

A Competency-Based Transformation in Computing and Engineering Education in the Digital Era

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Abstract In today's world, humanity is immersed in a digital era where technological advances driven by computers permeate everyone's life. The situation raises the need for computing and engineering education to inform students of their responsibilities to society and their preparation to enter higher education and the workplace. Competency and technical performance are central to this thinking. This article poses two questions: Has competency-based learning in computing and engineering transformed into the current digital age? If so, to what extent has computing and engineering education adopted competency-based learning in their curricula? The authors explore three reports affecting computing and engineering education to address these queries. They include the 2019 Chinese *Computer Education for Sustainable Competence* (Blue Book), the *Computing Curricula 2020: Paradigms for Global Computing Education*, and the 2023 *Infinite Possibilities: Report on the Digital Development of Global Higher Education*. The first emphasizes the importance and necessary elements of sustainable competency and agile education for computing and engineering in the digital era. The second defines competency as a triad of knowledge, skills, and human dispositions; it promotes the transformation from knowledge-based to competency-based learning. The third report provides a pathway for the modern digital development of global higher education in a digital and technological age. All three publications support directly or indirectly the transformation of competency into the current digital age. However, computing and engineering programs have yet to adopt competency-based learning in their curricula. Time can tell whether sustainable competency will permeate computing and engineering education globally. In the meantime, academicians and industry professionals should continue

pursuing the cause to prepare students and graduates adequately as they become part of the digital era.

Keywords computing education in the digital era, agile education, sustainable competency, digital transformation of higher education

1 Introduction

The digital age has brought many advances, challenges, and opportunities to people globally. People experience many new electronic and digital advances almost daily through new technologies such as modern banking and payment mechanisms, self-driving motor vehicles, and digital communication. These digital advances affect how people live, work, and communicate. Society becomes very dependent on technology, mainly digital technology.

The dependence on digital technology raises the issue of education in preparing future engineers, scientists, and technologists in the digital fields. The need for quality digital education has become more and more critical. Students studying digital technologies must function effectively at their learning institutions, and graduates must be competent in the workplace. They must have the necessary digital skills and human behaviors beyond knowledge to make a worthy contribution to the digital field.

1.1 | The Birth of Computing Competency

In the late 2000s, at the Software Engineering Institute (SEI) in Carnegie Mellon University, there was a dire need to produce quality software worldwide for the many evolving tools and architectures at that time. Under the direction of Nancy Mead, the SEI developed the software assurance (SwA) competency model in 2010 consisting of three components: knowledge, skills, and effectiveness, where knowledge is what an individual knows, skills are what an individual can do by

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applying knowledge, and effectiveness is the ability to utilize knowledge and skills productively.

Effectiveness refers to behavior attributes such as aptitude, initiative, enthusiasm, willingness, communication, teamwork, and leadership. The word “dispositions” echoes these seven attributes. Mead and Shoemaker (2013) described the SwA competency model. At the same time, the IEEE Computer Society built on its decade-long project called the Software Engineering Body of Knowledge (SWEBOK) (Bourque & Fairley, 2014). The two combined efforts led to the Software Engineering Competency Model (SWECOM, 2014), showing that competency consists of knowledge, skills, and ability.

1.2 | Posing Research Questions

This section presents the methodology to determine competency transformation in the digital age. The article is inspired by evolving developments that occurred in recent years. The authors pose two questions to address transformations in the digital age.

RQ-1: Has competency-based learning in computing and engineering transformed into the current digital age?

RQ-2: If so, to what extent has computing and engineering education adopted competency-based learning in their curricula?

The authors present current cases addressing competency-based learning to address these two questions. Based on the findings, they make recommendations for educators and researchers who plan to transform from knowledge-based learning to competency-based learning. While the challenge may seem onerous, the authors believe that programs can make an initial attempt to make this transformation.

1.3 | Making the Case for Digital Competency

This work explores computing and engineering education in the context of the digital age. It will highlight the significance of promoting essential skills and fostering entrepreneurship and innovation to prepare the next generation for challenges and opportunities in a digital world. It will present some of the highlights of the 2019 *Computer Education for Sustainable Competence* (Blue Book) (Twenty Experts Forum Team on Computer Education, 2019; hereinafter referred to as the Blue Book), the *Computing Curricula 2020: Paradigms for Global Computing Education* (ACM, 2020; hereinafter referred to as the CC2020 report), the *Infinite Possibilities: A Report on the Digital Development of Global Higher Education* (Secretariat of Global MOOC and Online Education Alliance, 2023; hereinafter referred to as the Infinite Possibilities report), and other projects and publications that foster competency and performance in a digital world.

2 Summary of the Chinese Blue Book Report¹

China has embraced competency as essential in developing computing and engineering programs. The Twenty Experts Forum on Computing Education (2019) in China published its 2019 *Computing Education for Sustainable Competence* (Blue Book). The effort addresses the need for competency in university environments, particularly in 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 (Impagliazzo, 2018). The Blue Book philosophy expresses the ways that China expects to adapt to technological change over the next dozen years. The following summarizes that effort.

2.1 | Adaptable and Sustainable Competencies

The emergence of the Blue Book has opened new ideas in transforming university computing and engineering education in China. The emerging fields of information technology (IT) and artificial intelligence (AI) have created novel opportunities for industry and academia. The AI industry has provided fertile ground for new industrial sectors such as intelligent enterprises and public services. The new industrial revolution (i.e., Industry 4.0) promises advances in networked intelligent manufacturing, service-oriented manufacturing, and robotics for industry and modern services.

Change on such a global scale brings new challenges for an information society. Societal changes present challenges for a digitally networked cognitive society, sustainable development of society and the environment, and the transference of information and knowledge. People also change. Younger generations have new attitudes and demands for professional development that require multi-dimensional approaches to learning with sustainable competencies to adapt to an evolving future. That means education must also change—especially at the university level.

It is essential to adjust to societal changes by developing sustainable competencies for higher education. Sustainable competency refers to the ability to (a) adapt to change and competitiveness of the future society, (b) be creative based on the missions and technology, and (c) perform and promote social and technical development (Twenty Experts Forum Team on Computer Education, 2019). Transboundary and rapid changes in new economies

¹ The following is a condensation of a summary of Xiaofei Xu’s presentation at the 2019 ACM Turing Conference (2019 TURC) in Chengdu, China, which appeared as Appendix I in the CC2020 report.

require computing and engineering talents to have more substantial sustainable competencies for the future. Many Chinese universities have participated in such engineering education reform. This practice has led to an ongoing, competency-oriented movement in higher education.

2.2 | Agile Education for Sustainable Competencies

Faced with multiple objectives and individualized human development demands, creating a sustainable, competency-oriented, agile form of education becomes essential. Agile education is an approach that combines theory, knowledge, ability, and human quality into a comprehensive education system (Twenty Experts Forum Team on Computer Education, 2019). Agile education realizes multiple iterative rounds of knowledge, learning, and promotional ability. It encourages the rapid learning of theory, technique, practice, and efficient, coordinated

education by multi-university and multi-domain educational resources.

Sustainable competency-oriented agile education involves instilling sustainable competencies in students over a four-year education experience. The learning perspective includes fundamental courses and general education followed by technical and core courses, followed by interdisciplinary elective courses, and culminating with individual development. A curriculum often defines this learning perspective. The practice perspective includes industry visits, yearly projects, course projects and scientific competence, professional training, industry internship, and graduate (capstone) projects. Combining learning and practice develops sustainable competencies in students, which is at the heart of agile education. Figure 1 illustrates this concept. The practice of agile education derives from the practical experience of the recent reform and innovation actions of worldwide computing and engineering education.

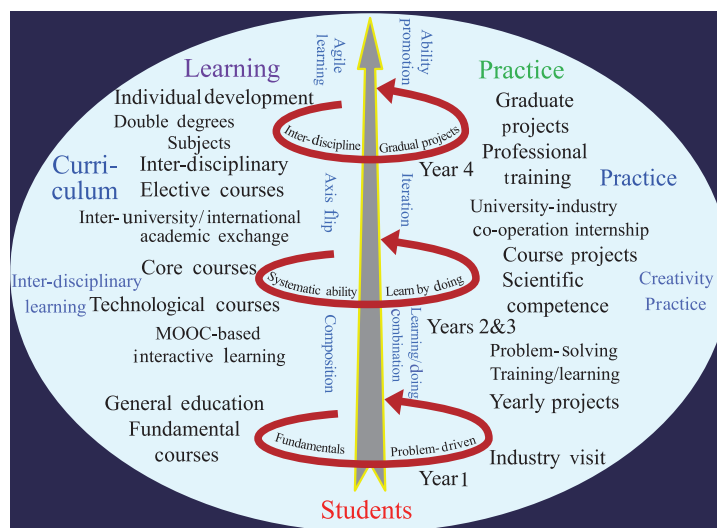


Figure 1 Agile Education and Sustainable Competencies

Note. Made by Xiaofei Xu.

2.3 | Factors Affecting Agile Computing and Engineering Education

In agile education, there is an emphasis on multiple cultivation objectives based on the diversity of students. Its purpose is to develop “education-on-demand” through a combination of a major-oriented program with individualized learning. Universities should provide massive and customized education systems through multiple cultivation objectives of their students. The teaching system would consist of a curriculum, teaching processes, teacher-student learning activities, resources, and quality evaluation methods.

In agile education, universities would classify their curricula and courses into multi-clusters of modules according to the needs of individualized students or groups

of specialties and directions to provide an environment of adaptive knowledge learning and ability training. Course modules include general education and fundamental clusters, specialty core course modules, interdisciplinary course modules, elective course modules, and experimental practice clusters. It might be necessary to make flexible compositions of the course modules, courses, or micro-courses to adapt the programs to student needs since they have more choices for their development.

Agile education requires a collaborative organization and resources. To implement agile education, it is necessary to coordinate the teaching and learning organization and resources, including multidisciplinary teams, educational facilities from multi-schools and multi-universities, and training resources from industry and society. Universities should establish virtual

inter-school and inter-university collaborative teaching centers for agile education and purpose learning by combining teaching resources from multi-institutions.

2.4 | Open Education Ecosystems for Agile Education

It is crucial to address the role of university management in implementing agile education. Universities must reform their management and support systems and ecosystems for agile education. Focusing on individual students, small groups, and flexible learning are critical elements for a successful transition. Universities should build an advanced agile education system, reform and restructure their management and support systems, and build an open education ecosystem for sustainable competencies. Suggestions for doing this include (a) setting up a flexible study term and a complete credit system for iterated learning and individualized cultivation, (b) establishing an undergraduate supervisor system and small group learning for individualized cultivation and development of students, (c) developing micro-courses and small course modules for flexible composition of

learning contents, (d) developing ability-oriented courses and learning units as learning models, and (e) establishing a university-industry collaborative education system that includes internships, creative projects, and entrepreneurship. Creating support resources for agile education is also crucial since the transformation to agile education requires abundant educational resources.

Agile education is conducive to open ecosystems for learning. Educational ecosystems encourage active promotion and constraint roles by engendering and developing an evolutionary education system. An open education ecosystem is a student-centric education system and environment that coordinates or integrates educational resources inside and outside a university. International resources are also possible through multi-channel collaborations for agile education and sustainable competencies development. A student-centric educational ecosystem can lead to interdisciplinary and comprehensive education, university-industry co-education, international joint education, creative and entrepreneurship education, and campus culture-based education. These, in turn, lead to agile education. Figure 2 illustrates these findings.

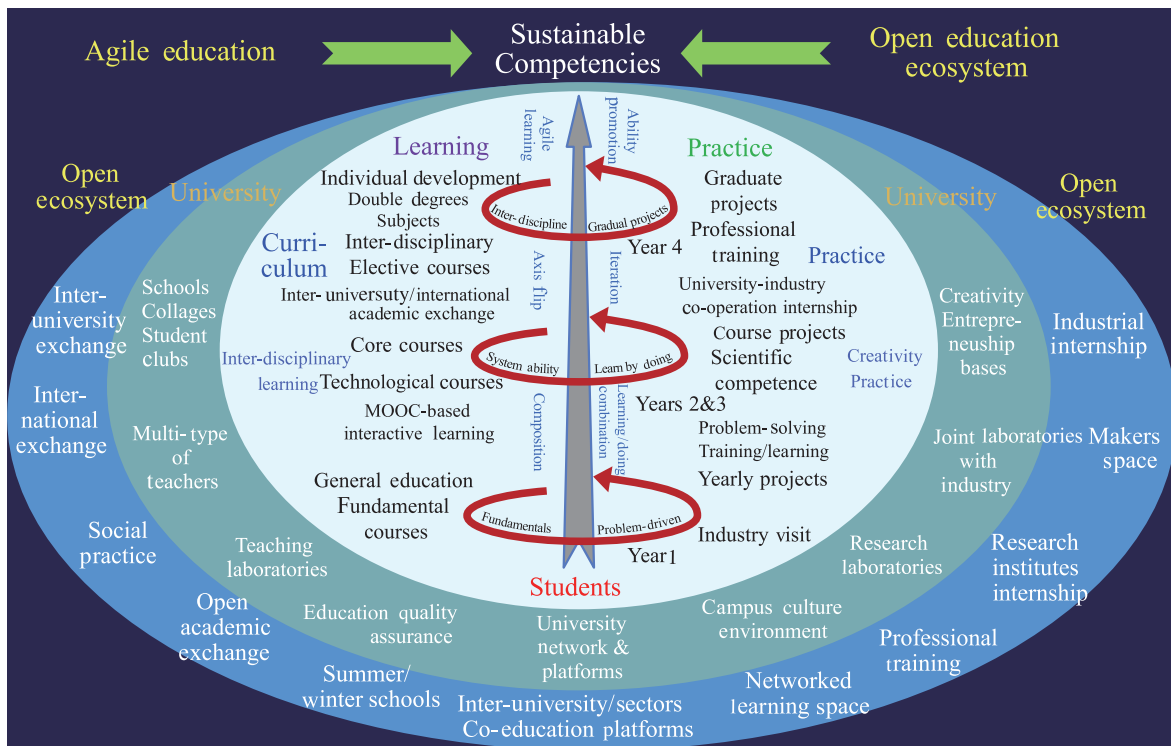


Figure 2 Open Ecosystems for Agile Education

Note. Made by Xiaofei Xu.

2.5 | Service-Oriented Computing Education

Service-oriented education is a natural outgrowth of agile education. Cultivating, ensuring, and continuously

enhancing students' sustainable competencies in their professional lives will become the future critical missions and educational service functions of universities. Educational transformation trends suggest that: qualified graduates ⇒ student lifetime sustainable competencies.

Service-oriented education is a new form of student lifetime sustainable development education. It performs a multi-phased, interdisciplinary, ongoing, and adaptive education that provides continuous multi-phases of agile education services for sustainable competencies during students' professional lives. Fundamentally, service-oriented education leads to (a) student lifetime-centric sustainable development continuous education, (b) individualized development purpose cultivation and learning, (c) open transboundary and interdisciplinary co-education services, (d) iterated multi-phased agile education and learning, (e) professional online and offline education centers, and (f) smart education service networked platforms. Ultimately, the process leads to students' lifetime sustainable competencies.

2.6 | Further Thoughts on the Blue Book

To cultivate innovative talents with sustainable competencies and adapt to the development of future emerging technologies and economies, it is essential to reform and restructure current higher education systems, models, and ecosystems with new forms of engineering and education for sustainable competencies. As a new and advanced education form, agile education promises to improve higher computing and engineering education. Xu (2023) promotes this concept in a presentation titled the Sustainable Competency-Oriented Software Engineering Education for the Future. These new forms of advanced education models and approaches (e.g., agile education, service-oriented education, intelligent education, and metaverse education) will achieve realization with practice and exploration at universities throughout China and beyond (Xu, 2023).

3 Summary of the CC2020 Competency Model²

The CC2020 Task Force had a diverse composition by gender, work, affiliation, geography, and global professional presence. It had 50 members (29 men and 21 women) representing 20 countries from 6 continents, where 43 came from academia and 7 from industry and government. For this effort, 6 people represented China. The CC2020 report received endorsement from 21 computing organizations and societies worldwide. The CC2020 report is available in both English and Chinese.

The CC2020 Task Force developed a definition of competency that evolved from those developed and

applied in the different educational frameworks reported in *Information Technology Curricula 2017: Curriculum Guidelines for Baccalaureate Degree Programs in Information Technology* (hereinafter referred as to IT2017 report) (ACM, 2017) and the SWECOM reports. The CC2020 report supports a consistent, scalable model for writing curricular specifications and competencies, provides a framework for creating competencies, and lets each program unit or curricular group develop its competencies for its purposes and interests.

3.1 | The CC2020 Competency Definition

The CC2020 report articulates the notion of competency as a practical educational goal that refines the Knowledge-Skill-Disposition (K-S-D) framework popularized in the IT2017 report. While the knowledge dimensions of computing have been extensively explored in the various computing curricula, what is meant by skill and disposition has had significantly less focus. Extending previous work, the CC2020 report specifies competency as composed of K-S-D dimensions observed within the performance of a task, T. That is, Competency = Knowledge + Skills + Dispositions, in performing a task taken in context. A competency specification enumerates knowledge, skills, and dispositions that are observable in accomplishing a task.

The four components (knowledge, skills, dispositions, and tasks) that structure the competency specification are defined as follows. Firstly, knowledge is the “know-what” competency dimension as a factual understanding. This dimension reflects the enumerated subject matter that teachers catalog as topics in their syllabi, and departments distribute and balance among the courses they develop in an academic program. Secondly, skills introduce the capability of applying knowledge to accomplish a task actively. Hence, a skill expresses an element of knowledge as acted upon with proficiency to define the “know-how” dimension of competency. Thirdly, dispositions frame the “know-why” dimension of competency and prescribe a temperament of quality of character in task performance. Dispositions moderate the behavior of applying “know-what” that becomes “know-how.” Fourthly, 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 efforts necessary to pursue and succeed efficiently and effectively. Figure 3 illustrates the conceptual structure of competency.

² The following is a condensation of material from the CC2020 report.

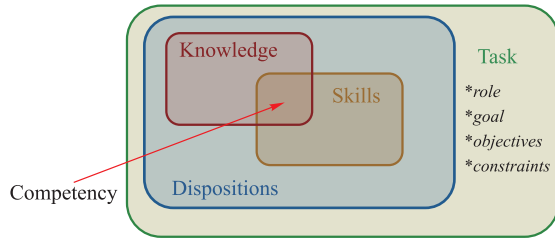


Figure 3 Conceptual Structure of the CC2020 Competency Model

3.2 | Competency Statements and Elements

A practical specification of competency is a synthesis of a colloquial, prose competency statement that sets out a task and the component structure of constituent K, S, and D elements necessary to succeed in that task. Essentially, a competency specification expresses a model of knowledge that is skillfully and professionally applied in some task execution. The competency statement

expresses the competency in terms that are familiar and understandable to a broad audience, typically using a familiar vocabulary that resonates with the stakeholder audience. The competency statement is then structurally augmented and amplified to enumerate knowledge, skills, and dispositions that complete the competency specification.

While the natural language of the competency statement favors a public audience, the competency component structure is more formal as it enumerates the components, e.g., knowledge elements demonstrated at a skill level and moderating dispositions determined necessary to demonstrate competency in the task. This structural enumeration of components is essential for automating comparative analyses and visualization of curricula. Having both the free-form of the competency statement and the more formal component-specific enumeration corroborates that the two perspectives align. Hence, a competency is a collection of specific components of knowledge, skills, and dispositions. Tables 1, 2, 3, and 4 present suggested elements of these dimensions.

Table 1 Elements of Computing Knowledge (Baseline Skills)

Users and organizations	Systems modeling	Systems architecture and infrastructure	Software development	Software fundamentals	Hardware
Social issues and professional practice	Security issues and principles	Virtual systems and services	Software quality, verification and validation	Graphics and visualization	Architecture and organization
Security policy and management	Systems analysis & design	Intelligent systems (AI)	Software process modeling and analysis	Operating systems	Digital design
IS management and leadership	Requirements analysis and specifications	Internet of things	Software design	Data structures, algorithms and complexity	Circuits and electronics
Enterprise architecture	Data and information management	Parallel and distributed computing	Platform-based development	Programming languages	Signal processing
Project management		Computer networks		Programming fundamentals	
User experience design		Embedded systems		Computing systems fundamentals	
		Integrated systems technology			
		Platform technologies			
		Security technology and implementation			

Note. From *Computing Curricula 2020: Paradigms for Global Computing Education*, by ACM/IEEE-CS, p. 49.

Table 2 Elements of Foundational and Professional Knowledge

Knowledge elements	Meaning
Analytical and critical thinking	A mental process of simplifying complex information into essential parts and evaluating results to make proper decisions
Collaboration and teamwork	Apportion challenging tasks into simpler ones and then work together to complete them efficiently
Ethical and intercultural perspectives	Ethical perspectives of the different viewpoints someone uses to view a problem in the context of individual human values
Mathematics and statistics	Use of numbers and theories abstractly, especially in the collection and analysis of numerical data
Multi-task prioritization and management	Processing several issues or tasks at once while arranging them according to importance to do a specific one first
Oral communication and presentation	Conveying a message orally using real-time presentations with visual aids related to audience interests and goals

(To be continued)

(Continued)

Knowledge elements	Meaning
Problem solving and trouble shooting	A logical and orderly search for the source of a unit problem and making the unit operational again
Project and task organization and planning	A process to provide decisions about a project concerning organization and planning to achieve a successful result
Quality assurance/control	Use of techniques, methods, and processes to identify and prevent defects according to defined quality standards
Relationship management	A strategy to maintain an ongoing level of engagement, usually between a business and its customers or other businesses
Research and self-starter/learner	Someone who begins or undertakes work or a project without needing direction or encouragement to do so
Time management	An ability to use a person's time in an effective or productive manner to work efficiently
Written communication	Use of a written form of interaction between people and organizations that provides an effective way of messaging

Note. From *Computing Curricula 2020: Paradigms for Global Computing Education*, by ACM/IEEE-CS, p. 50.

Table 3 Levels of Cognitive Skills Based on Bloom's Taxonomy

Remembering	Understanding	Applying	Analyzing	Evaluating	Creating
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, and giving descriptions	Solve problems in 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 solutions	Present and defend opinions by making judgments about information, validity of ideas, or quality of material	Compile information together in a different way by combining elements in a new pattern or by proposing alternative solutions

Note. From *Computing Curricula 2020: Paradigms for Global Computing Education*, by ACM/IEEE-CS, p. 50.

Table 4 Prospective Elements of Dispositions

Element	Elaboration	Element	Elaboration
Adaptable	Flexible; agile; adjust in response to change	Professional	Professionalism, discretion, ethical, astute
Collaborative	Team player, willing to work with others	Purpose-driven	Goal-driven, achieve goals, business acumen
Inventive	Exploratory; look beyond simple solutions	Responsible	Use judgment discretion, and act appropriately
Meticulous	Attentive to detail; thoroughness, accurate	Responsive	Respectful; react quickly and positively
Passionate	Conviction, strong commitment, compelling	Self-directed	Self-motivated, determined, independent
Proactive	With initiative, self-starter, independent		

Note. From *Computing Curricula 2020: Paradigms for Global Computing Education*, by ACM/IEEE-CS, p. 51.

The knowledge dimension of competency encompasses technical concepts (computing concepts), foundational and professional (indicative of a workplace), and domain-specific (the task setting). Table 1 illustrates 34 abbreviated knowledge areas partitioned into an ordered sequence of 6 categories. While the table is incomplete, it does provide an example of high-level vocabulary for computing knowledge rooted in the collective wisdom of different computing communities.

The 13 foundational and professional knowledge elements in Table 2 represent a subset of the professional listings derived from the IT2017 report. All professionals are commonly expected to demonstrate high skill levels in applying this knowledge, which deserves

explicit attention in baccalaureate programs. Industry often calls these *baseline skills* expected from all professionals, such as computing specialists and engineers. These elements may represent disciplinary elements (e.g., business, medicine, manufacturing) or global applications.

Skills define the second dimension of competency. One can think of skill as the proficient application of knowledge. Table 3 summarizes an ordered sequence of six cumulative skill levels (cognitive skill) and abbreviated definitions. These levels correlate with Bloom's taxonomy, permitting the adoption of a commonly agreed vocabulary as described in the 2001 revisions to Bloom's taxonomy of educational objectives (Anderson & Krathwohl, 2001).

Dispositions define the third dimension of competency. Table 4 displays 11 prospective dispositions derived from the literature. Disposition, as an intrinsic component of competency, represents the opportunity to express institutional and programmatic values expected in the workplace. Dispositional expectations enrich the description/assessment of competency and the related pedagogy. Ascribing a disposition to a skill indicates a clear commitment to self-reflection and examination that distinctly distinguishes a competency from a learning outcome. Dispositions are an essential characteristic of a well-structured competency model. People inherently know and recognize these elements of human behavior. The workplace and society assume that dispositions are expected of every competent computing

and engineering graduate.

3.3 | Creating Competency Frameworks

The competency model adopted in the CC2020 report suggests that statements surrounding competency include knowledge elements paired with skill levels together with dispositions. The following examples demonstrate a way to do this. Each of the three example competencies that follow specifies a statement of the task to be undertaken and itemizes the components deemed pertinent to effectively and efficiently accomplishing that task. Table 5 provides an example from computer engineering; Table 6 shows an example from software engineering.

Table 5 Competency Example from Computer Engineering

Competency title: A	
Competency statement Manage the design of a computer system for a manufacturer using appropriate tools, design digital circuits including the basic building blocks of Boolean algebra, computer numbering systems, and data encoding, with combinatorial and sequential elements	
Knowledge elements [Table #]	Skills level [Table 3]
Architecture and organization [1]	Understanding
Digital design [1]	Analyzing
Circuits/electronics [1]	Creating
Analytical and critical thinking [2]	Applying
Mathematics and statistics [2]	Analyzing
Problem solving and trouble shooting [2]	Understanding
Research and self-starter/learner [2]	Evaluating
Dispositions [Table 4]	
Self-directed	Meticulous
	Inventive

Note. From *Computing Curricula 2020: Paradigms for Global Computing Education*, by ACM/IEEE-CS, p. 51.

Table 6 Competency Example from Software Engineering

Competency title: B	
Competency statement Identify and document system requirements by applying a known requirements elicitation technique in work sessions with stakeholders, using facilitative skills, as a contributing member of a requirements team	
Knowledge element [Table #]	Skill level [Table 3]
Requirements analysis [1]	Evaluating
Oral communication [2]	Applying
Written communication [2]	Analyzing
Teamwork and collaboration [2]	Understanding
Disposition(s) [Table 4]	
Purpose-driven	Responsible
	Collaborative

Note. From *Computing Curricula 2020: Paradigms for Global Computing Education*, by ACM/IEEE-CS, p. 51.

4 The Viewpoints of the Digital Development of Global Higher Education³

The recent Infinite Possibilities report has raised the bar for producing high-quality education in a digital age. This report is guided by the Ministry of Education of the People's Republic of China. An author of this article, Xiaofei Xu, is a member of the writing group of the Infinite Possibilities report.

4.1 | The Highlights of the Infinite Possibilities Report

The highlights of the Infinite Possibilities report are briefly summarized to provide the reader with some of the ambitions and vision of digital education in computing and engineering for the future. This report addresses how humans invent technology, change society, and reshape the modes of production, life, and social interactions. With the invention of iron and later printing presses, human cognitive abilities and imagination changed. Technological applications to education exhibit similar characteristics with their pervasive transformative effects. Over the past decades, the world has witnessed that classrooms, smart classrooms, and immersive human-computer collaborative teaching environments have transformed education's fundamental conditions and infrastructure for the digital age.

Technology is also changing the most fundamental relationships within education. The traditional teacher-centered relationship is dissipating as teachers shift their focus from teaching to learning facilitators. Teaching and learning are moving from content-driven to multi-dimensional knowledge systems, while students have transformed from passive recipients to proactive learners. Teachers are no longer the owners of educational resources, and schools are no longer the sole providers of education.

Digital transformation has provided the foundation tools for innovative teaching and learning methods whereby personalized instruction on a massive scale has become possible. Technology development has provided opportunities for progress in educational evaluation, shifting the focus from the subject-object relationship to inter-subject relationship. Merging digital technology with higher education worldwide has promoted the systemic transformation of higher education and has reshaped educational concepts and goals. Digital technology has accelerated an unprecedented transformation in these areas. Digital technology has connected the world and has promoted the massive sharing and dissemination of educational resources. As a result,

governments, universities, and enterprises have taken more standardized measures to ensure higher education safety, health, quality, efficiency, and sustainable development in digital transformation.

History has told humanity to have an open and proactive attitude toward change. Digital technology has become the core driving force behind social and industrial transformations. Change presents opportunities and challenges whereby universities must lead social progress generated by technological innovation. While technology is neutral, its applications can result in positive and negative outcomes. Such challenges require the collective attention of the global higher education communities. Humanity becomes civilized through education, and education develops through technology. Promoting educational transformation and innovation is a shared task for all countries and people.

The mission of higher education is to create a better future world. Organizations should set an example for innovation and cooperation in the digital transformation of higher education. With this philosophy in mind, the Infinite Possibilities report is committed to consolidating global wisdom, forming global consensus, and gathering global forces to build a global community for the digital development of higher education. This report focuses on the application scenarios of digital technology in education, summarizes the historical context, achievements, and development trends of digital technology in global higher education, and proposes action strategies for the future digital transformation of education. This article provides an essential reference for understanding the level of digital development in higher education globally.

The Infinite Possibilities report has three chapters. The first chapter, titled "Deep Integration: Ubiquitous Transformation," addresses five areas: technological transformation, optimization, advancement, support, and empowerment. The discussion on the technologically driven transformation of learning environments addresses audio-visual sensory experiences, online learning spaces, ubiquitous learning environments, and intelligent human-machine collaborations. The discussion on optimizing learning resources addresses media forms, resource development, resource sharing, and automatic resource generation. The discussion that follows addresses technological advancements promoting the development of teacher and student competencies.

The second chapter, titled "Paradigm Reconstruction: Practicing Proactive Change," addresses four areas: personalized and targeted educational approaches, shared school-running models, flexible management systems, and standardized and reliable mechanisms. The area of fostering more personalized and targeted

³ The following is a summary of the 2023 *Infinite Possibilities: A Report on the Digital Development of Global Higher Education*.

educational approaches addresses interactive and immersive virtual teaching, data-driven and intelligence-supported targeted teaching, borderless and hybrid flexible learning, and personalized learning based on generative AI. The chapter also covers innovative and more open and shared school-running models by discussing cross-border collaborative education and cross-school credit recognition, internet-based resource integration and shared education, industry-education integration through intelligent platforms, and campus-free open education supported by metaverse.

The third chapter's title is "Challenges and Responses: A Collaborative and Win-Win Future." The chapter addresses three areas: digital technology in higher education, challenges for applying digital technology in higher education, and action strategies. The discussion on development trends of digital technology in higher education addresses the internet enhancing new connections in education elements, the internet of things to facilitate new digital education spaces, Big Data for targeted educational services, blockchain to accelerate new learning evaluation, generative AI for education and teaching, and metaverse advancing for an integrated virtual-physical education field. The chapter also addresses action strategies, including establishing an interconnected digital infrastructure for education, building a flexible and open mechanism for the recognition of digital learning achievements, training a highly skilled and continuously improving teaching workforce with digital literacy, developing ethics and security standards for the digital transformation of education, improving the governance system of higher education empowered by data, and building a research network and cooperation platform for the digital transformation of education. These achievements would significantly contribute to education in the digital age.

4.2 | Reflections on the Infinite Possibilities Report

From the above, higher education faces challenges and opportunities in the rapidly evolving landscape of the 21st century. The Infinite Possibilities report generated special significance for traditional educational paradigms. Its key themes include accessibility, personalized learning, global collaboration, and the role of emerging technologies.

One of the salient achievements in the digital development of higher education is enhanced accessibility and inclusivity. The widespread availability of online courses and degree programs has democratized education, breaking down geographical barriers and providing learning opportunities to previously excluded individuals. Massive Open Online Courses (MOOCs) have allowed learners across the globe to access high-quality

content from prestigious institutions. This inclusivity promotes diversity in higher education, fostering a global community of learners with varied backgrounds and perspectives.

Digital development has generated personalized learning, catering to students' needs and preferences. Adaptive learning algorithms analyze students' performance data to tailor educational content, pacing, and assessments. Integrating AI with machine learning algorithms facilitates the creation of intelligent tutoring systems. These systems provide real-time feedback, identify learning gaps, and recommend personalized resources to enhance student understanding. Educators can focus on mentorship and guiding students, creating a symbiotic relationship between humans and machines in learning.

The digital transformation of higher education has eliminated geographical boundaries. Virtual classrooms, collaborative online projects, and cross-cultural exchanges have become integral to the modern educational experience. Interconnected learning ecosystems allow students to engage in collaborative projects, share insights, and participate in joint research with peers from different continents. Virtual reality and augmented reality technologies enable new experiences, transporting students to virtual campuses and laboratories, transcending physical limitations, and enhancing the quality of education.

The digital development of global higher education is intrinsically tied to the evolution of emerging technologies. Blockchain technology can revolutionize credentialing and authentication processes, ensuring the security and integrity of academic records. Integrating augmented reality in education offers immersive and interactive experiences, enhancing understanding of complex subjects like science, engineering, and medicine.

Reflecting on the Infinite Possibilities report, one notices that technological advancements will continue to shape the future of education, presenting opportunities and challenges. The role of educators will evolve to encompass content delivery, mentorship, guidance, and the cultivation of critical thinking skills in the digital era. The integration of ethical considerations is crucial as higher education becomes increasingly digitized. Collaborative efforts among educational institutions, policymakers, and technology developers are essential to navigate responsibly the evolving landscape of digital education.

The Infinite Possibilities report has opened many possibilities. The accessibility and inclusivity afforded by online education, coupled with personalized learning experiences and global collaboration, have reshaped the traditional higher education landscape. Emerging technologies are pivotal in offering innovative solutions and transforming knowledge acquisition and dissemination. The future of global higher education is

dynamic, promising, and full of potential. By leveraging the power of technology and fostering a collaborative and inclusive learning environment, the world can embark on a journey toward educational excellence that knows no bounds.

5 Discussion and Results

This work has presented three educational developments: the Blue Book, the CC2020 report, and the Infinite Possibilities report. These are independent efforts but center around a central theme to provide competency for those entering the digital workforce. These efforts contain a central theme on the importance of computing education.

5.1 | Importance of Computing Education

One outcome of the three publications is the skill development of a digital workforce. Digital literacy is no longer optional; it is a prerequisite for success. Computing education equips individuals with the skills to navigate and contribute to the digital landscape. Proficiency in coding, data analysis, and problem-solving empowers students to meet the demands of an increasingly technology-driven workforce (Brown, 2019). Computing education also fosters critical thinking and problem-solving so students can become proficient in analyzing and solving complex problems. The ability to approach challenges systematically and think algorithmically is crucial and contributes to a well-rounded education (Wing, 2016).

Computing education also promotes innovation and creativity. The digital age thrives on innovation, and computing education catalyzes creative thinking. The world nurtures a culture of innovation that fuels technological advancements and economic growth by providing students with the tools to create software, applications, and digital solutions (Barr & Stephenson, 2011). The future job market will demand a workforce with strong computing skills. From AI to cybersecurity, proficiency in computing is becoming integral to a diverse array of industries. A solid foundation in computing education ensures that individuals are prepared for the dynamic nature of future careers (National Research Council, 2010).

The promises of computing education take work. Despite many efforts, there are disparities in access to computing education, with marginalized communities often facing limited opportunities. Addressing these inequalities is crucial to ensure that all students, regardless of background, can benefit from the transformative power of computing education (Margolis & Estrella, 2010). Additionally, the rapid evolution of

technology challenges educators to keep the curriculum relevant. Constant updates and adaptations are necessary to ensure that students are learning the most current and applicable skills in the ever-changing landscape of computing (Grover & Pea, 2013). Therefore, as one navigates the complexities of the digital age, computing education emerges as a linchpin for individual success and societal progress. By providing students with the skills, mindset, and knowledge required to thrive in an interconnected world, computing education becomes an indispensable component of contemporary education systems.

5.2 | Addressing the Research Questions

In Section 1.2 of this work, the authors presented two research questions and extensive summaries of three current reports. Section 2 addressed the Blue Book, Section 3 addressed the CC2020 report, and Section 4 addressed the Infinite Possibilities report.

The first research question, RQ-1, is as follows: Has competency-based learning in computing and engineering transformed into the current digital age?

The answer is in the affirmative based on the results from the Blue Book and the CC2020 report. The Blue Book promotes competency in computing and engineering and accomplishes this endeavor with detail and elegance. The central theme of the CC2020 report is the transformation from knowledge-based learning to competency-based learning. Hence, the CC2020 report supports RQ-1. The Infinite Possibilities report promotes worldwide learning in a digital setting, implying computing and engineering competence on a worldwide scale. Therefore, this effort satisfies the first research question. Since three significant global efforts support this question, it is safe to say that competency-based learning in computing and engineering has transformed into the current digital age.

The second research question, RQ-2, assumes the affirmative on RQ-1. Its statement is as follows. If so, to what extent has computing and engineering education adopted competency-based learning in their curricula?

The three publications above support the promise of curricular adaptation of their underlying principles. However, these publications have yet to prove that universities have adopted a competency-based approach to learning. Therefore, the second research question remains open. Future endeavors may answer such a query.

6 Conclusion

Three significant publications all articulate, directly or indirectly, that competency-based learning must be part of computing and engineering education. Sustainable

competency should always be part of technological and digital education, and it must be agile and responsive to rapid changes in the digital era. Competency is a triad of knowledge, skills, and human dispositions and must be part of all computing and engineering graduates' lives if they expect to succeed in the workplace.

The findings of this study provide vital insight into the status of digital education. They show that competency-based education is necessary for success in the workplace to meet the endurance of dramatic change in the digital era. The Blue Book argues that sustained competency is essential for stability in a changing technological world. It also promotes agility in being responsive to change. The CC2020 and its report have made the case that in a digital age, competency must prevail. Such competency involves human behavior or dispositions and skills at appropriate levels to perform a task in context. Knowledge alone is not sufficient to be successful in the digital era. Finally, the Infinite Possibilities report outlines the terrain for digital success. It has recommended several action strategies to achieve its goal, such as establishing an interconnected digital infrastructure for education and building a flexible and open mechanism to recognize digital learning achievements.

Despite the enthusiasm and almost boundless energies, the aspirations of many provide no guarantee that the goals of the three reports will succeed. For example, for the CC2020 report, scholars have written many papers and made numerous presentations; agencies have funded projects to promote competency. However, few computing and engineering programs have implemented competency in their curricula. The same is true with the Blue Book. While many believe in the merits of sustainable and agile competency, it is not easy to ascertain which computing and engineering programs have adopted and implemented such a philosophy. This pristine example of educational elegance has yet to be adopted globally. The Infinite Possibilities report is new, and it will take years to explore whether its robust promises will take hold globally. Therefore, educational institutions, computing and engineering organizations, and governmental agencies must be prepared to adopt the tenets of these three reports and provide the necessary funding to make their promises a reality.

More work is needed to monitor the future of these three publications. It will take human endurance and fiscal support to make these works come to fruition. The digital era is changing rapidly. The world cannot wait to see what happens. Professionals must act now to make sustainable competency and agile responsiveness an integral part of the digital era in which we live.

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