Advancing Computing Education: Assessing CC2020 Dispositions

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***Abstract*—This Innovative Practice Full Paper addresses the assessment of dispositions which, along with knowledge and skills, form the three legs of competency needed to perform a task in context, as described in recent computing curricular reports, particularly ACM/IEEE Computing Curricula 2020 (CC2020). Here, dispositions in CC2020 express the behavioral characteristics of competence, such as being adaptable, collaborative, or inventive. Instructors have assessed knowledge from the start of computing programs and have paid increased attention to assessing skills in recent decades. However, dispositions and their role within competency is relatively new, with little guidance available for assessing dispositions. Lately, computing instructors have begun to understand the importance of evaluating dispositions during the performance of tasks in the real world or in the context of the industry-based global Skills Framework for the Information Age (SFIA). Hence, this paper develops a criterion-based approach for use by educators in assessing competence based on a reflective portfolio of "real-world" achievements. Building on concepts developed by the UK Institute of Coding and other recent reports, this work demonstrates how this assessment approach relates to industry-based competency frameworks such as SFIA and the European e-Competence Framework (eCF). The paper also explores using the criterion-based approach in a classroom environment to help students focus on particular dispositions. Its main contribution is to advance the competency focus in academic computing programs and future computing curricula.**

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

I. Introduction

Recent computing curricular guidelines, particularly the ACM/IEEE Computing Curricula 2020 (CC2020) report [1], have recommended that post-secondary programs focus on competency-based learning rather than knowledge-based learning. This new emphasis represents a seismic shift in how computing educators teach and evaluate coursework, helping to shape post-secondary education for at least the next decade.

Professional competency is defined in the context of performing a goal-oriented task as a three-dimensional entity [1]:

Competency = Knowledge + Skills + Dispositions

As specialists in the knowledge dimension, computing educators have performed knowledge assessment from the start of computing programs, and have devoted increased attention to assessing skills only in recent decades. On the other hand, as the concept of dispositions and their role within professional competence is relatively new, neither these curricular reports nor current pedagogical practices provide much guidance on assessing dispositions.

TABLE I
Professional Dispositions from CC2020 [1]

Disposition	Synonyms
Adaptable	agile, changeable, flexible, universal, versatile
Collaborative	collective, communal, concerted, cooperative, team-player
Inventive	clever, creative, exploratory, innovative, imaginative
Meticulous	accurate, attentive, careful, detailed, thorough
Passionate	commitment, compelling, fervent, intense, vehement
Proactive	farseeing, forehanded, independent, provident, visionary
Professional	accomplished, adept, ethical, masterful, skillful
Purpose-driven	achiever, determined, goal-driven, persistent, tenacious
Responsible	accountable, amenable, dependable, reliable, trustworthy
Responsive	agile, prompt, reactive, receptive, respectful
Self-directed	ambitious, determined, distinctive, independent, unique

This notion of dispositions expresses the behavioral characteristics of competence as expected in the workplace. The CC2020 report identified eleven dispositions useful for graduates of computing programs. Table I lists these dispositions with suggested interpretations as presented in Section III.

As professional behaviors are critical to the workplace [2], prospective employer would be willing to hire a computing graduate who had demonstrated all or most of the eleven dispositions shown in Table I. Unfortunately, instructors instill few if any of these dispositions in post-secondary education. For example, currently few instructors explicitly evaluate students on their adaptability level or whether they are meticulous or purpose-driven. In such cases, students are unaware that these disposition elements are meaningful and essential in the workplace. Estimates typically are that around 95% of all computing graduates seek employment upon graduation; for one illustration, a computer science program that typically graduates around 200 students reports that 96% pursue employment [3], not advanced studies or alternative placements. Therefore, computing educators need to foster dispositions in the curriculum to produce a competent computing graduate.

Recent research on computing competencies lays some foundations on how curricula can include opportunities for students to develop and demonstrate dispositions and for teachers to assess professional competence [4]–[6]. Competence assessment, to be helpful, should preferably occur during the performance of tasks in the real world and consider guidance from competency frameworks developed by and for employers, i.e., it should not be a purely academic exercise. For example, responsibility characteristics in the industry-based global Skills Framework for the Information Age (SFIA) [7] were recently shown to cover CC2020 dispositions completely [8].

This study proposes a tool to support a holistic process to address the challenge of assessing dispositional competencies. Building on methods already used in professional disciplines, such as health sciences, the paper develops an assessment tool to assess the CC2020 dispositions. It describes the design principles for an assessment tool, and a criterion-based assessment method for comparing performance to a previously determined standard of achievement. Educators can use this approach to assess computing competencies based on real-world accomplishments evidenced (or reported) in a reflective portfolio. This approach derives from concepts developed by the UK Institute of Coding [9] and preliminary ideas laid out in recent ACM Innovation and Technology in Computer Science Education (ITiCSE) working group reports [4], [6], [10], [11] and other papers [5], [12], [13].

In addition to overall portfolio assessment, the paper explores using the criterion-based system in a classroom environment to support students in activities that focus on particular CC2020 dispositions.

Finally, it relates this approach to industry-based competency frameworks like SFIA [7] and the European e-Competence Framework (eCF) [14]. By emphasizing the assessment of dispositions using employer perspectives and needs, the paper's main contribution is to advance the competency focus in computing education and future curricula. Well-established professions, such as medicine, law, and teacher education, have long emphasized competence being inherent to their ethos. In short, this paper contributes to the ultimate goal of viewing computing as a profession in its own right.

II. Related Work

In non-computing fields, dispositions as a competency component have been under study in part or wholly for decades. This section highlights a few of these developments to motivate why fostering and assessing dispositions is a broad need in computing.

Some of the earliest work on computing competencies emerged in software engineering. Mead and Shoemaker [15] described the software assurance (SwA) competency model that comprises three elements: knowledge, skills, and effectiveness, where knowledge is what an individual knows, skills are what an individual does by applying knowledge, and effectiveness is the ability to utilize knowledge and skills productively. In other words, effectiveness refers to behavior attributes, i.e., dispositions, such as aptitude, initiative, enthusiasm, willingness, communication, teamwork, and leadership. The Software Engineering Body of Knowledge (SWEBOK) included the Software Engineering Competency Model (SWECOM) [16] with its three components: knowledge, skills, and ability, the last being similar to dispositions. SWECOM's *ability* identified ten such dispositions: aptitude, initiative, enthusiasm, work ethic, willingness, trustworthiness, cultural sensitivity, communication, team participation, and technical leadership [17].

The first computing curricular report to include dispositions explicitly was Information Technology 2017 (IT2017), defining competency as the sum of Knowledge, Skills, and Dispositions in context [18]. Dispositions, described as "socio-emotional skills, behaviors, and attitudes that characterize the inclination to carry out tasks and the sensitivity to know when and how to engage in those tasks" [19], were not explicitly listed in IT2017 as they were assumed to be exhaustive and self-evident in human behavior. Representing paradigms for undergraduate computing education, Computing Curricula (CC2020) identified eleven dispositions: adaptable, collaborative, inventive, meticulous, passionate, proactive, professional, purpose-driven, responsible. responsive, and self-directed [1]. Subsequent curricular reports, Information Systems 2020 (IS2020) [20] and Data Science 2021 (DS2021) [21], also embraced competency as a basis for computing education.

These curricular reports intend that dispositions be developed by students by the time they graduate, not simply covered in a dedicated "dispositions" module or course. This approach has two challenges: (1) where and how to accumulate the evidence, and (2) how to assess that evidence to confirm that dispositions achieved an acceptable level. This study focuses on the second of these challenges.

Portfolio development and management has been studied extensively. A simple portfolio might be a laboratory notebook, diary, or professional logbook for engineers' continuing professional development (CPD) [22]. Each student's physical or digital portfolio is assessed throughout their studies. Digital portfolios have gained popularity across higher education both as learning and as assessment tools [23]–[25]. Portfolios need to contain evidence of achievement, not merely of attendance or participation. Portfolio content should also be evaluative and, ideally, reflective [26]. Moreover, portfolio entries need to be validated not by the student but by external assessors such as course instructors, workplace supervisors, or peers. In medical education, where continuing professional development is typically mandatory [27], there have been difficulties but computing can benefit from its lessons.

III. The Basic Assessment Tool

This study develops a tool to support a holistic process to address the challenge of assessing dispositional competencies. The fundamental idea is to recognize that students can demonstrate dispositions through the tasks they complete throughout their studies. The assessment approach evaluates students' accumulated evidence recorded over time in their portfolios. The process ensures sufficient evidence becomes part of the portfolios for each disposition.

A. Assessment Tool Design Principles

The assessment tool design must be a scalable, consistent method for assessing a student's dispositional competencies based on evidence accumulated in a portfolio. Achieving professional competence means *repeated, successful demonstration* of professional activities over an extended period of time [28]. Thus, the assessment tool requires the demonstration of each disposition to have multiple portfolio item references to professional activities performed over the period recorded by the portfolio. The activities and tasks recorded in portfolio items can be drawn from academic and workplace experiences or generated by the educational learning experiences in courses and modules of the program of study. The activities may also include work-based or voluntary activities beyond the program's required curricula. Crucially, the activities recorded in any one item may demonstrate multiple dispositions, although each disposition would need to be teased out separately from the recorded evidence.

The assessment tool counts the number of portfolio item references for each disposition and determines the successful demonstration of the disposition when it meets or exceeds a configurable threshold.

Assessment tools that make binary evaluations of "yes" or "no" to indicate the presence or absence of adequate evidence for meeting a specific criterion can too easily be reduced to a conjunctive "tick list". The deficiency of this approach is that students could "fail" were they not to have scored the minimum number of "ticks" on any one of the dispositions. Furthermore, as individual student circumstances, opportunities, and learning experiences differ, a particular student portfolio may not have sufficient evidence to demonstrate all of the dispositions. Still, their portfolio could qualify as "satisfactory" if they demonstrated a majority of the dispositions. To avoid a conjunctive tick list trap and to account for individualized learning experiences, the assessment tool has five configuration parameters, set out in Table II. These parameters are used to calculate two portfolio assessment thresholds, as shown in Table III.

TABLE II
CONFIGURATION PARAMETERS FOR THE ASSESSMENT TOOL

Name	Definition
D	Number of dispositions listed in the tool
D_{Prop}	Minimum proportion of dispositions required to be demonstrated
I_{Min}	Minimum number of portfolio item references required to demonstrate any disposition
I_{Max}	Maximum number of portfolio item references that can be counted towards demonstrating any disposition
I_{Prop}	Minimum proportion of the maximum number of portfolio item references to be entered into the tool

TABLE III
CONFIGURABLE THRESHOLDS FOR THE ASSESSMENT TOOL

Name	Formula	Definition
T_D	$D \times D_{Prop}$	Minimum number of dispositions that must be demonstrated (rounded down)
T_{ID}	$D \times I_{Max} \times I_{Prop}$	Minimum number of portfolio item references that must be entered into the tool (rounded down)

The basic idea underlying the assessment scoring method is simple. For each disposition d, the tool counts the item references, I_d, and then uses these item reference counts to calculate the following disposition-level assessment scores:

- d score: 1 if $I_d \geq I_{Min}$, 0 otherwise
- I_d score: $MIN(I_d,\ I_{Max})$

These assessment scores ensure that at least I_{Min} item references are required to demonstrate a disposition, and I_{Max} item references are sufficient.

Based on these individual scores, the tools calculates two overall assessment scores. The S_D *overall disposition score* is the number of dispositions d for which $I_d \geq I_{Min}$ over all D. The S_{ID} *overall item references score* is the sum of the lesser of I_d item references and I_{Max} over all dispositions D:

$$S_{ID} = \sum_{d=1}^{D} MIN(I_d\ ,\ I_{Max}) \quad (1)$$

The evaluation outcome is "Pass" if the condition below is met:

$$S_D \geq T_D\ AND\ S_{ID} \geq T_{ID} \quad (2)$$

If the condition is not satisfied, the outcome is not "fail", but "Not yet".

B. Use of the Basic Assessment Tool

The configuration parameters, threshold values, and overall assessment scores described in the previous subsection are incorporated into a simple assessment tool.

1) Recording Portfolio Evidence in the Assessment Tool: A portfolio is assessed by reviewing and evaluating its entries. An item reference is entered in the tool for each corresponding disposition for which an entry in the portfolio shows evidence for demonstrating that disposition. For traceability and evaluation purposes, the item references should link to the corresponding portfolio entries, using a date, URL, paragraph number, or similar.

For example, a student may record their contributions to a group project in the following portfolio entry:

> 21st November: Together with members of the project team, met with two representatives from our customer - the company for which we are building a prototype website. As a team, we obviously needed to meet the customer, to understand their needs and elicit detailed requirements. However, we had not prepared any strategy to interact with the customer - and it could easily have descended into chaos. Fortunately, Jan took the lead in the discussion, and (unexpectedly) asked me to collate the requirements as they came up. The meeting was actually quite successful - because Jan had given us each specific areas on which to focus, the discussion was very focused, rather than just meandering. The customer was happy with the list of requirements I fed back to them when we finished - and complimented me on the way I had summarized them. I now understand a lot more about why it is important to organize a team so that everyone has a defined role.

This entry demonstrates that the student adapted quickly to an unexpected request (*Adaptable*, *Responsive*), collaborated with Jan and the other team members (*Collaborative*), and, since the customer was happy with the resulting set of requirements, acted carefully and professionally (*Meticulous*, *Professional*). Thus, the entry provides evidence of five dispositions and portfolio item references for all five would be entered in the assessment tool. This simple example illustrates how the assessment tool functions and indicates how to evaluate a portfolio entry as providing evidence of particular dispositions.

Assume the portfolio item references written in black in Table IV have been made already (the columns with 1, 2, 3, and 4 headings). The five new item references for "21st November" are underlined in red. These five references, associated with five different dispositions, are spread across all four columns. Other portfolio item references will have similar distributions, demonstrating new dispositions or reinforcing evidence already recorded.

TABLE IV
SAMPLE PORTFOLIO ITEM REFERENCES AND DISPOSITION-LEVEL SCORE CALCULATIONS IN THE ASSESSMENT TOOL

Disposition	1	2	3	4	Count	Scores I_d	Scores d
Adaptable	21 Nov				1	1	0
Collaborative	14 Sep	21 Nov			2	2	1
Inventive					0	0	0
Meticulous	21 Nov				1	1	0
Passionate					0	0	0
Proactive					0	0	0
Professional	7 Sep	21 Sep	7 Oct	21 Nov	4	3	1
Purpose-driven					0	0	0
Responsible					0	0	0
Responsive	21 Nov				1	1	0
Self-directed	7 Sep				1	1	0

2) Assessing Portfolio Evidence: The assessment scoring method was implemented in a spreadsheet with three sections: the configuration parameters, the data entry and individual scores calculation area, and the outcomes section.

The main data entry and assessment scoring area are similar to Table IV. The last three columns illustrate how to score item references and dispositions. The item references count I_d is checked against I_{Max} to calculate the I_d score and against I_{Min} to calculate the d score as described in Section III-A.

The portfolio item references example in Table IV has the following configuration parameters: I_{Max} = 3 and I_{Min} = 2. Thus, the I_d score for $I_{Professional}$ is 3, although its I_d count is 4. The d score for three dispositions, *Adaptable*, *Meticulous*, and *Self-directed*, is 0 because they have only one item reference at the time of evaluation. By indicating which dispositions were not yet demonstrated, the tool facilitates formative assessment that both the teacher and student can use to review the stage of professional development and determine appropriate strategies for further development.

The outcomes section of the tool has assessment thresholds and score calculations for the overall disposition count score S_D and overall item references sum S_{ID}, as defined in Section III-A. These scores are compared with the thresholds T_D and T_{ID} (condition 2) to record the assessment outcome of "Pass" or "Not yet".

The ethos of developing dispositions should be to encourage further professional development and learning for those students who have not yet demonstrated particular dispositional competencies, rather than to inform them that they have "failed". Thus, the outcome is "Not yet" meaning that the student will need to be encouraged to develop the particular disposition in future activities.

IV. Enhancements to the Basic Assessment Tool

This section examines a few enhancements to the basic assessment tool presented in Section III.

A. *Use within a Single Module*

As the complete set of CC2020 dispositions are meant to be developed throughout a student's program of study, the basic assessment tool treats each disposition equally. Although this may be appropriate for the synoptic assessment of students' portfolios at graduation, it is not helpful for teachers of individual courses or modules, which may afford opportunities for the explicit development or demonstration of only a subset of the dispositions.

In such contexts, the assessment process is largely the same. It matches information about activities recorded in the student portfolio against the subset of dispositions targeted by the module. In addition to the targeted subset of dispositions, the assessment notes where activities have also resulted in a student demonstrating other dispositions. The "relevant subset" are termed "essential" (in the context of a particular module), and the remainder as "supplementary". Each disposition can be labelled in the tool either "E" or "S", respectively.

TABLE V
ADDITIONAL CONFIGURATION PARAMETERS FOR THE ENHANCED ASSESSMENT TOOL

Name	Definition
E	Number of essential dispositions listed in the tool
E_{Prop}	Minimum proportion of essential dispositions required to be demonstrated
IE_{Avg}	Minimum average portfolio item references across the essential dispositions

Two new configuration parameters, shown in Table V, account for the essential dispositions, E, and the proportion of these essential dispositions that should be demonstrated, E_{Prop}. To emphasize the focus on the essential dispositions, a third parameter, IE_{Avg}, is introduced to represent the minimum average portfolio item references across the essential dispositions. The configuration parameters I_{Min}, I_{Max}, and I_{Prop} retain the same semantics as in the basic tool and are not shown in Table V. However, these values need to be set to values appropriate to the context of a single module.

Table VI shows the new thresholds for the enhanced tool. The threshold T_E is calculated in the same way as its counterpart in the basic tool, T_D. The addition of the IE_{Avg} parameter leads to a third threshold, T_{IE}.

TABLE VI
NEW THRESHOLDS FOR THE ENHANCED ASSESSMENT TOOL

Name	Formula	Definition
T_E	$E \times E_{Prop}$	Minimum number of essential dispositions to be demonstrated
T_{IE}	$E \times IE_{Avg} \times E_{Prop}$	Minimum number of portfolio item references for essential dispositions hat must be entered into the tool (rounded down)

The overall assessment scores, S_E and S_{IE}, also retain the meaning of the corresponding overall assessment scores in the basic tool. The S_E *overall essential disposition score* is the number of essential dispositions e for which the item references count $I_e \geq I_{Min}$ over all E. The S_{IE} *overall essential item references score* is the sum of the lesser of I_e item references and I_{Max} overall essential dispositions E, as shown in the following equation:

$$S_{IE} = \sum_{e=1}^{E} MIN(I_e\ ,\ I_{Max}) \tag{3}$$

The overall outcome is now "Pass" if the following condition holds:

$$S_E \geq T_E\ AND\ S_{IE} \geq T_{IE}\ AND\ S_{ID} \geq T_{ID} \tag{4}$$

Depending on the number of dispositions identified as "essential", it may be necessary to adjust the configuration parameters, particularly I_{Min}, IE_{Avg}, and I_{Prop} to ensure that the relative values of the thresholds T_E and T_{IE} make sense for the context of the module or course in which the tool is used.

B. Assessing against a Professional Skills Framework

Despite the synonyms presented in Table I, the eleven dispositions identified in CC2020 are relatively high-level concepts that describe behavioral and motivational characteristics. Thus, these dispositions are independent of any specific set of technical content knowledge, skills, and activities; they are characteristics that cut across technical competencies. The value of focusing on dispositions is that they help to bridge the gap between *academic knowledge and skills* and *professional competence*, as required of new graduates by prospective employers.

Employer-led skills frameworks typically describe both technical activities and behavioral characteristics that employers value in their employees. Therefore, expressing dispositions in terms of characteristics drawn from an employer-led skills framework should ensure that the demonstration of dispositions is of real value to employers. It also provides an opportunity to both (1) engage the student in experiences that enable the development of desired dispositions, and (2) assess students' dispositions by determining how students approach real-world activities in the workplace.

For a skills framework to be amenable to the assessment tool outlined here, the framework must meet the minimum requirements in Table VII

TABLE VII
SKILLS FRAMEWORK ASSESSMENT REQUIREMENTS

	Assessment Requirement
1	Behavioral characteristics are separate from technical skills and task-specific activities, that is, the characteristics are abstracted from and common across activities in which students engage
2	Groupings of characteristics correspond to specific levels of responsibility or experience reflected by work-related roles, such as assistant, practitioner, team leader, manager, with at least one level being appropriate for new graduates
3	A range of characteristics underpin the manifestation of all eleven dispositions

The absence of these requirements would make it difficult to use the characteristics defined in a skills framework to assess dispositions. If the characteristics are associated with or embedded in particular technical activities, then they cannot be used to assess dispositions separately from technical achievements. If there is no sense of the level of experience or responsibility, reflected by groupings of characteristics, then it is not possible to target the assessment at the level appropriate for new graduates. If the behavioral characteristics do not demonstrate all eleven dispositions, then it is not possible to assess the omitted dispositions in terms of the characteristics.

Table VIII summarizes the extent to which the major skills frameworks that span broad areas of the computing profession meet these three requirements. Unfortunately, the actual investigation of the frameworks is beyond the scope of this paper. Still, the table shows that only the Skills Framework for the Information Age (SFIA) [7] currently meets these three

TABLE VIII
SKILLS FRAMEWORKS EVALUATION AGAINST REQUIREMENTS

	Separate behavioral attributes	Grouping appropriate for new graduates	Coverage of CC2020 dispositions by behavioural attributes
SFIA [7]	Yes	Yes	Yes
e-CF [14]	No	n/a	n/a
SWECOM/ SWA-COM [16]	Yes	No	Yes?
NICE (Cyber) [29]	Partly?	Yes?	Not yet
iCD [30]	No	No	?

requirements. However, the NICE cybersecurity framework may also do so in the future [29].

SFIA specifies generic behavioral characteristics expected at seven different levels of responsibility (or experience), orthogonal to the technical skills and activities. The seven levels are: Follow (1), Assist (2), Apply (3), Enable (4), Ensure (5), Initiate (6), and Set Strategy (7). Each level describes a set of "responsibility characteristics", grouped under five broad attributes of autonomy, influence, complexity, knowledge, and business skills [31].

SFIA Level 3 "Apply" is appropriate for new graduates, who should be capable of *applying* the knowledge and skills they have gained during their degree program. SFIA Level 3 is the reference level to be demonstrated for IPthree "Technologist" [32], and for BCS "Registered IT Technician" [33]. The responsibility characteristics for Level 3 of SFIA provide complete coverage of the 11 CC2020 dispositions [8].

Hence, an alternative to assessing students' demonstration of the CC2020 dispositions is to assess their demonstration of the 24 SFIA Level 3 responsibility characteristics. The same approach used for both the basic and the enhanced assessment tools can be applied to map portfolio items to the more detailed responsibility characteristics rather than to the high-level CC2020 dispositions.

SFIA responsibility characteristics are designed to be relevant in the real world of commerce or industry, and such they may not be applicable in an educational environment. However, it would be preferable to assess dispositions and competencies in a real-world context rather than in a purely educational setting [6]. Therefore, it may be appropriate to denote some of the responsibility characteristics as *supplementary*, as long as sufficient are retained as *essential* to ensure that the essential characteristics provide complete coverage of the CC2020 dispositions.

The assessment tool that uses SFIA responsibility characteristics has configuration parameters, thresholds, and an assessment scoring method similar to those described for the enhanced assessment tool. Parameters I_{Min}, I_{Max}, and I_{Prop} have the same semantics related to the portfolio item references that document activities demonstrating SFIA characteristics.

Instead of the eleven CC2020 dispositions, the tool includes the 24 SFIA Level 3 responsibility characteristics. Of the 24 characteristics, the parameter EC counts the "essential characteristics", and EC_{Prop} is the proportion of the essential characteristics that must be demonstrated by at least I_{Min} item references recorded in the assessment tool for each characteristic.

TABLE IX
DATA ENTRY AND ASSESSMENT SCORING EXAMPLE OF SFIA RESPONSIBILITY CHARACTERISTICS

Responsibility Characteristics (SFIA *Autonomy* attribute)	1	2	3	4	E?	Count I_d	Scores I_e	I_s	e
Works under general direction.	x	x	x	x	Y	4	3		1
Receives specific direction, accepts guidance and has work reviewed at agreed milestones.	x	x	x	x	N	4		3	
Uses discretion in identifying and responding to complex issues related to own assignments.	x	x			Y	2	2		1
Plans and monitors own work (and that of others where applicable) competently within limited deadlines.	x	x	x		Y	3	3		1
Determines when issues should be escalated to a higher level.	x				Y	1	1		0

Table IX shows an example of the data entry and scoring area for the first five responsibility characteristics, grouped as the SFIA attribute *Autonomy*. In this example, four of the five characteristics are deemed "essential", indicated by the "Y" in the *E?* column; only the second in this group is deemed "supplementary." For clarity, simple crosses indicate a portfolio item reference, although, in real use, they would normally need to be resolvable references to the relevant portfolio items. The last three columns on the right show the values of the item reference scores I_e and I_s, and essential score e. Their calculations are described in Section III-A. In this example, I_{Min} is set to 2, and I_{Max} is set to 3. Therefore, the item reference scores for the first two characteristics are 3, even though the item reference count is 4. The essential score for the last characteristic is 0 since the I_{Min} of 2 has not been met.

TABLE X
CALCULATION EXAMPLE FOR THE T_{IC} THRESHOLD

C	I_{Max}	I_{Prop}	T_{IC}
24	3	65%	46 (= 24 x 3 x 65%)

TABLE XI
CALCULATION EXAMPLE FOR THE T_E AND T_{IE} THRESHOLDS

E	E_{Prop}	IE_{Avg}	$T_E \leq E_{OK}$	$T_{IE} \leq I_E$
18	80%	2	14 (= 18 x 80%)	28 (= 18 x 2 x 80%)

The evaluation outcome area of the enhanced assessment tool has calculations of the values of the thresholds and scores of the overall assessment. Tables X and XI show an example of threshold calculations based on configuration parameters values. Summing up characteristic-level individual assessment scores (essential and supplementary), the tool calculates overall assessment scores. It then applies the evaluation conditions (analogous to condition 4) by comparing the overall assessment scores with the threshold values to determine the portfolio evaluation outcome.

C. Scope for Development to support Indirect Assessment

Bowers et al [8] demonstrated that the SFIA Level 3 responsibility characteristics, as a set, provide complete coverage of the eleven CC2020 dispositions. Hence, a noticeable development would be to use the mapping between SFIA responsibility characteristics and the CC2020 dispositions from [8] to construct a version of the assessment tool in which portfolio item references are mapped against the responsibility characteristics and associated automatically with the related CC2020 dispositions. In principle, this should allow indirect assessment of demonstration of the dispositions by measuring demonstration of the SFIA characteristics.

In particular, it would allow teachers to explain to students, in some detail, how they had demonstrated specific dispositions and to suggest concrete actions - expressed in terms of the SFIA characteristics - that could contribute to improving their evidence for particular dispositions.

However, the mapping between SFIA responsibility characteristics and dispositions is many-to-many. For example, the characteristic, "Plans and monitors own work [...] competently within limited deadlines" demonstrates aspects of seven dispositions, including *Professional*, which is itself supported by 20 of the 24 SFIA characteristics. Furthermore, the number of responsibility characteristics that map to each disposition ranges from 2 to 20. The number of dispositions supported by a single characteristic ranges from 2 to 7.

How should a portfolio item demonstrating a particular SFIA characteristic be counted against any disposition it supports? Adding a reference to a portfolio item that demonstrates just one SFIA responsibility characteristic could have a different impact if that characteristic were one of twenty supporting a single disposition, or one of two supporting another. Similarly, if that characteristic supported seven dispositions, it would be counted many more times than a characteristic supporting just two. Clearly, some form of normalization is needed.

Space does not allow a detailed description of the prototype tool for indirect assessment, which is being used to explore questions such as the normalization issue or how to set the thresholds for the SFIA characteristics and the corresponding CC2020 dispositions. However, some of the principles are introduced, along with possible solutions.

For example, as a first approximation, it can be assumed that each characteristic contributes equally to each disposition it supports and vice-versa. The "score" for each disposition, S_d, is derived from the count of item references demonstrating each corresponding characteristic, I_{ch}, needs to be scaled both by the number of characteristics contributing to the disposition, N_{ch}, and by the number of dispositions to which a characteristic contributes, N_d. Dividing the total number of item references mapped to a disposition by the product, $N_{ch} \times N_d$, would almost certainly be too harsh. However, dividing (effectively) by the square root of the product would seem more reasonable and dimensionally correct).

Thus, a possible normalization would calculate the contribution to each disposition supported by a given SFIA responsibility characteristic as the sum of the number of item references counted against that characteristic, I_{ch}, divided by the square root of the number of dispositions supported by that characteristic. The contributions to each disposition would then be summed, and the total divided by the square root of the number of characteristics supporting the disposition. The score for the disposition, S_d, would thus be given by

$$S_d = \left(\sum_{ch=1}^{N_{ch}} \frac{I_{ch}}{\sqrt{N_d}} \right) \div \sqrt{N_{ch}} \qquad (5)$$

An alternative approach could seek to quantify the importance of each responsibility characteristic in the demonstration of the disposition, i.e., improving on the assumed equal contribution of a characteristic to all dispositions to which it is mapped. The normalization algorithm could then take account of the resulting weights associated with each characteristic to disposition mapping. Although this would allow for a more nuanced normalization approach, it would require considerable effort to complete the weightings within the mapping.

There are also questions regarding the parameters and thresholds for demonstrating individual dispositions, particularly for the number of portfolio item references required; these would depend on the normalization algorithm selected.

Further work will allow the evaluation of a range of normalization processes and the corresponding alternative calculations.

V. Discussion

Since the focused introduction of competency to ACM/IEEE curricular recommendations, understanding of how dispositions contribute to overall competence continued to develop, culminating with their articulation in CC2020. However, little guidance has yet appeared on assessing competency, and the dispositional elements- in particular. This situation challenges instructors seeking to incorporate dispositional awareness and development into their courses. The common advice has been that students should repeatedly exhibit the eleven elements of disposition throughout their studies to achieve the dispositional component of competency.

The approach presented in this paper transforms the task of assessing dispositional competency in several ways. First, it changes the emphasis from focusing on activities designed to assess the demonstration of particular dispositions to recognizing that students can demonstrate dispositions through a wide range of tasks they complete throughout their studies. So, the assessment task changed from considering the outcomes from defined, synoptic challenge activities to evaluating evidence accumulated over time and recorded in some kind of portfolio. The mechanical aspect of the task ensures there is sufficient evidence in the portfolio for each disposition, which is automated by a series of Excel spreadsheets described in this paper.

The expectation is that students will gain a minimal level of competence by graduation. The presented approach offers a criterion-based assessment style for dispositions. Assessors must read the portfolio in sufficient detail to evaluate which dispositions students have demonstrated some aspect(s) in each portfolio entry. However, they need not worry over whether each entry demonstrates dispositional competencies.

The assessment tools are also configurable through a set of parameters, used both to tailor a tool for a particular context and reduce the number of portfolio entries that need evaluation. For example, the parameter I_{Max} means that entering everything from the portfolio into the tool may be unnecessary since only the first I_{Max} item references count for each dispositional element.

Recent literature [8] presented an attempt to map from SFIA responsibility characteristics to dispositions, which demonstrated that the set of responsibility characteristics for SFIA Level 3 covers the full set of CC2020 dispositions and describes activities in more detail than abstract dispositions. This mapping underpins the extension presented in Section IV-C, enabling portfolio items to be evaluated against the SFIA responsibility characteristics and then mapped to the dispositions. The mapping mentioned earlier [8] may well be amenable to refinement, leading to simplification of the normalization algorithm summarized in Equation 5. This outcome may improve, for example, the treatment of the dispositional element "inventive", for which the current normalization algorithm may be a little harsh simply because it is the only disposition supported by just two responsibility characteristics.

The approach used in Section IV-B was developed for the Institute of Coding [34]. IoC microcredentials incorporating this assessment are planned. The authors plan to present a worked example, using these tools, at a future venue.

A few configurable spreadsheet tools are provided as samples to support all of these assessment methods [35].

VI. Conclusions

CC2020's focus on competencies will likely influence curricular recommendations beyond the coming decade. With competencies come dispositions. Educators should expect that the assessment of dispositions with their students should become a mainstay, similar to the evaluation of student knowledge and skills. Hence, students should expect to develop dispositions throughout their studies, and should collate evidence within a portfolio.

This paper described an assessment approach based on matching portfolio items against a set of dispositions. The tool discussed in this paper demonstrates how matching the contents of a portfolio against dispositions can form the basis for an assessment of students' demonstration of dispositions. In particular, it supports feedback to students on their ongoing development of dispositions.

A portfolio developed over the lifetime of a student's program of study can provide synoptic evidence across all eleven dispositions. Selected dispositions may relate to a local context, such as an individual course or module, and the configurations available in the enhanced tool support more focused assessment for such contexts.

Industry-focused skills frameworks (e.g., SFIA) describe the competencies valued by employers. Furthermore, dispositions have been shown to be reflected in "soft skills" captured in such frameworks. For example, the SFIA Level 3 responsibility characteristics have been shown to cover all eleven dispositions, and can therefore suggest more specific activities to "operationalize" the development of dispositions [8].

The extended assessment tool based on SFIA characteristics incorporates a mapping from SFIA characteristics to CC2020 dispositions. Evaluation of the normalization required for this indirect assessment of dispositions is ongoing, and will be reported in future papers.

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