information systems. Although these viewpoints evolved independently, their conclusions are very similar. For computing and other disciplines, knowledge has always been the focus of the study area. Computing curricular reports often describe a discipline through knowledge areas (KAs), knowledge units (KUs), and learning outcomes (LOs). Sometimes, people refer to this phenomenon as the KA-KU-LO or Ka-Ku-Lo syndrome, whereby lists of topics are associated with each knowledge unit. These curricular reports generally do not provide guidance related to skills or guidance related to human behavior particularly reflected by performance in the workplace.

Information Technology

The information technology IT2017 report [17] broke away from the traditional use of the Ka-Ku-Lo paradigm. The report embraced competency-based learning, particularly since almost all graduates from information technology degree programs enter the industry or government workplace. It adopted the term competence to mean the performance standards associated with a profession or membership to a licensing organization. In fact, assessing some level of performance in the workplace is a frequently used metric for competence measure. That is, competencies are what a graduate should bring to a job.

In education, success in career readiness requires students in degree programs to develop a range of qualities typically organized along three dimensions: knowledge, skills, and dispositions. Any working definition of competency must connect these three dimensions. The IT2017 report described this concept simply as:

Competency = Knowledge + Skills + Dispositions

in context. This canonical triadic model of competency avoids perpetuating the practice of using the knowledge lens. Instead of centering curricular guidelines on a body of knowledge, the IT2017 report used competency as the centerpiece of learning for information technology.

Information Systems

Competency has also played a part in the recent Master of Science for Information Systems report, also known as (MSIS2016) [18]. Instead of specifying a body of knowledge or a set of courses as occurred in the prior MSIS2006 report, this curricular model identified a set of graduate competencies. In this context, the term "competency" refers to the graduate ability to use knowledge, skills, and attitudes to perform specified tasks successfully. The report defines competency as follows.

> *Competencies represent a dynamic combination of cognitive and metacognitive skills, demonstration of knowledge and understanding, interpersonal, intellectual and practical skills, and ethical values* [19].

In this context, competency is an integrative concept that brings together graduate knowledge, skills, and attitudes.

The MSIS2016 report specified competency areas as the highest-level categorization. The areas, in turn, included competency categories, and these categories specify the actual competencies. Competency areas and competency categories are much more stable and depend less on technology. Also, there may be more local variation in the competencies than at the higher levels.

C. Software Engineering Competency Model

The software engineering competency model (SWECOM) [20] describes capabilities for software engineers who participate in the development of and modifications to software-intensive systems. The model specifies skill areas, skills within skill areas, and work activities for each skill. Activities occur at five levels of increasing proficiency. The model suggests that competency is a combination of knowledge, skill, and ability. A competent person has the knowledge and ability to perform work activities (skills) at a given competency level. The competency model includes cognitive attributes, behavioral attitudes, and technical skills. Some cognitive skills include reasoning, analytics, problem-solving, and innovation skills. Behavioral attributes include aptitude, enthusiasm, trustworthiness, cultural sensitivity, as well as communication, teamwork, and leadership skills.

The SWECOM is very similar to the IT2017 and the MSIS2016 philosophies of competency. Knowledge and technical (computing) skills are where the behavioral attributes correspond to disposition or ability, respectively. Competency is central to the model and provides a modern view to generate excellence in computing education.

D. The China "Blue Book" Project

China and its education ministry have embraced competency as an important element in the development of computing and engineering programs. Over the past five years, publications emerged surrounding the importance of competency in computing and engineering education. The Forum of Chinese Twenty-Experts on Computing Education, in which more than twenty senior professors on computing have engaged, has recently published its "Blue Book" [21] to address the need for competency in university environments, particularly as it applies to computing and engineering education programs. The China Computer Federation also emphasized computing education for competencies in its 2018 Future Computer Education Summit (FCES 2018) publication [22].

IV. The CC2020 Project

The Computing Curriculum 2020 (CC2020) project as described in Clear et al 2017 [23] is an initiative launched jointly by several professional computing societies (principally ACM and the IEEE Computer Society (IEEE-CS).) CC2020 summarizes and synthesizes the current state of curricular guidelines for academic programs that grant baccalaureate-level degrees in computing to provide a portfolio of resources useful to students, industry, government agencies, educational institutions, and the public on a global scale. The project aims not only to reflect the state-of-the-art in computing education and practice but also to provide insights into the future of the field of computing education for the 2020s and beyond. The participating societies engaged a global task force of 50 individuals representing organizations from academia, industry, and government.

A. Aspects of Knowledge-based Learning

As already mentioned, knowledge-based learning involves a collection of knowledge areas (KAs) for a discipline that subdivides into knowledge units (KUs). In turn, each KU contains a set of learning outcomes often associated with a set of topics. This form of learning involves knowledge that students have already learned and eventually bring to further study or the workplace. Teachers transfer knowledge to students through experience, notes, textbooks, or other means. Having received the knowledge, students have an achievement expectation and work toward demonstrating that achievement. Almost all universities worldwide produce graduates through knowledge-based learning.

However, the traditional knowledge-based learning paradigm may no longer be appropriate for the computing field. Technology now influences new ways of learning that employ many non-traditional learning formats thereby challenging traditional methods. Furthermore, universities produce computing graduates who may be intellectually able but have difficulties in workplace settings. While knowledge-based learning is commendable, it is less effective and may not be useful when technical skills and human behaviors are in demand for a changing computing and engineering world.

B. Components of Competency-based Learning

CC2020 has developed a definition of competency and a template for specifying the subject matter of baccalaureate computing education. This model supports a consistent, scalable model for writing curricular specifications suitable for visualization and analysis. CC2020's definition of competency has evolved from numerous competency models developed and applied in different educational frameworks and definitions.

While the knowledge dimensions of computing have appeared in various computing curricula guidelines, what is meant by skill and disposition have had significantly less focus. Extending previous work, the CC2020 project specifies competency composed of K-S-D dimensions observed within the performance of a task, T. Therefore,

Competency = [Knowledge+ Skills+ Dispositions] in Task

A competency structure (see Fig. 1) shows knowledge, skills, and dispositions that are observable in the accomplishment of a task, a task that prescribes purpose within a work context [24].

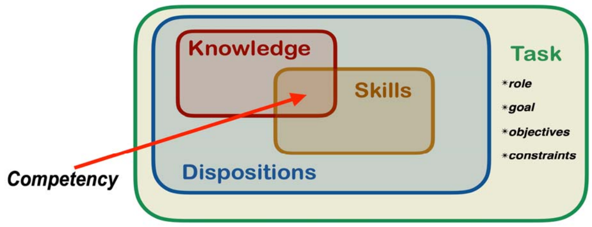

Fig 1. Illustration of Competency

Knowledge is the "*know-what*" dimension of competency that is factual. An element of knowledge designates a core concept essential to a competency. This dimension reflects the enumerated subject matter that teachers catalog as topics in their syllabi, departments distribute and balance among the courses they develop in an academic program, accreditation organizations stipulate in their accreditation criteria, and employers identify in job descriptions of their workers. Traditionally, curriculum guidelines for computing education have predominantly used this designation of knowledge elements composed of facts based upon scientific derivation or proof.

Skills express the "*know-how*" and usually develop over time and with practice. They refer to the capability and strategy for applying knowledge to perform a task in context. Competency occurs when knowledge is applied in action to accomplish a task, hence in an application. Consequently, skill development often requires engagement in a progressive hierarchy of higher-order cognitive processes. CC2020's definition of competency has adopted Bloom's levels of cognitive process [25] to specify the degree of skill expected in successful task accomplishment.

Dispositions frame the "*know-why*" dimension of competency, which prescribes a requisite character or quality in task performance. Dispositions shape the discernment of skillful engagement of knowledge and skills. Specific to a task at hand, dispositions exert a moderating or controlling influence on a practitioner's choices by proposing or projecting a desirable quality onto the outcome. Dispositions characterize socio-emotional tendencies, predilections, and attitudes that characterize the inclination to carry out tasks and the sensitivity to know when and how to engage in those tasks [26]. Hence, dispositions denote the values and motivation that guide applying knowledge while designating the quality of knowing. Assessment of "Know-why" values usually occur indirectly through patterns of behavior or reflective practice.

Task is the construct that frames the skilled application of knowledge and makes dispositions concrete. Task expressed as a colloquial prose statement provides the setting to manifest dispositions, where individuals moderate their choices, actions, and effort necessary to pursue and succeed efficiently and effectively. A task definition often stipulates pragmatic engagement that reflects professional practice relevant to the vision for the program graduates.

C. On Teaching Dispositions

Schussler argued that a disposition "concerns not what abilities people have, but how people are disposed to use those abilities" [27]. When conversing about a mindset and set of attitudes, the question is raised on whether one can teach a disposition or if it is some innate part of a person's character [28]. Some educators do not see the development of dispositions as part of their role, yet people often see lofty statements in the graduate profiles of expectations of the graduates of their institutions.

These expectation statements typically embody dispositions as an inherent outcome desired by society, employers, and students. In some sense, the disposition of being self-directed and tenacious achieves development through the experience of undergoing a tertiary degree, requiring time, stress, multiple demands, and sustained intellectual application. During a good degree program, students are exposed to novel concepts, models, practices, and techniques that they learn to apply to new situations, thereby consolidating the disposition of being "adaptable" or "learning how to learn." The challenge for individual educators is to contribute a piece of the jigsaw in building dispositions as a consistent component of the whole that is the degree.

D. On Visualization

A salient feature of the CC2020 project is its collection of visuals surrounding competencies, competency components, and other curricular-related concepts. The illustrations provide stakeholders with many visuals, allowing them to appreciate and use content elements found in the CC2020 report. A recent publication shows how stakeholders might use the report [29]. Many visualizations related to this effort will appear on the project website [30].

V. Towards Competency in a Modern World

The authors speculate that transitioning from knowledge-based learning to competency-based learning will be a challenge because current computing educators were educated by a knowledge-based approach and most continue to teach using that approach. Such a transition has many stakeholders.

A. Stakeholders in Competency-based Learning

It is important to know the audience for competency-based learning. The authors believe that this audience consists of (a) prospective students and their guardians, (b) current students, (c) industry personnel, (d) educational authorities, and (e) computing educators. When prospective students are considering studying computing at a university, they need to understand differences in computing programs. Although they want to study computing, very few will likely understand that there are many disciplines and the differences between them. Industry personnel refers to entities who are hiring certified students, are collaborating with universities to choose or specialize in a curriculum, or need a special course or are collaborating in a curriculum by mutual collaborations. Employers and recruiters need to understand what their employees need to know. Educational authorities are entities that have authority over university education, such as (national) ministries of education that govern and finance universities and national or international (e.g., European) bodies that rate, assess, or accredited (university) education, or define qualifications or certificates. Computing educators are teachers within computing academic units within a single school or university. They are responsible for the design and implementation of curricula or courses related to a computing discipline.

Computing educators should understand how their current curriculum as well as how a prospective curriculum fits within accepted curricular recommendations. It would be useful if educators were able to compare their curriculum to professional curricula guidelines to help them understand what may be missing, and visualizations could assist in this understanding.

B. Roles of Stakeholders

Stakeholders have their responsibilities. Parents and potential computing students need to explore the advantages of different paths of study. For example, students interested in computing careers would be ill-advised if they studied computer engineering while not mathematically inclined. University students in non-computing programs should investigate the proper path of study when switching to a computing specialist track.

Industry involvement is paramount in fostering competency-based learning. Industry-university relationships such as active participation in advisory boards, active internships, participation in capstone projects, or shadowing undergraduates in the workplace provide tremendous advantages to students. Educational authorities and professional societies also have valuable roles to play in promoting competency in computing education.

Academic institutions and computing educators can also play a vital role in competency-based learning. It is important to modify local curricula so students can experience a competency-based environment through modified curricular programs and developing new strategies for competency-based learning. Professional development strategies that couple funding with competency could produce positive results [31], including a broader role in producing educated citizens for civic participation in democratic societies [32].

C. Overall Worldwide Skills Gap in the Computing Industry

Students who graduate from a university computing program might assume that the baccalaureate degree is a basic qualification to attain a position and that those who have such degrees will be easily employable in the computing field. The high demand for computing professionals reinforces this idea. However, there has recently been a large influx in computing graduates; within this larger population there exists a greater potential for unemployment or underemployment, especially among graduates with weaker skills.

In contrast, the computing skills gap—the gap between technical skills of computing graduates and the skills expected by industry employers—is an ongoing challenge. Technical associations tend to focus on industry standards that foster skills development and that provide vendor-neutral computing certifications globally [33]. Technology has become a key enabler of innovation and organization growth, and technology trends are now driving changes in organizations. There is a forecast that shows the need for over 40 million additional college-educated workers, as well as 95 million workers globally with technology skills [34].

D. STEM Education and Computing Industry Needs

The skills gap that exists between the needs of industry and the capability of computing graduates is fueling a transition from the traditional knowledge-based approach to competency-based learning. From any typical university, almost all of the computing graduates enter the workplace in industry or government rather than attending graduate school. While universities are not training grounds for industry, there is an obvious disconnect between the computing graduates produced by universities and the needs of industry.

As an example of this, a survey by Burning Glass, a provider of data and analysis of labor market trends, reported the following [35]:

- More than 8 in 10 middle-skill jobs (82%) require digital skills, a 4% increase since 2014.
- Digital skills provide a career pathway into middle- and high-skill jobs.
- Digital middle-skill jobs represent roughly 38% of overall job postings.

Evidence such as this describes a mismatch between university production and their graduates' ability to fit in the workplace. In 2016, the United States produced 1,915,085 undergraduate baccalaureate degrees [36] of which 179,411 are in computer and information sciences and support services (with 35,342 in computer science) [37]. Since approximately 9.37% of college graduates are computing graduates (1.8% computer science graduates), the skills gap likely affects those seeking jobs in computing or related fields. Hence, there is a need to shift from a learning paradigm to a competency paradigm to mitigate the ongoing disparity.

E. Cost and Value of Knowledge-based Degree Programs

The emergence of competency-based learning in deference to knowledge-based learning raises the question of the value of a knowledge-based education. Institutions of higher learning, whether public or private, have experienced exponential growth in costs. Some institutions have closed for financial reasons while others face extreme challenges. Hence, the utilitarian aspects of university education come under question, especially when major employers are now gravitating toward employing short-term gap fillers such as those who have completed coding boot camps [38] instead of university graduates. It is also important to convince parents and political leaders of the value of a broad competency-based education. Furthermore, it is important to prepare adaptive graduates for uncertain and changing future skill needs in a changing technological world.

VI. Future Directions

The CC2020 project provides an overview of the computing education landscape related to undergraduate, (baccalaureate) programs. This overview is global in scope. Computing competency is the project's central theme that incorporates human attributes (dispositions) and technical skills with knowledge. Universities and their faculty members are experts in knowledge building and in most cases skill level. However, faculty members are often at a loss in developing dispositional qualities for their students. The CC2020 project and its report encourage computing programs to establish a proper environment and to necessitate that future curricular reports incorporate competency as part of their structure and recommendations.

Students and graduates of computing programs must be able to face change and become inventive in contributing to that change. One way to address this challenge is to include experiences in innovation, entrepreneurship, and maker-space activities in computing programs. Some engineering disciplines have been doing this for some time with their introduction to engineering exploration laboratories in the very first semester of study. The role of academics and the way they enable computing competencies is important to produce capable and competent graduates of computing programs who are proficient at the time of graduation to enter the workplace, to attend graduate school, or to contribute constructively in some way to society.

While the transfer of knowledge is the cornerstone of academia and universities, it is important to instill in students the need for performing related skills within a dispositional setting. Activities such as exploring video clips, subject wikis, experiences on professional development, MOOCs, and other supportive online materials available to the public encourage students to explore additional materials to help them develop lifelong learning skills because students must continue to learn long after they graduate from their computing programs. Learning in small groups (e.g. pair learning), constructive learning groups (e.g. teams), and other learning strategies help students develop new skill sets as well as developing dispositional attributes (e.g. collaborative, proactive) to become competent graduates.

Using competency in current and future computing curricular reports is an important result of the CC2020 project. Given that most graduates of computing programs enter the workplace, computing programs must prepare their graduates properly so they can perform as professionals and engage in productive careers.

VII. Summary and Conclusion

This paper has addressed the importance of competency-based learning for undergraduate computing programs. Competency-based teaching and learning approaches have been explored in previous decades. Recent information technology and information systems curriculum reports and the software competency model have moved from knowledge-based learning to competency-based learning.

The current CC2020 project, launched jointly by several professional computing societies, is recommending the transition to a competency-based framework structured with dimensions consisting of knowledge, skills, and dispositions in a task. This approach can help address the worldwide skills gap in the computing industry where a mismatch between university graduates' ability to fit in the workplace has been increasingly observed.

Now is the opportunity to embrace the needs of the stakeholders in computing education, all prospective students and their guardians, current students, industry and employers, educational authorities, and computing educators globally. By adopting a competency-based model of computing education and ensuring all future curricula adopt this model, it is possible to achieve this goal.

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References

[1] Houston, W.R. (1974) Exploring Competency-Based Education (Berkeley, CA, McCutchan)

[2] Magnusson, K. & Osborne, J. (1990) The Rise of Competency-Based Education: A Deconstructionist Analysis. *The Journal of Educational Thought*, Vol. 24, No. 1. Pp 5-13, April 1990

[3] McEwan, T. "Commercial competency and computing students: Using the skills framework for the information age in higher education," 2013 IEEE Frontiers in Education Conference (FIE), Oklahoma City, OK, 2013, pp. 286-292, DOI: 10.1109/FIE.2013.6684833.

[4] Frezza, S. et al., "Modeling global competencies for computing education," presented at the Proceedings of the 23rd Annual ACM Conference on Innovation and Technology in Computer Science Education, Larnaca, Cyprus, 2018.

[5] NCES National Centre for Education Statistics https://nces.ed.gov/programs/coe/indicator_chb.asp accessed May 20th, 2020

[6] ACM/IEEE, CC2020 Paradigms for Future Computing Curricula. *IEEE Computer Society and the Association for Computing Machinery,* 2020 in press

[7] Carr and S. Kemmis, *Becoming Critical: Knowing Through Action Research*. Melbourne: Deakin University Press, 1983

[8] Merriam-Webster. https://www.merriam-webster.com/dictionary/competency. Accessed 2019 June 3

[9] Harvard University. https://apps2.campusservices.harvard.edu/cas/empldocs/cs/harvard_competency_dictionary_complete.pdf.

[10] Gonczi, A. (1994). Competency-based assessment in the professions in Australia. Assessment in Education: Principles, Policy & Practice, 1(1), 27-44.

[11] NACCQ (1988) New Zealand Polytechnic Qualifications in Business Computing, National Advisory Committee on Computing Qualifications, ISBN 086468-018-X.

[12] M. Sahami *et al.*, "Computer science curricula 2013: Curriculum guidelines for undergraduate degree programs in computer science," *Association for Computing Machinery (ACM)-IEEE Computer Society,* 2013.

[13] Eraut, M. (1998). Concepts of competence. Journal of interprofessional care, 12(2), 127-139.

[14] Kafai, Y., Proctor, C., & Lui, D. (2019). From Theory Bias to Theory Dialogue: Embracing Cognitive, Situated, and Critical Framings of Computational Thinking in K-12 CS Education. presented at the meeting of the Proceedings of the 2019 ACM Conference on International Computing Education Research, Toronto ON, Canada. https://doi.org/10.1145/3291279.3339400

[15] Melrose, M. (1998). Exploring paradigms of curriculum evaluation and concepts of quality. Quality in Higher Education, 4(1), 37-43.

[16] Clear, T., & Young, A. (2001). Met a Researcher? Research Paradigms among those new to Research. In S. Mann (Ed.), The 14th Annual Conference of the NACCQ (Vol. 1, pp. 23-31). Napier New Zealand: NACCQ, Hamilton. https://www.citrenz.ac.nz/conferences/2001/23.pdf

[17] ACM (2017). Information Technology Curricula 2017 Curriculum Guidelines for Baccalaureate Degree Programs in Information Technology, Association for Computing Machinery (ACM) IEEE Computer Society (IEEE-CS), ISBN: 978-1-4503-6416-4, DOI: 10.1145/3173161, Weblink: https://dl.acm.org/citation.cfm?id=3173161.

[18] ACM (2017) Topi, H., Karsten, H., Brown, S. A., Carvalho, J. A., Donnellan, B., Shen, J., et al. (2017). MSIS 2016: Global Competency Model for Graduate Degree Programs in Information Systems, 40(1). Retrieved from http://aisel.aisnet.org/cais/vol40/iss1/186

[19] Lockoff, J., Wegewiis, B., Durkin, K., Wagenaar, R., Gonzales, J., Isaacs, A. K., Donà dalle Rose, L.F., & Gobbi, M. (Eds.) (2010). A Tuning guide to formulating degree programme profiles: Including programme competencies and programme learning outcomes. Bilbao, Spain: University of Deusto. Retrieved from http://core-project.eu/documents/Tuning%20G%20Formulating%20 Degree%20PR4.pdf

[20] IEEE Computer Society. 2014. Software Engineering Competency Model (SWECOM). Technical Report Version 1.0. IEEE-CS. https://www.computer.org/web/ peb/swecom.

[21] "Blue Book" (2019) The Blue Book Working Group of the Forum of Chinese Twenty-Experts on Computing Education in China. Computer Education for Sustainable Competence, China Higher Education Publishing, January 2019 (in Chinese).

[22] Impagliazzo, John. (2018) The Role of Competency and the Future of Computer Education. *Communications of the China Computer Federation*; Volume 14, Number 9; September 2018. (in Chinese)

[23] Clear, A., Parrish, A., Zhang, M. & van der Veer, G. CC2020: A Vision of Computing Curricula. In Proceedings of the 2017 ACM SIGCSE Technical Symposium on Computer Science Education, March 2017, pp 647–648https://doi.org/10.1145/3017680.3017690.

[24] Waguespack, L., et al., "Adopting Competency Mindful of Professionalism in Baccalaureate Computing Curricula," in EDSIGCON 2019, 2019.

[25] ACM/IEEE Joint Task Force on Computing Curricula, Software Engineering 2014 Curriculum Guidelines for Undergraduate Degree Programs in Software Engineering. IEEE Computer Society and the Association for Computing Machinery, 2015

[26] Perkins, David N., Eileen Jay, and Shari Tishman. 1993. "Beyond Abilities: A Dispositional Theory of Thinking." Merrill-Palmer Quarterly 39 (1): 1–21.

[27] Schussler, D.L. "Defining dispositions: Wading through murky waters". The Teacher Educator 41, 4, (2006): 251-268.

[28] Clear, T. (2017). Meeting Employers Expectations of DevOps Roles: Can Dispositions Be Taught? ACM Inroads, 8(2), 19-21. https://doi.org/10.1145/3078298

[29] Takada, Shingo, et al. (2020). "Toward the Visual Understanding of Computing Curricula" in *Education and Information Technologies*, Springer Nature.

[30] CC2020 Website (2020). https://www.cc2020.net/. Accessed 2020 Mar 23.

[31] McNaught, C. (2019). A narrative across 28 years in academic development. International Journal for Academic Development, 1-5.

[32] Dewey, "What Does Pragmatism Mean by Practical," *The Journal of Philosophy Psychology and Scientific Methods,* vol. V, no. 4, pp. 85-99, 1908.

[33] CompTIA, Information Technology (IT) Industry & Association; https://www.comptia.org/. Accessed 2017 Dec 2.

[34] Olson, M. 2016. "A Multilateral Approach to Bridging the Global Skills Gap." Cornell HR Review, 5/8/15, p. 1.

[35] Burning Glass. (2017). The Digital Edge: Middle-Skill Workers and Careers. https://www.burning-glass.com/wp-content/uploads/Digital_Edge_report_2017_final.pdf. Accessed 14 May 2019.

[36] Perry, Mark J. 2018. Table of the Day: Bachelor's degrees for the Class of 2016 by field and gender. Oh, and the overall 25.6% degree gap for men! http://www.aei.org/publication/table-of-the-day-bachelors-degrees-for-the-class-of-2016-by-field-and-gender-oh-and-the-overall-25-6-college-degree-gap-for-men/. Accessed 2019Aug17

[37] DataUSA. 2019. https://datausa.io/profile/cip/computer-and-information-sciences-and-support-services. Accessed 2019Aug17.

[38] Q. Burke, C. Bailey, L. A. Lyon, and E. Green, "Understanding the Software Development Industry's Perspective on Coding Boot Camps versus Traditional 4-year Colleges," in Proceedings of the 49th ACM Technical Symposium on Computer Science Education, 2018, pp. 503-508.