Computing Competencies: Mapping CC2020 Dispositions to SFIA Responsibility Characteristics

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***Abstract*—In the past decade, academic computing curricular guidelines have shifted from specifying knowledge and occasionally technical skills to establishing the overall competence expected of graduates. For instance, Computing Curricula 2020 (CC2020) guidelines identify competency as knowledge, skills, and dispositions where "dispositions" correspond to the behavioral and professional characteristics driven by employer needs and captured by industry-driven frameworks, such as the Skills Framework for the Information Age (SFIA). Computing programs thus must also ensure that graduates have these characteristics to improve initial employment and long-term career prospects. This paper aims to understand and achieve consistency between academia and industry curricular frameworks. The CC2020 dispositions map to the responsibility characteristics for SFIA Level 3, the level appropriate for a new graduate. As the mapping is not one-to-one, the paper reviews the extent to which each SFIA responsibility characteristic requires and enables the CC22020 dispositions, identifying potential shortcomings and, conversely, the importance of each disposition as it supports the responsibility characteristics. The developed mapping is validated by relating the CC2020 dispositions to the SFIA behavioral factors, the principal "21st Century Skills," and relevant competency-based educational frameworks. Thus, dispositions in competency-focused curricula map to the actual competencies sought by employers. Finally, the paper postulates that future computing curricula must further develop the CC2020 dispositions and relate them to SFIA to guide academic programs in their preparation of career-ready graduates to reduce the current "skills gap".**

***Index Terms*—Skills Frameworks, Computing Competencies, Dispositions, SFIA, Computing Curricula 2020.**

I. Introduction

The gap between employer requirements and the capabilities of computing graduates has undergone investigation and received publication in recent years. For example, Shadbolt [1] and Hart [2] identify common perceptions of a lack of real-world experience and work readiness, particularly concerning interpersonal skills. Also, given the widely held perception that students enroll for bachelor's degrees in computing to improve their career prospects, it is appropriate for curricular guidelines to reference the skills and behavioral characteristics identified by employers. Computing programs must ensure that graduates have the skills set out in industry frameworks to enhance their employment prospects, considering the reported skills gap.

Academic curricular guidelines published in 2017 for bachelor's programs in information technology (IT2017) [3] and informatics [4] addressed the skills gap by introducing professional competencies, which comprise knowledge, skills, and dispositions. Most recently, the ACM and IEEE Computer Society issued the Computing Curricula 2020 (CC2020) report [5], which represents paradigms for global computing education. In particular, CC2020 uses competencies across all computing disciplines, emphasizing the importance of dispositions among competency components for academic programs. Also, interest has grown in "21st Century Knowledge and Skills (C21)" [6], [7] developed for school curricula. To raise the profile of interpersonal skills, others, such as Ward [8], have proposed using C21 skills as a profiling lens for the accreditation of computing degree programs.

Industry groups have developed skills and competency frameworks that specify technical skills and people/social skills in parallel with these academic activities. In computing, arguably the most widely used is the Skills Framework for the Information Age (SFIA) [9], which has been updated incrementally since its inception in 2001, with version 8 released in 2021. Uniquely, SFIA distinguishes behavioral characteristics from technical competencies, grouping them to characterize seven distinct levels of responsibility that might correspond to various stages in an individual's career trajectory.

To our knowledge, there has been no previous study seeking to operationalize dispositions by referencing a professional competency framework. This paper addresses this unanswered question and makes two contributions. First, it presents an approach that characterizes dispositions in terms of professional workplace behaviors. These characterizations are actionable descriptions of experiences that academic programs can and should develop in their graduates. Second, this study describes and applies a validation approach to ensure that the computing dispositions presented in the CC2020 report and their mapping to SFIA responsibility characteristics are appropriate.

The rest of the paper is organized as follows. After a brief overview of the CC2020 dispositions and relevant industry and educational competency frameworks (Section II), Section III describes the CC2020 disposition mapping to SFIA Level 3 "Apply" responsibility characteristics. Section IV describes the validation approach and Section V discusses the many-to-many mapping between CC2020 dispositions and SFIA responsibility characteristics and raises questions of interest for further research. Concluding remarks are in Section VI.

II. Background

Even if new to computing, the notion of competency is not new, and its concept goes back centuries and millennia. For example, as early as the 18th century BCE, the Babylonian Code of Hammurabi required artisans to transfer competence in their crafts to the next generation, which eventually led to crafts guilds in Medieval Europe and the notion of apprenticeship [10]. It is also not new to modern professions, as the teaching [11], medical [12] and legal [13] professions have a well-developed understanding of competency.

Competencies have been defined as follows [14]:

> "...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, competency identifies with a job- and role-related behavior, performance, and effectiveness. It is a person-centered concept that requires demonstrating technical knowledge, skills, and disposition that characterizes job expertise.

ACM/IEEE-Computer Society's curricular guidelines for Information Technology (IT2017) [3] heralds a dramatic shift away from a curricular framework primarily based on content knowledge to one that emphasizes the centrality of competency in IT education. The IT2017 report introduces an operational definition of competency that connects three interrelated dimensions: knowledge, skills, and dispositions. It affirms the importance of a professional context that enables students to practice, develop, and demonstrate their competencies. Before the release of IT2017, the Software Engineering Competency Model (SWECOM) [15] and the report on graduate Information Systems programs known as MSIS2016 [16] also use competencies to frame their curricular recommendations. The IT2017 report and CC2020 report describe the competency concept simply as:

$$Competency = Knowledge + Skills + Dispositions$$

where Knowledge designates the "know-what" dimension of competency, Skills designate its "know-how" dimension, and Dispositions encompass one's beliefs, values, attitudes, social, emotional, and volitional qualities or the "know-yourself" and "know-why" dimension. Figure 1 from CC2020 illustrates the conceptual structure of competency contextualized by the *task* in which someone performs competency.

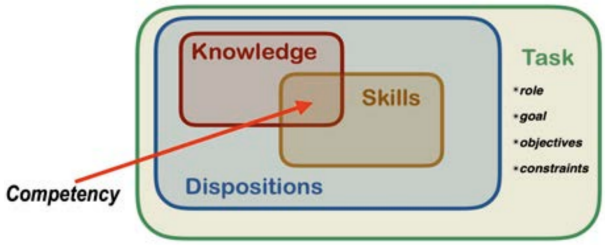

Fig. 1. Conceptual Structure of the CC2020 Competency Model

A. CC2020 Dispositions

Within competency, people have recognized knowledge for millennia, with schools and universities adept at conveying it from teacher to student. Additionally, skills have also become well-established as performative forms of expertise. Consider a musician, a dancer, a carpenter, or a surgeon. They all possess specific skills performed at some level of expertise. Dispositions, however, have not received the attention they deserve.

Dispositions express the human dimension of competency or qualities within an individual and behavioral patterns shaped by personal beliefs, values, and attitudes. They act as intentions and sensitivities and determine whether, what, and how individuals might use their knowledge and skills [17]. Dispositions moderate one's behavior of applying knowledge and skills [18], [19]. Thus, competency is a collection of specific knowledge, skills, and dispositions components.

CC2020 defines eleven dispositions derived from the literature, as listed in Table I, along with equivalent elaborations.

TABLE I
CC2020 DISPOSITIONS

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

Dispositions intricately involve statements related to academic and workplace activities. People inherently know and recognize dispositional characteristics of human behavior. Although it may be challenging to teach dispositions, faculty can facilitate student learning and development of dispositions through competency-based pedagogical and assessment approaches, including sustained and deliberate practice, case

TABLE II
DISPOSITIONS SURVEY OF GRADUATES AND INDUSTRY PROFESSIONALS FROM U.S. AND THE WORLD

Disposition	U.S. Results	Global Results	Weighted Average
Adaptable	85.0%	93.5%	92.0%
Collaborative	75.0%	89.0%	86.6%
Inventive	75.0%	91.3%	88.5%
Meticulous	70.0%	91.3%	87.6%
Passionate	70.0%	85.9%	83.1%
Proactive	79.0%	96.7%	93.6%
Professional	75.0%	95.7%	92.0%
Purpose-driven	70.0%	96.7%	92.1%
Responsible	80.0%	100.0%	96.5%
Responsive	75.0%	64.1%	66.0%
Self-directed	95.0%	95.7%	95.5%
Mean	77.2%	90.9%	88.5%

studies, participation in authentic and performative experiences, peer evaluation, and self-reflection activities. Both workplace and society expect that dispositions are part of every competent computing graduate.

A research study involving more than six hundred high-performance computing (HPC) professionals in the United States and the world investigated to what extent dispositions were meaningful in the HPC community [20]. Table II shows the results from 114 respondents (19% response rate). The global responses for most dispositions were more favorable than those from the United States. For example, there was a greater than 90% favorable inclination for dispositions for six out of eleven dispositions from weighted-average respondents and eight out of eleven from global respondents. This simple survey shows that dispositions are a significant dimension of competency, as applied to HPC, and are also likely to be an essential component of all computing.

A separate study [21] explores dispositions in computing education, emphasizing relevant pedagogical theories, various skill frameworks, as well as competencies and standard practices in other professional disciplines such as medicine and law. It concludes that there is an integrative nature to content knowledge, skills, and professional dispositions in defining professional competencies. The report also examines appropriate pedagogies and competency assessment approaches, provides guidelines for evaluating student achievement against relevant professional competency frameworks, and explores strategies to offer students professional experiences.

B. Industry Competency Frameworks

Employers look for a return on their investment when hiring new graduates. Therefore, they focus on what recent graduates can do and how well they carry out tasks on the job. Also, working in real-world environments has economic and financial consequences. Therefore, skills and dispositions have highly significant meaning in the workplace. Industry competency frameworks help employers associate skills and a range of other characteristics corresponding to professional dispositions with workplace activities requiring such competencies. Among industry competency frameworks in computing, this paper views SFIA as the most relevant for helping academic programs develop professional competencies in their graduates. The rest of this section provides an overview of SFIA and two other IT-related competency frameworks and concludes with some comparison remarks.

1) Skills Framework for the Information Age (SFIA): SFIA [22] describes professional skills and competencies required across the broad field of computing. It is the reference framework for the IFIP International Professional Practice Partnership (IP3), which sets standards for computing professional bodies to certify individual professionals (IP3P) and technologists (IP3T) [23]. SFIA has become a widely adopted competency framework, with users in more than 180 countries, from small employers, professional bodies, and public sector organizations to multi-national corporations and governments. The framework is published in a dozen languages, and a global community updates and maintains the document through an open and collaborative process.

SFIA currently (Version 8) lists more than 120 technical skills that employers have indicated as necessary for their IT functions [9]. SFIA also characterizes seven generic *levels of responsibility* across five key areas of Autonomy, Influence, Complexity, Knowledge, and Business Skills [24]. The seven levels are Follow (Level 1), Assist (Level 2), Apply (Level 3), Enable (Level 4), Ensure/Advise (Level 5), Initiate/Influence (Level 6) and culminate with Set Strategy/Inspire/Mobilize (Level 7).

SFIA is used to specify jobs or roles for hiring. Employers usually seek evidence of a range of job-related behaviors in candidates. So, SFIA also identifies eleven *behavioral factors* [25], listed in Table III. It maps these 11 factors to the responsibility characteristics. Based on the responsibility characteristics, these behavioral factors are also generic and relevant to organizational structures and working methods, specifically in particular organizations.

TABLE III
SFIA BEHAVIORAL FACTORS

Collaboration	Creativity	Communication Skills
Decision Making	Delegation	Execution Performance
Influence	Leadership	Learning & Prof. Development
Planning	Problem Solving	

A two-dimensional matrix with rows denoting skills and columns denoting responsibility levels represents the SFIA framework. Thus, an individual can demonstrate competence in a skill at a particular level by performing the tasks and activities specified for a cell in the framework. These include both level-based technical activities and the demonstration of the responsibility characteristics for that level.

2) Other IT Industry Competency Frameworks: The European e-Competence Framework (e-CF) [26], and the "i Competency Dictionary" (iCD) frameworks are two other examples

of information technology (IT) competency frameworks that help employers evaluate their employees' performance.

The European e-Competence Framework (e-CF) [26] intends to be an alternative to SFIA aimed at European IT professionals. The e-CF defines a "competency" as the "demonstrated ability to apply knowledge, skills, and attitudes for achieving observable results." In the e-CF framework, the "ability to carry out managerial or technical tasks" represents a skill, while "cognitive and relational capacity" denotes the attitude component of competency. Forty-one competencies, each with five proficiency levels, comprise the e-CF framework. The competencies cover application development, information security, and change management content knowledge topics.

The iCD framework is a significant project of the Information Promotion Agency (IPA) [27], an organization governed by the Ministry of Economic, Trade, and Industry of Japan. Developed by a government agency, iCD is made available to industry users rather than being developed by industry. More than a thousand companies in 24 countries use the iCD framework, although Japanese companies dominate its use. The iCD framework leverages existing bodies of knowledge such as the Software Engineering Body of Knowledge (SWEBOK) [28] and Project Management Body of Knowledge (PMBOK) [29]. iCD attempts to connect IT knowledge to IT competencies expected in the workplace by maintaining task and corresponding skills dictionaries at four different granularity layers. For example, a Task $\times$ Skill table classifies the skills needed to accomplish a task. This Task $\times$ Skill table could be vast for many tasks and skills.

SFIA, e-CF, and iCD differ in availability, granularity, and update frequency. Although iCD is updated annually and available in English and Japanese, its use remains predominantly in Japan. The e-CF has a triennial update and is available in several European languages. Still, it has yet to build an ecosystem of users and support structures outside the European Union. Even though SFIA updates every three years, it is available in twelve languages. It has worldwide use, and it is also attracting interest in higher education.

C. Educational Competency Frameworks

1) 21st Century Skills: The notion of "21st-century skills" (*C21 skills*) grew out of a growing perception of the need to prepare children better for employment in the "knowledge economy" as it developed in the late 1990s and early 2000s [6]. In addition, there is a growing realization that C21 skills apply across all professions, thus applicable in higher education, for example, Ward et al. [8]. However, rather than a single global vision, disparate projects evolved independently and proposed C21 skills frameworks in international, national, and regional contexts. Therefore, no single definition exists of what C21 skills comprise or how to develop and assess these skills.

Attempts to integrate these different frameworks led only only to limited success [7], [30], [31]. Voogt and Roblin [30] compared eight popular frameworks noting that significant differences remain between them despite the considerable overlap. They also noted that C21 skills transcend disciplinary subjects across a wide range of professions. However, several frameworks explicitly specify core subjects and support the defined skills. Excluding core subjects, Voogt and Roblin [30] identified 16 C21 skills with different levels of representations across frameworks, shown in Table IV. For example, collaboration and communication exist in all eight frameworks, but learning to learn and adaptability occur in only a few.

TABLE IV
COMMON C21 SKILLS REPRESENTATION ACROSS DIFFERENT FRAMEWORKS, ADAPTED FROM VOOGT & ROBLIN [30, TABLE 4]

Framework Representation	**C21 Skills**
All frameworks	Collaboration, Communication, ICT literacy, Social and/or cultural skills and citizenship
Most frameworks	Creativity, Critical thinking, Problem-solving, Developing quality products/ Productivity
Some frameworks	Learning to learn, Self-direction, Planning, Flexibility and Adaptability
One framework	Risk taking, Manage and solve conflicts, Initiative/Entrepreneurship, Interdisciplinary themes

2) Other Competency-based Educational Models: Competency-based educational models adopt a holistic view of learning that complements content knowledge acquisition and cognitive skills development with fostering learning and development of professional dispositions. What follows is an overview of two competency-based educational models from the *Education for Life and Work* report of the National Research Council [6] and Fink's *Significant Learning* model.

TABLE V
INTRAPERSONAL AND INTERPERSONAL COMPETENCIES, ADAPTED FROM THE NATIONAL RESEARCH COUNCIL'S REPORT [6, TABLE 2-2]

	Intrapersonal competencies
Intellectual openness	Flexibility, adaptability, artistic & cultural appreciation, personal & social responsibility, intellectual interest & curiosity
Work ethic	Initiative, self-direction, responsibility, perseverance, metacognition, self-reflection, professionalism, career orientation
Positive core self-evaluation	Self-monitoring, self-evaluation, self-reinforcement
	Interpersonal competencies
Teamwork and collaboration	Communication, collaboration, teamwork, cooperation, coordination, empathy/perspective taking, service orientation, conflict resolution, negotiation
Leadership	Leadership, assertive communication, self-presentation, social influence with others

The *Education for Life and Work* report [6] identifies three domains of competencies for success in school, workplace, and other areas of adult responsibility:

- *Cognitive competencies* involving thinking, memory, reasoning, and related skills
- *Intrapersonal competencies* that include self-regulation of one's behavior and emotions to reach one's goals, including learning goals

- *Interpersonal competencies* by which individuals express information to others, interpret others' messages, and respond appropriately.

Content analysis of several proposed skills taxonomies leads to a competency classification scheme around the three domains of cognitive, intrapersonal, and interpersonal competencies [6]. The classification scheme further decomposes into closely related competency clusters for each domain. For example, the cluster of cognitive competencies encompasses content knowledge and skills. The clusters of intrapersonal and interpersonal competencies, shown in Table V, are dispositional competencies. They describe affective and social qualities, attitudes, personal beliefs, and values within an individual, influence one's subsequent behaviors, and reflect learning and workplace environments.

Another competency-based educational model that explicitly identifies and promotes dispositions is the Significant Learning model [32]. Proposed in 2003 by L. Dee Fink, the model complements the cognitive view of learning in Bloom's popular taxonomy [33] with a human-centric view to emphasize the value of learning and its lasting change to the student's individual, social, and work life.

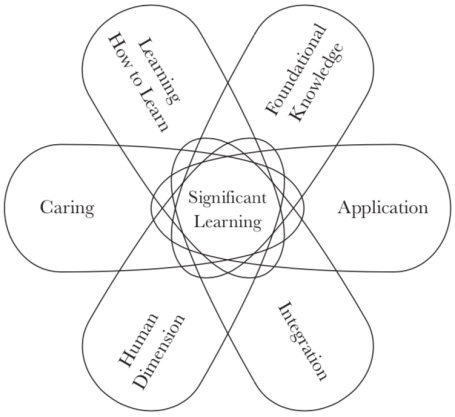

Fig. 2. Significant learning model [32]

The three dimensions on the left in Figure 2 convey that learning reaches significance when students (a) learn about themselves and others (human dimension), (b) care about what they learn as it connects to personal values and interests (caring dimension), and (c) make learning an integral part of their lives (learning how to learn). These dimensions are in alignment with intrapersonal and interpersonal competencies in the *Education for Life and Work* study. The human dimension refers to understanding oneself and others to act and interact more effectively, which means managing one's internal states, impulses, resources and knowing how to direct actions and interactions while being aware of others' feelings, needs, or concerns. Caring raises awareness of the personal and social implications of learning and affective responses in students, such as curiosity, interest, and personal and social responsibility. Learning how to learn includes self-regulation strategies coupled with critical reflection on lifelong learning and valuing continuous improvement.

In the US, the National Institute for Standards and Technology has published a Workforce Framework for Cybersecurity (NICE Framework) that describes the tasks, knowledge, and skills needed to perform cybersecurity work [34]. The intent is to enable organizations to develop the competencies of their workforce to perform cybersecurity work.

III. Mapping the Dispositions

Despite the lists of synonyms shown in Table I, CC2020 dispositions are somewhat abstract. This paper uses industry-focused descriptions of workplace tasks and activities that require and enable the demonstration of each CC2020 disposition. The SFIA Level 3 "Apply" *responsibility characteristics* describes performative tasks expected of computing graduates and map them to the eleven CC2020 disposition concepts, as shown in Table VI. Each checkmark indicates where a SFIA responsibility characteristic reasonably indicates the corresponding CC2020 disposition.

SFIA Level 3 is appropriate for recent graduates with basic computing competence who are not yet in a position to "Enable" (Level 4) others. The mappings of degree outcomes completed by the Institute of Coding [35] in the UK supports this level selection. It is also the SFIA level specified for both the British Computer Society (BCS) Registered IT Technician [36] and IP3 Technologist [37].

Each responsibility characteristic determines the disposition(s) needed to demonstrate that characteristic to construct the mapping. The counts associated with responsibility characteristics (3rd table column) show the number of dispositions supporting each responsibility characteristic. The counts related to dispositions (2nd table row) show the number of responsibility characteristics that require each disposition.

The mapping is not one-to-one. A responsibility characteristic may exhibit more than one disposition, which may support more than one responsibility characteristic. The mapping is deliberately inclusive, resulting in the significant overlap between the responsibility characteristics that a particular disposition supports and the dispositions required to support specific responsibility characteristics. There was no attempt to generate a minimal or irreducible mapping. Likewise, there was no attempt to demonstrate orthogonality between the dispositions or the responsibility characteristics. Instead, the purpose and utility of the mapping are to operationalize the dispositions by describing workplace-relevant contexts in terms of generic tasks that create conditions for dispositions to manifest.

IV. Validation

To remove subjectivity, the mapping shown in Table VI needs validation. The top row represents the eleven CC2020 dispositions and shown in Table I. The left column shows SFIA responsibility characteristics for Level 3 (Apply), grouped into five key areas (autonomy, influence, complexity, knowledge, and business skills). The mapping checks with (a) the SFIA (v8) behavioral factors (Table III), (b) the 21st Century Skills

TABLE VI
MAPPING BETWEEN SFIA LEVEL 3 RESPONSIBILITY CHARACTERISTICS AND CC2020 DISPOSITIONS

SFIA Level 3 Responsibility Characteristics			Adaptable	Collaborative	Inventive	Meticulous	Passionate	Proactive	Professional	Purpose-driven	Responsible	Responsive	Self-directed
...			6	9	2	7	7	7	20	7	12	10	13
Autonomy	Works under general direction.	2							✓		✓		
	Uses discretion in identifying and responding to complex issues related to own assignments.	4	✓						✓			✓	✓
	Receives specific direction, accepts guidance and has work reviewed at agreed milestones.	3				✓			✓		✓		
	Determines when issues should be escalated to a higher level.	5		✓				✓	✓		✓	✓	
	Plans and monitors own work (and that of others where applicable) competently within limited deadlines.	7				✓	✓	✓	✓	✓	✓		✓
Influence	Interacts with and influences colleagues.	7		✓			✓	✓	✓		✓	✓	✓
	Has working level contact with customers, suppliers and partners.	4	✓	✓					✓			✓	
	May oversee others or make decisions which impact routine work assigned to individuals or stages of projects.	4		✓				✓			✓		✓
	Understands and collaborates on the analysis of user/customer needs and represents this in their work.	4		✓					✓	✓		✓	
	Contributes fully to the work of teams by appreciating how own role relates to other roles	4		✓					✓		✓	✓	
Complexity	Performs a range of work, sometimes complex and non-routine, in a variety of environments.	4	✓		✓					✓			✓
	Applies a methodical approach to routine and moderately complex issue definition and resolution.	4				✓			✓	✓			✓
	Applies and contributes to creative thinking or finds new ways to complete tasks.	4	✓		✓			✓					✓
Knowledge	Has a sound generic, domain and specialist knowledge necessary to perform effectively in the organization typically gained from recognized bodies of knowledge and organizational information.	3					✓		✓	✓			
	Demonstrates effective application and the ability to impart knowledge found in industry bodies of knowledge.	3		✓			✓		✓				
	Has an appreciation of the wider business context.	3							✓	✓	✓		
	Absorbs new information and applies it effectively.	4	✓				✓					✓	✓
Business Skills	Demonstrates effective oral and written communication skills when engaging on issues with colleagues, users/customers, suppliers and partners.	5		✓			✓		✓	✓	✓		
	Understands and effectively applies appropriate methods, tools, applications and processes.	3				✓			✓				✓
	Demonstrates judgement and a systematic approach to work.	4				✓			✓		✓		✓
	Effectively applies digital skills and explores these capabilities for their role.	4				✓		✓	✓				✓
	Takes the initiative to develop own knowledge and skills by identifying and negotiating appropriate development opportunities.	6	✓				✓	✓	✓			✓	✓
	Security, privacy and ethics — demonstrates appropriate working practices and knowledge in non-routine work.	5				✓			✓		✓	✓	✓
	Appreciates how own role and others support appropriate working practices.	4		✓					✓		✓	✓	

(Table IV), (c) the intrapersonal and interpersonal competencies identified in the Education for Life and Work report (Table V), and the Significant learning taxonomy (Figure 2).

A. Comparison using SFIA and C21 Frameworks

The mapping of CC2020 dispositions [5] in Table I compares with the SFIA behavioral factors [25] in Table III and the canonical list of C21 skills [30] in Table IV. Table VII shows that there are comparison points for all but three of the dispositions in both of the behavioral factors and C21 skills. The three dispositions are *passionate*, *professional*, and *responsible*, all italicized in the table.

Several behavioral factors and C21 skills map better to foundational and professional knowledge and skills identified in the CC2020 report than dispositions. However, there are two notable exceptions in the C21 skills, which map to neither: *ICT*

TABLE VII
CC2020 DISPOSITIONS, SFIA BEHAVIORAL FACTORS AND C21 SKILLS

CC2020 Dispositions	SFIA Behavioral Factors	21st Century Skills
Adaptable		Flexibility / adaptability
Collaborative	Collaboration; Communication skills	Collaboration
Inventive	Creativity	Creativity
Meticulous	Evaluation Performance	
Passionate		
Proactive	Learning/Professional Development	Self-direction
Professional		
Purpose-driven	Planning	Planning
Responsible		
Responsive	Influence	
Self-directed		Learning to learn; Self-direction

literacy and *Social/cultural skills and citizenship*, although the former is an explicit SFIA responsibility characteristic.

Comparing the realization of each disposition in Table VI with the expansion of corresponding SFIA behavioral factors and the definitions for matching C21 skills validates the mapping. The appropriate test is whether any SFIA responsibility characteristic mapped to a particular disposition does not align with the behavioral factor expansion or C21 skill definition. Conversely, the validation may suggest mapping a disposition to additional SFIA responsibility characteristics.

Table VIII compares the SFIA responsibility characteristics that express the CC2020 disposition "Collaborative" in Table VI with the SFIA behavioral factors "Collaboration" and "Communication," and the C21 skill "Collaboration," as defined in the *Partnership for 21st Century Skills* (P21) [38] framework. P21 framework offers convenient and brief definitions for individual C21 skills. The check marks indicate where the inclusion of a SFIA responsibility characteristic is supported either by the corresponding SFIA behavioral factor (SFIA-BF) or by the corresponding definition in the P21 version of the C21 skill.

Although there is overlap between the C21 skill and the SFIA behavioral factors, it is incomplete. In P21, collaboration groups with communication, which agrees with the behavioral factors selected in Table VII: it isn't easy to collaborate without effective communication. However, while the SFIA behavioral factor mapping focuses on a minimal set – can the person communicate? – the C21 skill also considers *what* is communicated and, to some extent, *why*.

There are two responsibility characteristics, italicized in Table VII, that are not supported by either the (minimal) behavioral factors or by the C21 skills. These represent "vertical" collaboration, within some form of reporting hierarchy; the authors contend that this is a genuine aspect of collaboration and should remain in the realization of "collaborative".

Similar validations and discussions were effected for each of the dispositions, confirming the mapping in Table VI, but space does not permit their inclusion here.

TABLE VIII
"COLLABORATIVE" SUPPORTED BY SFIA RESPONSIBILITY CHARACTERISTICS VS. SFIA BEHAVIORAL FACTORS AND C21 SKILLS

SFIA Responsibility Characteristics	SFIA BF	P21
Determines when issues should be escalated to a higher level		
Interacts with and influences colleagues		✓
Has working level contact with customers, suppliers and partners.	✓	
May oversee others or make decisions which impact routine work assigned to individuals or stages of projects		
Understands and collaborates on the analysis of user/customer needs and represents this in their work	✓	✓
Contributes fully to the work of teams by appreciating how own role relates to other roles	✓	✓
Demonstrates effective application and the ability to impart knowledge found in industry bodies of knowledge		✓
Demonstrates effective oral and written communication skills when engaging on issues with colleagues, users/customers, suppliers and partners	✓	✓
Appreciates how own role and others support appropriate working practices		✓

B. Comparison using Educational Competency Models

Using the competency clusters of intrapersonal and interpersonal competencies (ICC) identified in the *Education for Life and Work* report [6], the authors refined the mapping of CC2020 dispositions to SFIA responsibility characteristics to understand and improve the CC2020 formulation of dispositions. They applied Fink's taxonomy of significant learning to CC2020 dispositions, SFIA responsibility characteristics, and the mapping between them to verify that the six dimensions of significant learning encompass the dispositions required by industry. Fink's taxonomy provides strong support at the higher level of granularity of the five generic attributes that organize SFIA responsibility characteristics. For example, the SFIA "Autonomy" attribute maps to the "Human Dimension" of significant learning, while SFIA "Influence" has responsibility characteristics in the "Caring" dimension.

At the finer-grained level of responsibility characteristics, consider the seven responsibility characteristics associated with the "Purpose-driven" disposition. Table IX shows that each SFIA responsibility characteristic maps to competency conceptualizations in both educational models, as shown by the corresponding ICC clusters and significant learning dimensions. Competencies formulated in educational models thus relate to actionable descriptions that students should engage and educators may design to help foster dispositions.

The discussion shows that dispositions are valid compared with SFIA and C21 frameworks and educational competency models and that the mapping between them is appropriate.

V. DISCUSSION

This section makes crucial observations about the many-to-many mapping of the SFIA responsibility characteristics and CC2020 dispositions. Each disposition contributes to the mapping, although the interpretation of differing terminology is sometimes required. Real-world descriptions of SFIA re-

TABLE IX
"PURPOSE-DRIVEN" SUPPORTED BY SFIA RESPONSIBILITY CHARACTERISTICS VS. INTRA- AND INTERPERSONAL COMPETENCIES (IIC) AND SIGNIFICANT LEARNING DIMENSIONS (SLD)

SFIA responsibility characteristics	**IIC**	**SLD**
Plans and monitors own work ... competently within limited deadlines	work ethic	human dimension
Understands and collaborates on the analysis of user/customer needs and represents this in their work	intellectual openness	human dimension
Performs a range of work, sometimes complex and non-routine, in a variety of environments	intellectual openness	integration
Applies a methodical approach to routine and moderately complex issue definition and resolution	work ethic	application
Has sound generic, domain, and specialist knowledge, ... typically gained from recognized bodies of knowledge and organizational information		knowledge
Has an appreciation of the wider business context	work ethic	caring
Demonstrates effective oral and written communication skills when engaging on issues with colleagues, users/customers, supplies, and partners	collaboration	caring

sponsibility characteristics suggest how to interpret CC2020 dispositions to benefit future graduates.

A. SFIA and CC2020 Mapping (Table VI)

Table VI illustrates several ideas. It suggests that the eleven dispositions identified in CC2020 provide different levels of usefulness as they are at different levels of granularity. For example, "Professional" contributes to 20 out of the 24 responsibility characteristics, which is unsurprising as the responsibility characteristics attempt to capture what it means to be "computing professional." Two other dispositions, "responsible" and "self directed," contribute to 10 and 11 characteristics, respectively. At the other end, "inventive" contributes to just two responsibility characteristics, with the remainder contributing to between four and eight.

The mapping in Table VI is all-or-nothing. A finer gradation is needed to capture the nuances of the mapping between any two items. For example, the column corresponding to the "Collaborative" disposition has checkmarks for "Determines when issues should be escalated to a higher level" under "Autonomy" and for "Interacts with and influences colleagues" under "Influence." The latter is more strongly related to the "Collaborative" disposition than the former, but the checkmarks do not bring this out. So using graded levels, say Low, Medium, High, would be useful, i.e., "Determines when issues should escalate to a higher level", and tagged as Low while "Interacts with and influences colleagues" as High.

Conversely, at least two CC2020 dispositions support each SFIA responsibility characteristic: there is no case in which a disposition maps to only a single responsibility characteristic. However, for all six responsibility characteristics supported by just two or three CC2020 dispositions, one of the dispositions is "professional," which is indicative that "professional" is too generic to be a disposition.

As Table VI maps SFIA responsibility characteristics to dispositions, it shows the activities – implied by the responsibility characteristics – that a graduate who has developed the corresponding dispositions should demonstrate.

B. SFIA-based Descriptions of CC2020 Dispositions (Table X)

Derived directly from Table VI, Table X shows the responsibility characteristics supported by a subset of the dispositions. But, again, several dispositions support each responsibility characteristic, and several responsibility characteristics support each disposition. In other words, the description of any one disposition in Table X is not the complete picture. Instead, the description of each disposition indicates which SFIA responsibility characteristics an individual may display with that particular disposition ***provided*** and that they also have other dispositions required to support those characteristics.

Given the many-to-many mapping, it is inevitable that overlaps exist between descriptions. For example, the characterizations for "inventive" in Table X is a strict subset of those for "adaptable." Thus, the descriptions – or, rather, characterizations – of the dispositions presented in Table X do not strictly realize the dispositions in isolation; rather, they express, using industry-developed descriptions of workplace behavior, the kinds of activities supported by each disposition.

C. Other Observations

Additional questions are worth exploring. Might the mapping be refined sufficiently by comparison with other frameworks to reduce the overlap to an "acceptable" level? What does this say about the disposition of being "professional"? Is the set of dispositions either unitary or orthogonal, and does this matter? Can one deduce anything from the occasional apparent "nesting" of dispositions? Table VII shows comparison points exist for all but three of the dispositions in one or both of the behavioral factors and C21 skills. The two omissions, *professional* and *responsible*, are italicized in the table.

VI. CONCLUSIONS

The shift in academic computing curricular guidelines from focusing only on knowledge and possibly technical skills to more holistically on overall competence heralds the growth of computing as a profession. Competency, as articulated in CC2020, includes dispositions in addition to knowledge and skills. Dispositions correspond to the behavioral and professional characteristics identified in employer-centered frameworks, thus helping to bridge the "skills gap."

This paper further enables the melding of minds between academia and employers. Its contributions include:

- Providing the first formal attempt to relate CC2020 dispositions with employer-centered skills framework using SFIA as the paradigm.
- Confirming that CC2020 dispositions represent full coverage of these behavioral and professional characteristics in the SFIA framework and the requirement that all the dispositions are needed to provide this coverage.
- Establishing an operational correspondence between CC2020 dispositions and employer-informed activities

TABLE X
DESCRIBING SELECTED CC2020 DISPOSITIONS IN TERMS OF SFIA RESPONSIBILITY CHARACTERISTICS

CC2020 Disposition	**SFIA v8 Level 3 responsibility characteristics**
Adaptable	Uses discretion in identifying and responding to complex issues related to own assignments. Has working-level contact with customers, suppliers, and partners. Performs a range of work, sometimes complex and non-routine, in a variety of environments. Applies and contributes to creative thinking or finds new ways to complete tasks. Absorbs new information and applies it effectively. Takes the initiative to develop own knowledge and skills by identifying and negotiating appropriate development opportunities.
Inventive	Performs a range of work, sometimes complex and non-routine, in a variety of environments. Applies and contributes to creative thinking or finds new ways to complete tasks.
Meticulous	Receives specific direction, accepts guidance, and has work reviewed at agreed milestones. Plans and monitors own work (and others where applicable) competently within limited deadlines. Applies methodical approach to routine and moderately complex issue definition and resolution. Demonstrates judgment and a systematic approach to work Security, privacy, and ethics — demonstrates appropriate working practices and knowledge in non-routine work. Understands and effectively applies appropriate methods, tools, applications, and processes. Effectively applies digital skills and explores these capabilities for their role.
Passionate	Plans and monitors own work (and others where applicable) competently within limited deadlines. Interacts with and influences colleagues. Has a sound generic, domain, and specialist knowledge necessary to perform effectively in the organization typically gained from recognized bodies of knowledge and organizational information. Demonstrates effective application and the ability to impart knowledge found in industry bodies of knowledge. Absorbs new information and applies it effectively. Demonstrates effective oral and written communication skills when engaging with colleagues, users, suppliers, and partners. Takes the initiative to develop own knowledge and skills by identifying and negotiating appropriate development opportunities.
Professional	Works under general direction. Uses discretion in identifying and responding to complex issues related to own assignments. Receives specific direction, accepts guidance, and has work reviewed at agreed milestones. Determines when issues should escalate to a higher level. Plans and monitors own work (and others where applicable) competently within limited deadlines. Interacts with and influences colleagues. Has working-level contact with users, suppliers, and partners. Understands and collaborates on analyzing user/customer needs and represents this in their work. Contributes fully to teams' work by appreciating how own role relates to other roles. Applies methodical approach to routine and moderately complex issue definition and resolution. Has a sound generic, domain, and specialist knowledge necessary to perform effectively in the organization typically gained from recognized bodies of knowledge and organizational information. Demonstrates effective application and the ability to impart knowledge found in industry bodies of knowledge. Has an appreciation of the wider business context. Demonstrates effective oral and written communication skills when engaging with colleagues, users, suppliers, and partners. Appreciates how own role and others support appropriate working practices. Demonstrates judgment and a systematic approach to work Takes the initiative to develop own knowledge and skills by identifying and negotiating appropriate development opportunities. Security, privacy, and ethics — demonstrates appropriate working practices and knowledge in non-routine work. Understands and effectively applies appropriate methods, tools, applications, and processes. Effectively applies digital skills and explores these capabilities for their role.
Self-directed	Uses discretion in identifying and responding to complex issues related to own assignments. Plans and monitors own work (and others where applicable) competently within limited deadlines. Interacts with and influences colleagues. May oversee others or make decisions that impact routine work assigned to individuals or stages of projects. Performs a range of work, sometimes complex and non-routine, in various environments. Applies methodical approach to routine and moderately complex issue definition and resolution. Applies and contributes to creative thinking or finds new ways to complete tasks. Absorbs new information and applies it effectively. Demonstrates judgment and a systematic approach to work Takes the initiative to develop own knowledge and skills by identifying and negotiating appropriate development opportunities. Security, privacy, and ethics — demonstrates appropriate working practices and knowledge in non-routine work. Understands and effectively applies appropriate methods, tools, applications, and processes. Effectively applies digital skills and explores these capabilities for their role.

and tasks to help educators design learning environments that enable students to develop dispositions.

Given the history of dispositions and their current emergence in professional practice and curricular reports, it is safe to say that dispositions have a place in computing education. Denial of this conclusion would place computing graduates at a disadvantage in the workplace. Increased convergence between CC2020 and SFIA for the computing competencies expected of graduates would help address the computing skills gap, thereby improving the outcomes for both students and employers.

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