

Toward Competency-Based Professional Accreditation in Computing

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ABSTRACT

Program accreditation in medical or religious professions has existed since the 1800s while accreditation of business and engineering programs started in the early twentieth century. With this long history, these disciplines have focused on ensuring the competence of their graduates, as modern society demands appropriate expertise from doctors and engineers before letting them practice their profession. In computing, however, professional accreditation started in the last decades of the twentieth century only after computer science, informatics, and information systems programs became widespread. At the same time, although competency-based learning has existed for centuries, its growth in computing is relatively new, resulting from recent curricular reports such as Computing Curricula 2020, which have defined competency comprising knowledge, skills, and dispositions. In addition, demands are being placed on university programs to ensure their graduates are ready to enter and sustain employment in the computing profession.

This work explores the role of accreditation in forming and developing professional competency in non-computing disciplines worldwide, building on this understanding to see how computing accreditation bodies could play a similar role in computing. This work explores the role of accreditation in forming and developing professional competency in non-computing disciplines worldwide, building on this understanding to see how computing accreditation bodies could play a similar role in computing. Its recommendations

are to incorporate competencies in all computing programs and future curricular guidelines; create competency-based models for computing programs; involve industry in identifying workplace competencies, and ensure accreditation bodies include competencies and the assessment in their standards.

CCS CONCEPTS

• **Social and professional topics** → **Accreditation; Computing education programs; Computer science education; Computing education;**

KEYWORDS

ITiCSE working group, professional accreditation, computing education, competency-based learning, computing pedagogies, computing competencies.

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1 INTRODUCTION

Professional accreditation has existed for more than a century in disciplines such as business [2], law [111], medicine [154], and teaching [243]. Accreditation informs the public that an entity (a program, a school, or an institution) has satisfied certain quality assurance expectations. Accreditation bodies produce standards or criteria that an entity must meet to receive accreditation.

Some accreditation criteria actively promote *competency* that includes academic knowledge, applicable skills, and professional dispositions. For instance, as part of its mission statement, the Accreditation Council for Continuing Medical Education states that the provider must have “expected results articulated in terms of changes in competence, performance, or patient outcomes that will

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be the result of the program” [154]. Likewise, the Association to Advance Collegiate Schools of Business, also known as AACSB International, is an American professional accrediting body for business schools and accounting programs. AACSB criteria “focus on competencies and what students will be able to demonstrate upon completion of their program of study” [2].

In computing, accreditation began in the United States when the Computing Sciences Accreditation Board (CSAB) [70] started academic accrediting programs in the mid-1980s. In the same time frame, the British Computer Society (BCS) [36] also started accrediting programs in the United Kingdom. Accreditation bodies in other countries also developed their standards and criteria for computing disciplines. The existing bodies of *knowledge* in the computing disciplines form a basis for these criteria.

In recent years, curricular reports in computing have focused on competency-based learning, most notably in Information Technology 2017 (IT2017) [204], Computing Curricula 2020 (CC2020) [48], Information Systems 2020 (IS2020) [143], and Data Science 2021 (DS2021) [71]). The broadest of these reports, CC2020, relies a great deal on IT2017, as well as other competency-focused curricular guidelines, such as the Software Engineering Competency Model (SWECOM) [127] and the Global Competency Model for Graduate Information Systems programs [240]. As a result, CC2020 could become as influential as its precursor Computing Curricula 2005 (CC2005) [144] with a significant possible impact on both the academic programs and the criteria used by accreditation bodies.

This current report partly extends the work of the ITiCSE 2021 working group that focused on Professional Competencies in Computing Education [200] in the global accreditation and competency in computing. In addition, the authors explored the meaning of competency reflected in recent professional publications. Further, this work examines how competency is included (or not) in accreditation standards in non-computing and computing domains in different countries.

1.1 Guiding Questions

Before proceeding further, note that a term that underlies this report is the notion of “professional formation” for which an excellent definition comes from the legal profession: “Professional Formation refers to the fostering of students’ formation of an ethical professional identity. This change from a focus on educational inputs like a course on professional responsibility to a focus on clearly-articulated learning outcomes relating to each student’s ethical development that are accessible is a significant paradigm shift in legal education.” [114].

Three questions about the standards and criteria used by accrediting bodies relative to the competency achieved by graduates upon placement in the workplace and long-term career success guided the authors’ effort:

- Q1:** How does accreditation contribute to professional formation and development of competency across various disciplines and countries?
- Q2:** How could accreditation bodies contribute to professional formation and development of competency in the computing domain?

- Q3:** How should accreditation bodies better align with the competency-based education models to support institutions in preparing computing graduates for professional practice?

Some additional insight to this work now follows.

The first query addresses how current accrediting bodies in different (non-computing) disciplines (e.g., medicine, law, engineering, teaching) embed competency in their standards or criteria. Accrediting bodies often focus on knowledge only and not skills or human attributes. Therefore, it would be appropriate for this work to attempt to understand accreditation status on a global scale.

The second query addresses *computing* accreditation bodies and how they address competency in their standards. University faculty members are experts with conveying computing knowledge. However, is knowledge alone sufficient for the modern computing workplace? This query deserved further investigation by the working group.

Finally, while the need to align competency-based education models and support institutions in preparing computing graduates for professional practice seemed appropriate, it was unclear how to accomplish such a goal. Because computing faculty members mainly assess student knowledge, accrediting bodies might do more to evaluate student competency beyond academic work in preparation for workplace performance.

This work addresses graduate competency and eventual graduate performance in the workplace. Except for isolated instances, a fundamental problem seems to exist between computing competency and accreditation. As stated above, most computing accrediting bodies currently focus on knowledge with little emphasis on other aspects that define competency. As a result, despite current market trends, graduates of computing programs face a workplace gap upon graduation. These graduates often have sufficient knowledge derived from their computing studies. However, graduates often have little or no experience applying that knowledge in the workplace. Furthermore, computing graduates often lack the skills and the human attributes to fulfill the workplace experience. Educators should understand that approximately 5% of computing graduates continue their education to graduate school [173]; hence, approximately 95% of computing graduates enter the job market. Do these graduates have the capacity to perform competently in the workplace?

1.2 Research Approach and Assumptions

The authors have adopted a case-study approach for this work [50, 186, 257]. The chosen cases and the rationale for their inclusion appear in this subsection. In addition, a template analysis [148] analyzes the cases where Section 3.1 explains the template employed.

Additionally, this report is a preliminary study, meaning that the authors recognize constraints on the scope of their work. Hence, this section discusses some assumptions and limitations made in various components of the study. It describes the beliefs and definitions underlying the authors’ approach to accreditation, leading to a focus on non-computing disciplines. In addition, it describes the process leading to the countries selected for this work.

1.2.1 Rationale for Studying Accreditation. In Section 2, the authors discuss accreditation. In short, accreditation is a process used in many fields to ensure that professionals can perform their jobs

conforming to professional standards. Globally, a government, professional bodies, or both enforce adherence to accreditation in many disciplines. For example, in many countries, people can teach in public schools only if they have learned their profession in specified educational programs recognized by an independent entity or organization. The same is true for other professional areas such as nursing, medicine, law, and engineering. These mature professions have relied on accreditation for decades to control entry to practice in the field. A central assumption of this work is that accreditation standards are widely accepted because professionals in those fields agree that this is an effective way to support professional formation. In this work, one of the questions the authors explore is how accreditation applies to professional practice in other fields and whether the experience with accreditation in other areas is relevant to the field of computing.

1.2.2 Selection of Disciplines. Accreditation of programs and graduate certification requirements are standard in many professions, from business to aviation to dentistry. Therefore, the authors used the following criteria when choosing fields on which to focus.

- The use of accreditation for entry into the profession is long-standing, globally widespread, and mature in that discipline.
- Accreditation for entry into the profession has vigorous enforcement by a government or professional boards.

The professions chosen for this study are law, medicine (physicians), nursing, primary and secondary education teachers, and engineering. The authors recognize that this is a limited sample and that the path from accreditation to professional practice varies significantly from country to country. Also, there are differences in the accreditation level for different professions. For example, lawyers and physicians are often educated in programs at the post-graduate level, whereas engineers, teachers, and nurses generally receive education in undergraduate programs. Hence, since this is a preliminary study, looking at this limited set of professions may provide insight as to whether accreditation in these fields offers lessons relevant to the computing profession. Section 3 details some characteristics of each discipline and findings on how agencies use and enforce accreditation for that discipline in various countries.

1.2.3 Selection of Countries. Studying accreditation across many countries has many complexities. For example, materials and regulations on accreditation are often published only in the primary language of each country, making them inaccessible to people who do not speak that language. In addition, a total consideration of accreditation in a particular field for a specific country may require deep familiarity with both the discipline and the country to understand how the practice in that country may vary from the published standards. Since this is a preliminary study, the authors accept that their ability to understand these complexities may be limited, but they still can learn lessons of value. Therefore, the authors have selected countries based partly on their knowledge and background, their ability to read the language of accreditation documents, familiarity with that country's education system, and familiarity with its governance practices and policies. The authors also strove to include countries from a geographically broad area, including South America, North America, Europe, Africa, Asia, and the Middle East. The authors recognize that this process is nonrandom and leads to

a selection of countries that is not necessarily balanced geographically. However, the authors feel that this limitation is acceptable for a preliminary study.

1.3 Paper Objectives

This work builds on the foundation of existing accreditation standards and criteria in computing and non-computing fields in a broad sample of national contexts. This study includes both Seoul Accord [209] signatories and major computing accreditation bodies worldwide. It also benefits from previous ITiCSE working groups that explored competencies defined in the CC2020 competency model for performing tasks within an appropriate context [48]. The outcome of this paper is *clearly distinct* because the authors have focused on worldwide professional accreditation standards in computing and compared them with similar standards in other disciplines. The authors then showed how computing accrediting bodies could promote competency within their respective standards and focused on the issues of assessing competency both from the perspective of program accreditation and the perspective of student outcomes assessment.

The objectives of this working group were as follows.

- (1) Explore professional accreditation bodies in *non-computing* fields and show how these bodies factor competency as a requirement for accreditation.
- (2) Review worldwide professional accreditation bodies in *computing* fields and explore how these bodies address competency as a requirement for accreditation.
- (3) Examine current approaches for assessing non-computing and computing professional competencies and provide valuable guidelines for improved competency evaluation for computing accreditation.
- (4) Explore how accrediting bodies address competency-based standards or criteria and suggest possible improvements.
- (5) Make practical recommendations for adopting competencies in computing curricula and accreditation criteria.

Therefore, this working group report could be influential in enhancing accreditation in the computing disciplines.

1.4 Paper Organization

This report includes a description and background for the meaning of accreditation and competency in Section 2. First, the accreditation subsection discusses an overview of accreditation in practice today; the competency subsection addresses competency based on the CC2020 report. Next, Section 3 discusses professional accreditation standards in non-computing fields sampled from a range of disciplines and national contexts. Finally, Section 4 examines worldwide approaches to computing accreditation, including the role played by international accords in setting up guidance for accreditation in computing.

The assessment of competencies within various accreditation settings is the focus of Section 5. The merger of competency and accreditation is the subject of Section 6, the salient theme of this paper. Since competency-based learning and accreditation are relatively new to most computing faculty, Section 7 addresses the suggested recommendations based on the conducted explorations.

Finally, Section 8 provides concluding remarks and offers suggestions for future activities. Appendix A provides additional details of accreditation in non-computing disciplines, which might interest some readers.

2 BACKGROUND

This section begins by posing a setting for graduate employment since most computing graduates enter the workforce. It then explains the meanings and interpretations of accreditation and competency, the central themes of this work, and highlights the interplay between accreditation and competency in a computing setting.

2.1 Graduate Employment

The employment of graduates is a topic of global interest, and there are attempts to measure its achievement in many different jurisdictions [239]. Moreover, producing more employable graduates represents a global challenge [44, 170, 181] and an opportunity to help address UN Sustainability Goal 4 to “Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all” [247].

Developing employable graduates requires the development of strong technical and professional competencies [47, 113, 200]. Given the reports of a digital-skills gap, for example [61, 160, 211, 242, 256], it would be possible to anticipate high employment rates for computing graduates. However, the published data does not always support this. For instance, in the UK, data from 2019-20 (admittedly during the global COVID-19 pandemic) reports 88% of graduates obtaining employment or further study (compared with 90% across all disciplines) and a further 8% of computing graduates being unemployed (compared with 5% across science and 6% across all disciplines) [120]. The comparable figure from the US is an unemployment rate of 5% [97].

In the European Union (EU), there is an EU-level objective that the employment rate for graduates from vocational education and training programs should be at least 82% by 2025 within three years of graduation for graduates aged 20-34 [93]. In 2021, in the EU, employment rates among recent graduates ranged from 58% in Italy to 93% in the Netherlands [94]. In Egypt, studies from 2008-16 indicate graduate employment from “practical studies” is 83% with higher employment for male than female graduates [13], although it was much less favorable in the humanities.

In Brazil [17], 70% of college graduates are employed after one year, engineering has 77% employability, and computing-related graduates have the highest employability rate of 82%. In Chile [169], computing programs have an employability rate of 88%. Although the average college graduate’s employability is unreported, it is known that lowest employability rates are for graduates in the theory of art or history of art, with a rate of 34% after one year of graduation. The highest is in civil engineering, with an employability rate of 93%.

In some jurisdictions, graduate employment is less favorable. For example, in China in 2015, graduate unemployment remained at approximately 30% since 2003 [44]. In South Africa, the rate was 33% for graduates aged 15-24 and 22% for graduates aged 25-34 (although the rate for non-graduates is considerably higher 64% and 35%, respectively) [78] in the first quarter of 2022. In Australia in

2021, full-time graduate employment in computing and information systems was 68% (admittedly lower than in previous years and during the COVID-19 pandemic) [197].

Employment rates in different jurisdictions result from surveys that graduates complete after graduation. For instance, in Brazil, the ABMES Employability Indicator [17] reports the employability rate of college graduates after one year from graduation. In Chile, the employability rates of graduates are required to be submitted by all universities to the MINEDUC (Ministerio de Educación) and are published by the Chilean government for applicants to consider before choosing a program [169]. In Australia, graduates complete the graduate outcome survey six months after graduation [197]. In the UK, graduates complete a graduate outcome survey approximately fifteen months after graduation [122], which is also shared with potential students as it is in Chile; and in the US, the Post-Secondary Employment Outcomes (PSEO) survey performs a similar role [248]. Given the different approaches and challenges in various jurisdictions, many figures appear broadly comparable. However, graduate employment appears lower in some jurisdictions than others. Graduate employment rates could be higher, and graduate under-employment rates lower in all the jurisdictions considered.

University graduates expect to obtain highly skilled positions; therefore, the graduate outcome surveys typically track that as well. Those individuals not employed in highly skilled work potentially attain the classification as being “underemployed”. For example, in China, the need for graduates to consider more precarious employment opportunities has been highlighted [156]. In Australia, 9% of computer and information systems graduates have part-time employment [197]. The portion of computing graduates employed in highly skilled employment in the UK is 83% (as opposed to 82% across science and 76% across all disciplines) [121]. The underemployment rate in the US is 16% [97]. Allowing for different survey approaches, underemployment is broadly comparable and shows room for improvement in all jurisdictions.

This combination of lack of full employment and underemployment has led to numerous reports such as [98, 156, 181, 210]. These reports make several recommendations to address the circumstance, including employability within curricular and co-curricular activities, employer-led-curricular and industry-focused projects, and growing placement/internship provision [98], all of which are mechanisms that support the development of competencies. For example, one study suggested that 85% of graduates perceive they do not have sufficient work experience to secure a job [181]. Other studies have highlighted the relationship between perceived employability and academic engagement [156]. However, there have been improvements in recent years, with unemployment rates reducing (e.g., in the UK from 12% in 2014-15 [210] to 8% in 2019-20 [120]). Of note, recommendations to date have tended to focus on adopting enhancement measures related to developing graduate competency. This report considers competency more directly and, in particular, how accreditation currently and potentially could address competency and enhance graduate employment.

2.2 Meaning of Accreditation

The word *accreditation* has several interpretations. The following discussion addresses accreditation as a process and its associated standards.

2.2.1 Accreditation Processes. Dictionary definitions of accreditation may be helpful. For example, Dictionary.com [79] describes it as:

- (1) the act of giving official authority or approval or the resulting status; certification,
- (2) the act of certifying an educational institution or program as meeting all official formal requirements of academic excellence (e.g., facilities, curriculum, faculty), or
- (3) the act of attributing or ascribing some quality, status, or action to a person or thing.

Accreditation can also mean the action or process of officially recognizing someone as having a particular status or being qualified to perform a specific activity. Accreditation bodies establish their standards to ensure that the operations of conforming entities have oversight by an authoritative body. For example, a traditional accreditation agency (e.g., ABET) assesses and accredits a conforming entity (e.g., computer engineering program) against relevant standards (e.g., ABET Criteria [4]).

Many authoritative or accreditation bodies exist worldwide. Their purpose is to ensure quality in the performance of individuals in a specific field. For example, the accreditation of a dental school states that the dental program satisfies standards to ensure that graduates from that school can perform at a level of competence to serve the public.

Likewise, almost all countries have processes to ensure quality in professional performance. For example, in many countries and disciplines, a two-stage process continues with an individual first demonstrating competency for probationary or supervised practice. Then, a further evaluation occurs where the individual must demonstrate a complete set of competencies expected for independent professional practice.

For some professions (as will be explored in Section 3), professional licensure/registration is compulsory for practice. In other disciplines, such as computing (and many engineering specialisms), licensure/registration is not mandatory. Accreditation regimes for these disciplines have emerged and have received several benefits [63, 68, 149] including schemes such as:

- is a kite-marking exercise that supports a globally-portable and recognized workforce;
- is a form of enhancement promoting subject review;
- helping to ensure the industry relevance of learning; and
- promoting the embedding of work-experience opportunities.

The use of accreditation is not universally well-received and has had criticism because:

- the regimes are too colonial or paternalistic in nature [174];
- the processes are unnecessarily bureaucratic and constrain innovation [116];
- there are dangers of accreditation streams being revenue streams in their own right rather than for the benefit of a discipline or wider society [149].

In computing, for the jurisdictions in which accreditation is available, not all universities will opt to seek it. However, reports indicate that uptake is significant and appears to influence non-accredited programs [24].

2.2.2 Accreditation Standards. Accreditation standards usually describe the accreditation process and the criteria to which an entity must conform. Accreditation authorities often have a commission that creates and enforces the standards, establishes policies for accreditation, and conducts the accreditation evaluation. Depending on the type of accreditation, the standards usually include typical or expected sections that address elements of quality assurance. For example, the following are common standards or criteria for educational programs [2, 218]:

- Mission, purpose, goals
- Governance, leadership, administration, organization
- Planning, resources, evaluation
- Students, learning experiences
- Faculty, scholarship
- Curriculum, academic program
- Educational effectiveness, assessment
- Institutional resources and support
- Integrity, ethics, transparency

Elements of this listing are inherent in almost all standards related to education.

Accreditation standards vary in type and length depending on the professional field. For example, standards for engineering programs can be as short as one page or more than forty pages, depending on the agency and country. In addition, the International Electrotechnical Commission of the International Organization for Standardization (ISO) [134] has developed processes under standard ISO/IEC 17011, within which many accreditation bodies operate. As a result, thousands of accreditation standards exist worldwide. Section 3 will highlight a few of them.

2.3 Meaning of Competency

The concept of competency goes back centuries and millennia. Modern professions, such as teaching [243], medical [100], and legal [111], have used competency and have a well-developed understanding of it. A detailed discussion of these ideas occurs in Section 3. Competencies within higher education include work in the 1990s on embedding transferable skills into degree programs [146]. This consideration has formalized over time to explore the potential to introduce transversal competence. Introducing competence into computing education has been a topic of growing interest over the last thirteen years [212]. Competency models for computing have also been around with varying acceptance levels since the 1980s (e.g., Industry Structure Model [142]) that later evolved into SFIA[232]. This work employs the CC2020 Competency model [48] as its underpinning competency model. In the following subsections, the authors explore the genesis of this competency model.

2.3.1 ACM/IEEE Competency Models. More than a dozen years ago, much activity surrounding competency and quality assurance occurred at the Software Engineering Institute (SEI) of Carnegie Mellon University. There was a dire need to produce quality software worldwide for the many tools and architectures that were

evolving at that time. Software computing conferences, notably the International Conference on Software Engineering Education and Training (CSEE&T), echoed this need and much discussion occurred on producing quality software.

At the CSEE&T convention in May of 2013, Mead and Shoemaker described the software assurance (SwA) competency model, which is the:

application of technologies and processes to achieve a required level of confidence that software systems and services function in the intended manner, are free from accidental or intentional vulnerabilities, provide security capabilities appropriate to the threat environment, and recover from intrusions and failures [162].

The software assurance (SwA) competency model consists of three elements: knowledge, skills, and effectiveness, where knowledge is what an individual knows, skills are what an individual can do by applying knowledge, and effectiveness is the ability to utilize knowledge and skills productively. Thus, effectiveness refers to behavior attributes such as aptitude, initiative, enthusiasm, willingness, communication, teamwork, and leadership. The word *dispositions* echoes these seven attributes.

The SwA competency model builds on prior software assurance curriculum work endorsed by the IEEE Computer Society and ACM [161]. It contains five levels of proficiency: technician (L1), professional entry (L2), practitioner (L3), senior practitioner (L4), and expert (L5). Individuals can use the software assurance competency model to improve their software assurance skills; universities can use it to align course content with skills needed in the workplace. Likewise, the industry can use the model to help employee professional growth and screen prospective employees; new graduates can use the model to map their skills to job position descriptions and interviews. For more information on the SwA competency model, consult the SEI technical report endorsed by the IEEE Computer Society [124].

In a parallel effort on software competency, the IEEE Computer Society made an effort to build on its decade-long project called the Software Engineering Body of Knowledge (SWEBOK). Several people had taken the initiative to develop competency surrounding SWEBOK. The result was the Software Engineering Competency Model (SWECOM), published in 2014 [127]. In this context, competency consists of three components: knowledge, skills, and ability. This concept is like the SwA model, where ability (dispositions) includes aptitude, initiative, enthusiasm, work ethic, willingness, trustworthiness, cultural sensitivity, communication, team participation, and technical leadership. In addition, SWECOM includes five competency levels for software engineering technical activities: technician, entry-level practitioner, practitioner, technical leader, and senior software engineer. A summary by Fairley [95] helps us understand the SWECOM model.

The SwA Competency and the SWECOM models thus introduced a new software engineering and computing dimension. In addition, the competency dimension of dispositions (effectiveness and ability) has elevated computing more toward a profession. As a result, some curricular guidelines have already adopted competency as a central theme, and future computing recommendations are motivated to adopt the same.

2.3.2 ISO Competency Model. In an initiative parallel to the work by the ACM and IEEE, ISO-24773 was developed as an international standard addressing the certification of professionals in software and systems engineering [102]. ISO-24773 models competence around [137]:

- knowledge,
- skill (application of knowledge in a controlled environment), and
- competency (repeated successful application of knowledge and skills in a professional context)

Computing is broader than software and system engineering, however there clearly are strong parallels with the CC2020 Competency model [48]. In addition, while the dispositions terminology originates within the ACM/IEEE competency model, similar constructs exist in other models. For example, in the SFIA Framework, dispositions are very similar to the generic attributes that describe evidenced behaviors required to achieve a given responsibility level [233].

2.3.3 Capability. An issue related to competency is *capability*. Capability is a subtly different concept. Comparing dictionary definitions of competency and capability may be useful. For example, according to Dictionary.com, competency cross-references competence that means: “1. quality of being competent; adequacy; possession of required skill, knowledge, qualification, or capacity. ... 3. sufficiency; a sufficient quantity.” [81]. Whereas capability means: “1. quality of being capable; capacity; ability; ... 2. the ability to undergo or be affected by a given treatment or action. ... 3. usually capabilities; qualities, abilities, features, etc., that can be used or developed; potential” [80].

The third aspect of the capability definition is the most illuminating. Thus, capability could be seen as “about having the potential to become competent” [152, p. 37]. Capability can mean not *yet demonstrated* competency, but given appropriate experience, should be able to do so. In the context of education, a capability may emerge before competency. It is possible to handle competence and capability differently in accreditation education programs. Indeed accreditation processes may look for evidence of competency or capability or some combination of the two. For example, capability could be a requirement for supervised or probationary practice, while competence could be a requirement for unsupervised professional practice.

The Institute of Coding explored the distinction between capability and competency in detail by mapping knowledge, capability, and competency against Simpson’s hierarchy [30]. That mapping is consistent with the competency model set out in ISO-24773 [137], as discussed in Section 2.3.1. There is also some debate as to whether it is possible to evidence beyond capability without participating in the workplace in some manner, i.e., placement, internship, live project, etc.[30]. Arguably, the more opportunity an individual has to repeat successfully application in the real world, the more opportunity one has to develop competency. This approach is similar to the “Task” aspect of the CC2020 model.

2.4 Competency Interpretation

One definition of competency is as follows [115]:

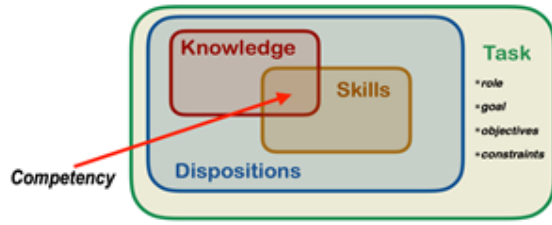


Figure 1: Conceptual Structure of the CC2020 Competency Model [48][p47]

“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). Also, it includes 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 related to the study of jobs and roles.”

In this context, competency identifies with role-related behavior, performance, and effectiveness. Hence, competency is a person-centered concept requiring the demonstration of technical knowledge, skills, and human behavior within a task or job context.

The Information Technology (IT2017) report [204] signaled a shift from knowledge-based learning to competency-based learning with three interrelated dimensions:

$$\text{Competency} = \text{Knowledge} + \text{Skills} + \text{Dispositions}$$

in context. Knowledge designates the *know-what* dimension, skills designate the *know-how* dimension, and dispositions designate the *know-why* dimension. Figure 1 from CC2020 illustrates competency contextualized by a *task*. IT2017 affirms the importance of a professional context that enables students to practice, develop, and demonstrate their competencies.

2.4.1 Reflections on Knowledge. The knowledge dimension of competency is well understood. Students have acquired knowledge since birth. Students learn words, phrases, arithmetic, and even computing ideas at a young age. They formally develop knowledge through schooling and then at the university.

Educators at all levels are experts in transforming information into student knowledge. The CC2020 report identified knowledge represented in two forms: computing knowledge and foundational (professional) knowledge. The CC2020 report [48, p. 49] illustrates thirty-four abbreviated knowledge areas partitioned into an ordered sequence of six categories. Although the table is incomplete, it does provide a basis for computing knowledge.

The CC2020 report [48, table 4.2, p. 50] expresses thirteen elements of foundational and professional knowledge, repeated here in Table 1. Baseline skills is an industry phrase for these thirteen elements, and people performing tasks in the workplace should possess these thirteen characteristics at some level. For example, one would expect computing professionals to adhere to baseline skills in performing a task.

Table 1: CC2020 Elements of Foundational and Professional Knowledge [48, table 4.2, p. 50]

Knowledge Elements	Meaning
Analytical and Critical Thinking	A mental process of simplifying complex information into basic parts and evaluating results to make proper decision
Collaboration and Team-work	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 the importance of doing 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
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 the 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 effectively or productively to work efficiently
Written Communication	Use of a written form of interaction between people and organizations that provides an effective way of messaging

2.4.2 Reflections on Skills. The CC2020 report defines skill as the proficient application of knowledge. The CC2020 report [48, table 4.3, p. 50] summarizes an ordered sequence of six cognitive skill levels with abbreviated interpretations as verbs. These are remembering, understanding, applying, analyzing, evaluating, and creating.

The CC2020 report shows that a skill becomes a couple between knowledge elements and skill levels. For example, in the context of computer engineering, three knowledge elements are electrical circuits, organization, and digital design. In performing a task, a knowledge element couples with a skill level. The CC2020 report example from computer engineering [48, p. 51] illustrates this and shows that these skills intersect knowledge elements with skill levels.

2.4.3 Reflections on Dispositions. Dispositions express the human dimension of competency expressed through individual behavioral patterns. Dispositions reflect one's behavior when applying knowledge and skills [49, 206]. The CC2020 report describes eleven dispositions derived from the literature. The CC2020 report [48, table 4.4, p. 1] lists these dispositions with equivalent elaborations, repeated here in Table 2.

Dispositions relate to academic and workplace activities. People inherently know and recognize these dispositional characteristics of human behavior. Faculty members can facilitate student dispositional development through competency-based pedagogical approaches. In essence, dispositions act as the *glue* that joins knowledge and skills to produce competency. The workplace and society expect dispositions to be part of every competent computing graduate.

Table 2: CC2020 Dispositions [48, table 4.4, p. 51]

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

3 PROFESSIONAL ACCREDITATION STANDARDS IN NON-COMPUTING DISCIPLINES

This section explores accreditation standards from various non-computing professions to set the stage for exploring computing accreditation in Section 6. For each selected profession, the authors examined the standards or criteria, particularly from the competency standpoint as explained in Section 2, bringing in perspectives from several countries. In the interests of t should be noted that there are other professions, for example, the geo-specialties that also focus on competencies [18] in accreditation [19]. However, discussing the disciplines selected here is sufficient for the focus on computing competencies and accreditation.

Entry into critical professions is regulated at the national or regional government level in the examined countries. It typically involves a mix of program-level accreditation and certification/licensing of individuals. Certification for individuals typically implies the presence of professional qualifications, while licensure means authorization to practice the profession. For most professions, the candidate must attend an approved or accredited educational program, which may include required internships or other workplace programs. In certain professions, candidates must pass exams or evaluations to obtain a license to practice. This section examines program accreditation and individual candidate certification/licensure standards in non-computing disciplines.

3.1 Explanation of summary tables

A table summarizes the exploration of each discipline. Tables include accompanying notes with observations abstracted from the emerging patterns. The summary table for the engineering discipline appears towards the end of this section as Table 3, with the other four tables displayed in Appendix A. The key themes emerging across all the disciplines and summaries appear in Section 3.7. This table represents the template used for the template analysis [148] employed in this work.

Within the tables, the rows convey the following information, usually with *Yes/No* entries in the table or *frn* depicting *further research needed* to indicate a response.

Country the country/state summarized in this column

Sources citations to the source documents supporting the data in the column

Individual recognition/certification? Can individual graduates attain any form of recognition or certification confirming their competence?

Institution/School accreditation? Is there a mechanism to accredit the university or school delivering relevant degree programs?

Program accreditation? Is there a mechanism available by which individual programs can be accredited as reaching some required standard?

Accredited degree required? If individual recognition/certification is available, is graduation from an accredited degree program a requirement?

Length of program (years)? May be a number, a range (e.g., 3-5 or several semesters (e.g., 8 Sem)

Curriculum defined by For accredited programs, which specifies the (minimum) curriculum - the Government (or a minister, or government body), a professional body or some other group?

Competency evidenced in program? Is there a requirement for students to demonstrate *competence* during their studies?

Post-study experience required? If individual recognition or certification is available, does a graduate need to complete a period of post-study experience to gain recognition/certification?

Individual assessment necessary? If individual recognition or certification is available, does a graduate need to complete an individual assessment through a body other than their university?

Recognition/certification for licensure? If recognition or certification of individuals is available, is it required for licensure?

CPE/D required? If individual recognition or certification is available, is evidence of continuing professional education or development needed to renew or retain that certification?

For clarity, it is worth noting that individual certification or recognition differs from licensure (license to practise) [6]. However, in some countries or for some disciplines, they combine into a single process.

3.2 Medical Accreditation and Licensure

For the medical profession, the authors explored the accreditation standards related to competency from Brazil, Chile, Egypt, Russia, Canada, the USA, and the UK. For the interested reader, Table A.1 in Appendix A discusses the details while the following provides a summary:

- For medicine, there is considerable unanimity, with all countries offering external recognition/certification, which requires an individual assessment following graduation.
- Recognition also appears to require an accredited medical degree, although accreditation processes in the Russian Federation seem still under development.
- Furthermore, accreditation of the medical school or the programs is, or soon will be, mandatory in all six countries.
- The programs are all significantly longer than a standard bachelor's degree, but most countries require postgraduate

experience or an embedded internship; Chile seems to be an exception.

- However, in all six countries, there is a concept of license to practice, which requires formal external recognition/certification. In Chile, doctors must prove that they have passed a professional examination - this probably counts as *certification*.
- Most countries appear to have mechanisms to certify (examine) doctors who have trained under foreign jurisdictions but wish to practice in that country.

3.3 Nursing Accreditation and Licensure

The authors explored the accreditation and licensing standards for the nursing profession across seven countries: Brazil, South Korea, United Arab Emirates, Russia, South Africa, the United States, and the United Kingdom. Since there are many nursing specialties and titles, this review focuses on the level similar to the Registered Nurse designation in the US. The interested reader can find the detail in Appendix A, Table A.2; the key points now follow:

- Nursing programs, like computer science, are mainly at the undergraduate level with optional graduate programs. The programs typically are four years, although there are shorter programs for certain nursing designations such as Licensed Practical Nurse or Nurse Assistant.
- Across all seven countries, recognition (licensing) from an entity other than the undergraduate program is required.
- In two countries, South Korea and the UAE, licensing is under the control of a governmental body. In four countries, Brazil, South Africa, the US, and the UK, licensing occurs through a separate nursing council or board, although still mandated by law.
- In five of the seven countries, the individual seeking licensure must pass an assessment, usually an exam. In the UK, a test is a mandate only for candidates educated overseas. In Brazil, the government has proposed a requirement for a test but has not implemented it.
- External approval of nursing programs is necessary for six countries. The approval occurs by either the national government, the nursing council that approves the programs, or by state governments in the US. Additionally, in the US, there are voluntary external accreditors. About 88% of the BS/Nursing programs in the US are accredited by one of these bodies.
- Six countries required evaluation of competencies or skills in addition to knowledge-based assessment. Unfortunately, the information is not available for Russia.
- The only country to require a postgraduate working period is the UAE, and only for nurses who are foreign nationals.
- Continuing education to maintain licensure is a requirement in four countries and not required in three: Brazil, South Korea, and South Africa.

In summary, nursing is a field where individual licenses are typically required and controlled at the governmental level. In most cases, program approval is also necessary, either directly by a governmental body, a nursing council, or a board that collaborates with the

government. In addition, the evaluation of skills and competencies is a common requirement.

3.4 Teaching Accreditation and Licensure

The authors explored the accreditation and licensing standards for the teaching profession across seven countries: Brazil, Chile, Egypt, Russia, South Africa, the United Kingdom, and the United States. The interested reader can find the detail in Appendix A, Table A.3 while the key points are below:

- Teacher education programs, such as computer science, are mainly at the undergraduate level with optional graduate programs. The programs are typically four years, although some countries have shorter programs for candidates with a prior university degree.
- Across all seven countries, recognition (licensing) from an entity other than the undergraduate program is required.
- In all seven countries, licensing is under the control of a governmental entity, either at the national or state level.
- In five of the seven countries, the individual to be licensed must pass some evaluation. This assessment is based wholly or partially on a knowledge based test, but in Russia, the UK, and some states in the US, part of the assessment is competency-based using a portfolio or video.
- External accreditation or approval of the teacher education program is necessary for four countries, not required in one country, and in two countries (Chile, Egypt), the information was not readily available. In all four countries requiring program approval, this is done either by the national or state governments in the US. Additionally, in the US, there are voluntary external accreditors. However, less than half the programs in the US are accredited by one of these bodies.
- Four countries required evaluation of competencies or skills in addition to knowledge-based assessment. South Africa and Brazil do not, and it was impossible to determine if Chile does.
- Three countries do not require a working period after graduation for a license. However, the UK needs an additional active period for full certification. In the US, many states have a tiered licensing system and require either a certain number of years of teaching or graduate work to obtain higher levels.
- Information on whether teachers are required to complete continuing education to maintain their license was unavailable for three countries and not needed in three countries. In the United States, however, most states require continuing education to hold a teaching license.

In sum, the teaching profession is a field in which individual licenses are typically required and controlled at the governmental level. In most cases, program approval is a requirement by a governmental entity, and accreditation by non-governmental entities is less critical. In addition, there is evidence that evaluating skills and competencies are becoming more common.

3.5 Engineering Accreditation and Licensure

This subsection studied accreditation standards related to competency in engineering from Brazil, Canada, Chile, China, Egypt,

Germany, Italy, Japan, and Russia, as summarized in Table 3 and the accompanying notes. Here are the key points:

- Engineering programs are mainly at the undergraduate level with optional graduate programs. There is variance regarding the program length, with Japan, Italy, and Germany having the shortest programs - three years - and Chile having the longest one, at six years.
- Four countries require individual recognition/certification for practice engineers: Egypt, Italy, Canada, and Japan
- All countries have institution/school accreditation and program accreditation required.
- In six countries, the government usually defines the curriculum; Canada and Egypt have the curriculum defined by engineering professionals, and in Chile, by the institution.
- Brazil, Egypt, China, Italy, Germany, Canada, and Japan require competency evidenced in the program.
- Post-study experience is not required officially by any of the countries. But Chile and Brazil strongly emphasize the relevance of internship experiences.
- Individual assessments of engineering professionals are necessary for Italy, Canada, and Japan.
- Recognition/certification (without assessment) is necessary for Brazil, Egypt, China, Italy, Canada, and Japan.
- None of the countries requires continuing education from their engineering professionals.

3.6 Legal Accreditation and Licensure

For the legal profession, the authors explored the accreditation standards related to competency from Brazil, Chile, Egypt, Russia, and England (UK). Table A.4 in Appendix A summarizes the details of the findings.

- Across all five countries, professional registration is available and mandatory for the legal profession, with only a few exceptions.
- In most cases, an accredited law degree is required, but in England, not only are law degrees not accredited by one of the regulatory bodies, but students without a law degree can, in principle, attempt the individual assessment.
- The baseline qualification for the law seems to be the first degree of three to five years, although, in Egypt and England, there are routes for graduates in non-law subjects to complete a postgraduate law degree.
- In most countries, a period of postgraduate experience is required before individuals are assessed individually by the relevant professional body. The minimum length of experience varies from 6 months (Chile) to two years (Russia, England); in Egypt, while the minimum period appears not to be specified, there are strict specifications for practice training.
- In Chile, it is the institution that acquires accreditation rather than individual programs such as Law.
- In one of the five countries (Russia), the national government is involved directly in setting and regulating degree and professional standards; in two countries (Egypt and England), an arms-length body defines law degree curriculum content, and in three countries (Chile, Brazil, England), it is

the relevant professional body or bodies that set and monitor individual standards and assessment.

- Even when curricular and assessment standards are set by arms-length or professional bodies, there would seem to be strong government backing, with statutes stipulating at least compliance with the specified criteria and processes.

3.7 Summary of Findings

Several threads emerge for the professional disciplines explored in this section. First, with very few exceptions, an accredited degree from an accredited (or recognized or approved) university is a requirement for a professional graduate to practice. The main exceptions seem to be in teacher education, but prospective teachers must also obtain professional recognition from a government-controlled body after completing their degree.

The distinctions between completion of an accredited degree, professional recognition, and licensure (being permitted to practice) have been unclear for some countries and disciplines, with no single model applicable across all countries and all fields. This situation has complications by the arrangements made for professionals who have gained professional recognition from a country different from the one in which they wish to practice. A requirement for explicit local qualification is despite the claimed portability of professional recognition (certification) by, for example, ABET [6] through the agreements made by the International Engineering Association [207], which covers twenty-nine countries.

The need for local qualification can arise when a professional must work within local regulations, not studied in the country or state where they gained their certification. Such local codes emerge from governments or governmental bodies in most cases, but there are examples of the regulations and curricula defined by professional bodies. Any requirements for local re-qualification can render the notion of portability somewhat moot.

These distinctions are complicated further by the apparent variety of professional recognition and licensure mechanisms. In the UK and most of Europe, the underlying model seems to be one of professional recognition, with the membership of some form of professional *register* taking the role of *license to practice*. For the USA and other jurisdictions, the emphasis appears to be on the *license to practise*, with whatever mechanism is used for licensure also fulfilling the role of individual professional recognition/certification. In their research for this section, the authors encountered variations in each approach, including their combination. It would be helpful to explore this area further, to clarify whether there are distinct approaches or whether the apparent distinctions are artifacts of how the documented information was available to the authors. A detailed investigation in the future would be helpful.

Professional recognition is a requirement before a graduate can practice in any of the domains explored in this section. It seems clear from the discipline summaries that professional recognition often requires a period of relevant experience following the completion of undergraduate study (medicine, law, engineering). Sometimes the undergraduate program includes significant real-world experience in the form of internships (or co-op) placements (teaching, nursing).

Table 3: Accreditation of programs for engineering discipline

Country	Brazil	Chile	Egypt	China	Italy	Russia	Germany	Canada	Japan
Sources	[167]	[54]	[84, 85, 221]	[40, 41, 43]	[57, 87, 194, 195]	[14, 132, 238]	[91, 226–228]	[39, 88, 89, 125]	[112, 139, 141]
Individual recognition/certification?	No	No	Yes	No	Yes	Yes	Yes	Yes	Yes
Institution/School accreditation?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Program accreditation?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Accredited degree required?	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Length of program (years)?	5	4-6	5	4	3	4	3	4	3-4
Curriculum defined by	Govt	Institution	SCU	Govt	Govt ⁵	Govt	Govt ⁵	Engineers Canada	Govt
Competency evidenced in program?	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Post-study experience required?	No ¹	No	No	No	No	No	No	No	No
Individual assessment necessary?	No	No	No	No	Yes	No	No	Yes	Yes
Recognition/certification needed for licensure?	Yes ²	No	Yes	Yes	Yes	No	No	Yes	Yes
CPE/D required?	No	No	No	No	No	No	No	No	No

¹ Internships are highly recommended, but they are not mandatory

² To work as an engineer, professionals must register at the Regional Engineering and Architecture Council (CREA)

³ The shorter programs, eight semesters, are usually called Execution Engineering *a Field Name* (Ingeniero de Ejecución Nombre del Area). It has a hands-on approach, with shallower knowledge of theories. The longer programs are called Civil Engineering *a Field Name* (Ingeniero Civil “Nombre del Area”), and it has a deeper knowledge of theories.

⁴ Supreme Council of Universities in Egypt

⁵ European Standards and Guidelines

For disciplines for which professional recognition follows immediately on completing a baccalaureate degree, the program length tends to be longer than the norm for non-professional degrees.

Finally, this exploration of non-computing disciplines focuses on competency in accreditation. Accreditation in all jurisdictions ensures knowledge assessment, while most require evaluating skills. Some, such as Italy, also require evidence of autonomy and responsibility (dispositions), but, again, the interpretation of the term *competency* is not the same in all jurisdictions.

4 COMPUTING ACCREDITATION

This section explores the current state of accreditation (as defined in Section 2.2) in the computing disciplines at two levels. First, it looks at the role of competency (as defined in Section 2.3) within existing computing accreditation standards within a select set of countries. Second, Section 4.2 explores competency covered in international accords relating to computing accreditation, such as the Seoul Accord [209]. Section 1.2 addressed the rationale for the countries chosen. The accreditation regimes are analyzed using template analysis [148], employing the template explained in Section 3.1.

4.1 Competency in Computing Accreditation in Select Countries

This section explores accreditation and licensing standards for the computing profession at the undergraduate level across a selected set of countries, including Brazil, Chile, China, Japan, Estonia, Germany, Russia, England (UK), and the US. Table 4 summarizes these findings and their accompanying notes. The rest of this section highlights a few interesting aspects of computing accreditation.

Below is a summary of various computing programs in selected regions worldwide:

- Computing programs, like computer science, are noted as between three and five years long. This pattern is in keeping with the norms for the duration of the jurisdiction where delivered.
- All eight countries offer institution/school and program accreditation. But only Russia offers individual recognition/certification.
- The majority of the countries have a curriculum defined by the government. Non-governmental universities in Egypt have a degree of flexibility in setting their curriculum to match other international standards.
- Brazil, Japan, Russia, Egypt, and the UK require evidence of a competency-based program.

Table 4: Accreditation of computing programs

Country	Brazil	Chile	China	Japan	Estonia	Germany	Russia	UK
Sources	[165, 166, 205]	[54]	[40, 42, 43]	[139, 140]	[1, 86]	[7, 8]	[123, 129, 264, 265]	[20, 92, 131, 133, 135, 245]
Individual recognition/certification?	No	No	No	No	No	No	Yes	No
Institution/School accreditation?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Program accreditation?	Yes ¹	Yes	Yes ⁴	Yes ⁵	Yes ⁶	Yes ⁷	Yes ⁸	Yes ⁹
Length of program (years)?	4-5 ²	4-6 ³	5	4	4	3	4	3-5 ¹⁰
Curriculum defined by	National Minister of Education	Institution	Gov.	Gov.	frn	Gov.	Gov.	Institution
Competency evidenced in program?	Yes	No	No	Yes	frn	frn	Yes	Yes
Post-study experience?	No	Yes	No	frn	frn	frn	No	No
Individual assessment necessary?	No	No	No	No	No	frn	Yes	No
Recognition/certification needed for licensure?	No	No	frn	frn	frn	frn	frn	No
CPE/D required?	No	No	frn	frn	frn	frn	frn	No

⁰ Note that *frn* depicts *further research needed* to indicate a response.

¹ Program guidelines are self-evaluated by each institution every five years, and all institutions go through the Education Minister Evaluation after self-evaluation. An independent group of researchers check the self-evaluation accuracy and considers many other aspects of education to accredit the program and the institution.

² Computer science, information systems are four years, and computing engineering are five years

³ Execution Engineering in Computing usually lasts four years and Civil Engineering in Computing last five or six years, depending on the institution.

⁴ China Engineering Education Accreditation Association (CEEAA)

⁵ Japan Accreditation Board for Engineering Education (JABEE)

⁶ Estonian Higher Education Accreditation Centre (EHEAC)

⁷ German Accreditation, Certification and Quality Assurance Institute (ACQUIN)

⁸ Information and Computer Technologies Industry Association (APKIT)

⁹ Chartered Institute for IT (BCS), The curricula exit standards for CITP accreditation

¹⁰ Standard Bachelor's is three years, Bachelor's with a year-long industrial placement (sandwich program) is four years, and the Integrative Master's is four years, or five years if it includes a year-long industrial placement.

- Only Chile requires a post-study experience for graduating students to receive their diplomas.
- Only Russia requires an individual assessment for professionals working in computing.
- None of the countries requires CPE/D in computing careers.

Chile. The Comisión Nacional de Acreditación (CNA-Chile) is responsible for institutional and program accreditation. However, it does not provide specific guidelines for computing, permitting each institution to create programs to best benefit their students as long as students meet their self-selected student outcomes.

China. The China Engineering Education Accreditation Association (CEEAA) [43], a member of the China Association for Science and Technology (CAST) [40], accredits computing programs using Complementary Criteria for Computer Related Engineering Programs [42]. Unfortunately, no official English version was available. However, a translation of the Chinese version reveals that the curricular structure aligns with a standard computer science program, with an emphasis on systems and system design. In addition,

the criteria mentioned here require programs to ensure that students receive adequate training, coursework, professional practice, and a significant capstone project. Unfortunately, the criteria here do not address competency in the form of knowledge, skills, and dispositions.

Estonia. The Estonian Quality Agency governs institutional accreditation in higher education for Higher and Vocational Education (EKKA) [86]. Accreditation consists of four phases: a self-analysis by faculties, a foreign expert evaluation, a decision of an autonomous recognized body, and the self-improvement efforts of individual institutions. Regular assessment of study programs began with the creation of the Estonian Higher Education Accreditation Centre (EHEAC) in 1997, which addresses the third phase of the accreditation process. A council of the EHEAC can render three accreditation actions: accredited, conditionally accredited, and not accredited. The EHEAC provides general criteria for all programs of study, including computing programs, but does not provide specific computing learning outcomes and competency.

Germany. Started in Germany and expanded since then, the Accreditation, Certification and Quality Assurance Institute (ACQUIN) [8] has been serving as the primary accreditation body for computer science and related disciplines since its founding in 2001. ACQUIN's accreditation policies and procedures comply with the Standards and Guidelines for Quality Assurance in the European Higher Education Area, which define the assessment criteria and the accreditation process [7]. The focus is on three aspects of quality assurance: standards for internal quality assurance, standards for external quality assurance, and standards for quality assurance bodies. These quality assurance guidelines provide ten criteria for internal quality assurance in compliance with national legislation and national and international scientific standards. The ACQUIN accreditation standards intend to be discipline-agnostic. Thus, no specific criteria exist for computing programs.

Japan. The Japan Accreditation Board for Engineering Education (JABEE) provides engineering accreditation standards, including computer science and information science. The same nine-point engineering criteria is used for computer science programs along with discipline-specific interpretations [140]. JABEE also uses an outcome-based evaluation for accreditation. It does not question the approach used to achieve program outcomes as long the program correctly assesses and verifies that its graduates have achieved the program learning outcomes [139]. In addition to computing-related outcomes conforming to ACM/IEEE-CS curricular guidelines or the guidelines of the Information Processing Society of Japan, the JABEE criteria for computer science include preparation for working in diverse societies and cultures and understanding the impact of technology on public welfare and the environment, professional ethics, collaborativeness, and continuous professional development.

Russia. Undergraduate programs do not have a standardized naming convention. Still, the programs must identify a government-approved academic standard and one or more government-approved professional standards where it expects its graduates to be employed [123]. For example, the Information and Computer Technologies Industry Association (APKIT) [129] develops professional standards in IT and serves as the leading accrediting body for undergraduate computing programs, establishing accreditation standards for computing [265]. A program applying for accreditation must satisfy the five APKIT criteria involving professional competencies, required program curriculum, and faculty competence. The APKIT professional standards revolve around a set of skill/knowledge pairings in the context of a specific task. In particular, graduates must demonstrate a level of competency defined as a skill/knowledge pairing. Unfortunately, although the documents seem to list an equivalent of the term 'disposition' for each competency, no specific information is provided [263].

United Kingdom. In the United Kingdom (UK), the Chartered Institute for IT (BCS) [20, 64, 68, 136] accredits engineering-related programs under the auspices of the Washington Accord [133] under license from the UK Engineering Council [245] concerning Chartered Engineer (CEng) and computing programs under the auspices of the Seoul Accord [209] in relation to the BCS's standard Chartered IT Professional (CITP). In addition, the BCS supports

registration to a variety of professional memberships [21] that require applicants to demonstrate knowledge and competence in a workplace setting. BCS-accredited programs meet appropriate exit standards (defined by the accreditation sought, such as CITP or CEng) [62, 63], supplemented by other evidence of program quality. The Engineering Council defines competence as "the ability to carry out appropriate tasks to an effective standard. Achieving competence requires the right level of knowledge, understanding and skill, as well as a professional attitude" [244, p. 40], which is broadly comparable with the working definition for competence used in this report.

In addition to accrediting bachelor's and master's degree programs, the BCS also accredits competencies via accreditation to the Registered IT Technician (RITTech) standard [20, p. 13]. To obtain RITTech accreditation, a university must evidence that upon completion of an industrial placement, Degree Apprenticeship or Foundation Degree, all successful students will have reached the minimum standards of experience, responsibility, competence, and interpersonal skills set out in the RITTech standard [22]. The domain of IT skills also received guidance from recognized skills frameworks such as Skills Framework for the Information Age (SFIA) [232] or the European Competence Framework (e-CF) [138]. For RITTech, having post-qualification work experience is not necessary; however, for CITP or CEng registration, post-qualification professional practice experience is required. Therefore, professional registration degree qualifications become a mechanism to evidence capability (as discussed previously in subsection 2.3.1). However, degree qualifications combined with experience are becoming a mechanism to evidence competence, as discussed earlier.

Other UK accreditation bodies include TechSkills [225], the Institute of Engineering and Technology (IET) [131], and the UK National Cyber Security Centre [179].

United States. Computing program accreditation in the US is primarily in the domain of ABET [3] with its accreditation commissions on computing, engineering, engineering technology, and applied and natural science. Computing programs that do not include the word *engineering* in their titles are accredited by the Computing Accreditation Commission (CAC) using the CAC Criteria [4]. Computer engineering and software engineering are accredited by the Engineering Accreditation Commission (EAC) using the EAC Criteria [5]. These criteria include general criteria that all accredited programs must meet by that commission and specific program criteria for programs in recognized disciplines such as computer science or software engineering. As ABET is a signatory, these criteria align with the appropriate international accords discussed next.

4.2 International Computing Accords

This subsection examines several major international accords and treaties related to accreditation in the computing sphere. The primary focus is computing accreditation under the Seoul Accord [209]. Still, this section first reviews several other accords: the Dublin Accord [82], the Sydney Accord [222], the Washington Accord [133], and Lima Accord [10]. The accords cover computing disciplines such as computer engineering, software engineering, and other computing engineering and technology programs.

Dublin Accord. The Dublin Accord is an “international agreement establishing the required educational basis for engineering technicians” that is part of the International Engineering Alliance [82]. Established in May 2002, this accord currently has nine signatories through their professional societies. These include Australia, Canada, Ireland, Malaysia, New Zealand, Korea, South Africa, the United Kingdom, and the United States. The agreement establishes mutual recognition of Engineering Technician qualifications. The signatories have committed to developing and recognizing good practices in engineering education.

Sydney Accord. Established in June 2001, this “international agreement between bodies responsible for accrediting engineering technology academic programs” is part of the International Engineering Alliance [222] with 11 current signatories through their professional societies: Australia, Canada, Chinese Taipei, Hong Kong, China, Ireland, Korea, Malaysia, New Zealand, South Africa, the United Kingdom, and the United States. The agreement establishes mutual recognition of good engineering education practices focused on academic programs dealing with engineering technology that provides a “key foundation for the practice of engineering technology” and recognizes that the roles of engineering technologists are part of a wider engineering team [222].

Washington Accord. This “international agreement between bodies responsible for accrediting engineering degree programs” is part of the International Engineering Alliance [251]. Established in 1989, this accord currently has twenty signatories through their professional societies, with eight organizations holding provisional signatory status. It is a “multilateral agreement responsible for accreditation or recognition of tertiary-level engineering qualifications to assist the mobility of professional engineers.” The signatories have committed to developing good practices in engineering education through academic programs and recognize that accreditation of educational engineering programs forms a basis for engineering practice. It also “establishes and benchmarks the standard for professional engineering education across those bodies” [251].

Lima Accord. This multilateral agreement covers the accreditation of undergraduate engineering programs between organizations in Latin America and the Caribbean [10]. It is founded on the collaborative development of good engineering education practices and ensuring continued equivalence and mutual recognition of these engineering programs through comparable accreditation standards and procedures. This agreement is a relatively young accord, having started in 2014. However, it will likely affect international recognition of engineering and computing programs.

The European Quality Assurance Network for Informatics Education (EQANIE). In Europe, EQANIE was founded in 2009 [92] and provides a similar role to the Accords in a European context. EQANIE “is a non-profit association seeking to enhance evaluation and quality assurance of informatics study programmes (sic) and education in Europe” [92]. Additionally, EQANIE operates its European quality label (Euro-Inf). EQANIE and authorized entities perform Euro-Inf accreditation. Some entities include the National Agency for Quality Assessment and Accreditation of Spain (ANECA), the Accreditation Agency for Degree Programmes in Engineering, Informatics, the Natural Sciences and Mathematics e.V., Germany (ASIIN), and the

Chartered Institute for IT (BCS). As discussed earlier, the United Kingdom (UK) signatory, the BCS, accredits engineering programs under the Washington Accord and computing programs under the Seoul Accord. Therefore, BCS’s CITP accreditation may have an extension to qualify for the European Union offering of Euro-Inf accreditation [92]. Likewise, CEng accreditation may receive an extension to the European Union offer *Eur Ing* registration [96].

4.2.1 The Seoul Accord. This work pays special attention to the Seoul Accord, an international agreement between bodies responsible for accrediting computing academic programs [209]. Established in 2008, it is a “multilateral agreement among bodies responsible for accreditation or recognition of tertiary-level computing and IT-related qualifications.” There currently are nine signatories that include professional societies in Australia, Canada, Hong Kong, Japan, Korea, Mexico, Taiwan, the United Kingdom, and the United States. The Seoul Accord “aims to ensure transparency in accreditation, remove arbitrary practices and policies, become the international authority on quality assurance, and develop and promote best practices to improve education in computing and IT-related disciplines.” [209].

4.2.2 Seoul Accord Graduate Attributes. The Seoul Accord defines graduate attributes to “form a set of individually-assessable outcomes that are indicative of a graduate’s potential competency” [209, section D] upon graduation from an accredited program. These attributes succinctly summarize the capabilities that characterize graduates of all computing programs within the purview of the accord. Each signatory must minimally include the agreed-upon attributes and may optionally add others to differentiate specific programs accredited by that signatory.

The accord is driven by the principle of substantially equivalent qualifications requiring not identical curricular content or program outcomes but focused on graduates prepared to enter professional computing careers. The graduate attributes thus allow for substantial equivalence without mandating them, i.e., they do not represent “international standards” for accreditation. They, however, circumscribe programs recognized by the Seoul Accord and enable the development of outcomes-based accreditation criteria for their use.

Table 5 summarizes the Graduate Attributes, per the Seoul Accord that applies only to the *Computing Professional* graduate. Although the Seoul Accord mentions *Computing Technologist* Graduate and *Computing Technician* Graduate, which represent lower entry points into the computing profession, the Accord is reserved only for the *Computing Professional* graduate. As the table shows, there are ten categories ranging from academic preparation, computing knowledge, modern computing tools, ethics, and lifelong learning.

4.2.3 Competencies in the Seoul Accord. The Graduate Attributes shown in Table 5 do not explicitly call out competencies, as defined in CC2020. However, the Seoul Accord explicitly calls out a computing problem in any domain whose solution requires applying computing knowledge, skills, and generic competencies.

Item 2 in the table focuses on knowledge aspects of CC2020 competency, while items 3–5 highlight skills needed by a computing graduate. Items 6–9 focus on a mix of skills and dispositions, while item 10 brings out the entire gamut of knowledge, skills,

Table 5: Seoul Accord: Computing Professional Graduate Attributes [209, section D5]

Category	Computing Professional Graduate Attribute
1 Academic Education	Completion of an accredited program of study designed to prepare graduates as computing professionals
2 Knowledge for Solving Computing Problems	Apply knowledge of computing fundamentals, knowledge of a computing specialization, and mathematics, science, and domain knowledge appropriate for the computing specialization to the abstraction and conceptualization of computing models from defined problems and requirements
3 Problem Analysis	Identify, formulate, research literature, and solve complex computing problems reaching substantiated conclusions using fundamental principles of mathematics, computing sciences, and relevant domain disciplines
4 Design/Development of Solutions	Design and evaluate solutions for complex computing problems, and design and evaluate systems, components, or processes that meet specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations
5 Modern Tool Usage	Create, select, adapt and apply appropriate techniques, resources, and modern computing tools to complex computing activities, with an understanding of the limitations
6 Individual and Team Work	Function effectively as an individual and as a member or leader in diverse teams and multi-disciplinary settings
7 Communication	Communicate effectively with the computing community and with society at large about complex computing activities by being able to comprehend and write effective reports, design documentation, make effective presentations, and give and understand clear instructions
8 Computing Professionalism and Society	Understand and assess societal, health, safety, legal, and cultural issues within local and global contexts and the consequential responsibilities relevant to professional computing practice
9 Ethics	Understand and commit to professional ethics, responsibilities, and norms of professional computing practice
10 Life-long Learning	Recognize the need, and have the ability to engage in independent learning for continual development as a computing professional

and dispositions that are the hallmark of a successful computing professional.

One of the Seoul signatories, ABET, already has accreditation criteria that require competency “to the knowledge, skills, and behaviors that students acquire” [4]. In addition, ABET’s commissions accredit computing programs in more than 32 countries worldwide, which conform to the Seoul, Washington, Lima, Sydney, and Dublin accords.

4.3 Section Summary

This section presented the landscape of computing accreditation. It also showed the inclusion of competencies within the various accreditation criteria.

Nearly all approaches to accrediting computing programs focus on knowledge, with only a slight push toward skills. Computing curricula accreditation tends to be course or module-based, where the faculty focus on imparting knowledge and its assessment. While the attention to computing skills is negligible, arguably no accreditation criteria address human elements or evaluation of the dispositions, even though this dimension may appear in computing standards, such as the “behaviors” mentioned in the ABET accreditation criteria [4]. In summary, the current situation is that computing accreditation does not fully address the CC2020 notion of competency comprising knowledge, skills, and dispositions.

5 ASSESSING COMPETENCY

Section 3 identified several countries and professional disciplines where an individual must demonstrate competency to practice in the profession. Section 4 found that in most countries surveyed, there was no individual assessment of the competencies of graduates of computing programs. Section 4 also found that while there is some language concerning competencies in accreditation guidelines and international accords, in most cases, program accreditation focuses primarily on the graduates’ knowledge.

If accreditation schemes are going to promote competency, then it follows that there must be a mechanism by which an educational institution can assess the competencies of its students. This section demonstrates how competency assessment can be part of a computing curriculum. A more detailed discussion of determining computing competencies in an educational setting is available in [201].

Like any assessment approach, competency assessment in computing can be summative or formative, described as follows.

- (1) Summative assessment, which is *backward-looking* assessment that examines whether a student has learned something from an educational activity
- (2) Formative assessment, which is *forward-looking* assessment that determines “given that the student has learned x, is the student prepared to do y?” [99]

Realistic models exist for designing summative and formative assessments within a program of study that genuinely assesses the competencies of program graduates. This section looks at a few of these existing models and how to apply them to the computing field.

5.1 Assessing Competency: Knowledge, Skills, and Dispositions

As discussed in Sections 2.3 and 2.4, demonstrating competency involves demonstrating knowledge, skills, and dispositions in the performance of some job or task. It stands to reason that assessing competency implies assessing all three (knowledge, skills, and dispositions) in the context of appropriate tasks. Furthermore, Wiggins [253] notes that assessment best suited for competency-based learning is *authentic performance* that combines authentic tasks with *performer-friendly* feedback. These authentic tasks “anchors testing in the kind of work people do, rather than merely eliciting easy-to-score responses to simple questions” [253, p. 21]. Feedback is an integral part of an assessment for improving learning that should be immediate, frequent, based on criteria or standards, and communicated with empathy and in a friendly manner [99, p. 106].

To demonstrate competencies at the level that employers typically expect, a prospective or current employee must meet these four related conditions: this demonstration needs to be (1) in a real-world setting where the employee (2) successfully completes the specified tasks (3) repeatedly over (4) an extended period [137]. Thus, proper competency assessment should involve multiple tasks and measurements in work or work-like contexts. While examinations and quizzes may be sufficient for assessing knowledge, it is rather challenging to design tests to demonstrate skills or dispositions. A well-designed authentic assessment task can demonstrate

knowledge, skills, and dispositions, thus allowing each competency component to be assessed [32].

5.1.1 Assessing Knowledge. Assessment of content knowledge is the most straightforward and historically-established approach for educational professionals to design, grade and scale. It may require students to complete a broader range of assessments from traditional academic assessments, such as taking quizzes or examinations, writing essays or reports, and completing authentic assessment tasks. Occasionally, teachers assess knowledge indirectly by observing how students or graduates perform in practice. The most significant consideration for knowledge assessment as a component of competency assessment is to focus the assessment on the threshold, or key, domain concepts. The threshold concepts form the basis for future content knowledge development [60]; focusing on such threshold concepts avoids assessing potentially irrelevant content and promotes greater understanding by students [103].

5.1.2 Assessing Skills. Skills assessment must measure whether individuals *know how* to apply content knowledge and engage in processes that require strategies and repeated practice as opposed to the *know what* of knowledge assessment. Demonstrating skills usually include academic or real-world projects that provide opportunities to observe and evaluate evidence of skills regardless of whether the projects are part of a class or from a work-based experience such as an internship. Clear criteria and rubrics that describe the expected student performance have preference.

Some usable frameworks for skills assessment include the Japanese *i Competency Dictionary* (iCD) framework [117], SFIA [232], which has global usage, and the European e-Competence Framework (e-CF), aimed specifically at European IT professionals. Section 5.2 below gives an example of using the SFIA framework to assess skills. Relevant background literature includes the ITiCSE 2021 working group report [202] and the CC2020 report [48].

As argued by Bowers [30], one valuable approach is to develop skills assessments that are distinct from knowledge assessments. This switch requires assessment approaches to pivot from the *cognitive competence* of Bloom's taxonomy [23] that focuses solely on cognition to the *operational competence* of Simpson's and Miller's hierarchies [214] that focus on skills.

5.1.3 Assessing Dispositions. As expressed in the ITiCSE 2021 working group report on computing competencies [202], the assessment of professional dispositions is perhaps the least understood of the three competency components. Professional dispositions are cultivated behaviors desirable in the workplace, such as responsibility or persistence. An issue is that dispositions are inborn, personal traits that are naturally fuzzy. However, many professional dispositions are malleable, learnable, and, most importantly, observable and thus assessable. Like skills, one can assess dispositions and communicate effective feedback by engaging students in authentic tasks that "supply valid direction, intellectual coherence, and motivation for day-in and day-out work" [253, p. 21]. Still, the focus here is on dispositions, not skills.

Dispositions require assessment in tasks that reflect real-world situations, allowing students to demonstrate behaviors that manifest personalities. The more realistic the tasks, the more students

replicate real-world conditions and exhibit behaviors that manifest dispositions. Ideally, students can learn dispositions and be assessed on dispositions in work-based learning environments. Some computing degree programs incorporate significant work-based learning. For example, the graduate apprenticeship programs in UK [130, 236] and the co-op programs in Canada [119], but more common is to have credit-bearing internships either during the academic year or term breaks. However, placing and assessing students in a workplace setting is not always practical or even possible. In such cases, universities can revert to simulated environments in a laboratory setting to evaluate dispositions or in semester-long projects. Teachers can emphasize group work or teamwork in these environments to closely mirror real-life situations. The challenge of creating coursework becomes one of understanding and providing settings closer to real-world work environments. However, one cannot realistically achieve this without close interaction with business and industry.

Table 6, taken from Raj et al. [201, table 7], is an example of a rubric for assessing the eleven dispositions stated in the CC2020 report. Co-op or internship supervisors can use this rubric to evaluate the students they supervise, or instructors can use it to assess student performance in laboratory or project work. The rubric is also helpful for peer assessment. In this case, students should receive additional guidance on interpreting each disposition in the particular project context. Other peer assessment schemes may be employed to assess a combination of dispositions and skills in team working contexts [37, 66, 67]. In addition, teachers may use the self-assessment aspects of positive psychology to address some learner dispositions [65, 69, 192, 198].

Table 6: Rubric example for dispositions [201, table 7]

Disposition	Score					Score Value
	0	1	2	3	4	
Adaptable		✓				1
Collaborative				✓		3
Inventive					✓	4
Meticulous		✓				1
Passionate				✓		3
Proactive					✓	4
Professional				✓		3
Purpose-driven	✓					0
Responsible			✓			2
Responsive				✓		3
Self-directed				✓		3
Totals	1	2	1	5	2	
Average Score						2.45

As stated earlier, a single demonstration of a task is typically insufficient to demonstrate that learners *repeatedly* and *over an extended period* apply necessary skills with an appropriate disposition. Moreover, a single demonstration also does not provide the opportunity for student feedback and student improvement. One approach to disposition assessment is for each student to create a portfolio to demonstrate dispositions through the tasks they complete throughout their programs of study. Portfolios are slowly gaining importance, especially when seeking or changing jobs. Student portfolios will need to include evidence of their successful

completion, more than once, of several related tasks to constitute evidence of real-world competency.

A recent publication developed a tool to support a holistic process to address the challenge of using a portfolio to assess dispositional competencies [31]. The tool lets programs set the minimum number and the sufficient number of portfolio references needed to demonstrate a disposition. The device is also flexible in allowing for individual circumstances. For example, combining a portfolio with work-based experiences inevitably means that students will have different opportunities and learning experiences. In addition, a particular student may not have sufficient evidence to demonstrate all the dispositions. In this case, a portfolio could still qualify as *satisfactory* if it reflects most dispositions.

5.2 Assessing Competency Based on a Professional Skills Framework

In developing dispositions assessments, one can build on existing models, such as SFIA [232] and iCD [117], designed to meet real industry needs. The SFIA Foundation has developed detailed guidance for self-assessment and assessment by a supervisor or independent assessor [231]. These guidelines are straightforward and comprehensive but assume a thorough familiarity with SFIA. The iCD framework is used for periodic assessment of an individual's performance by appropriate managers. The assessment items are at the lowest level of the skills hierarchy, so several thousand are available for use [117].

SFIA defines behavioral characteristics independently of the technical activities and arranges them into seven levels corresponding to different levels of experience and responsibility. At each level, there is a set of characteristics arranged under the five broad headings of *influence*, *autonomy*, *complexity*, *knowledge*, and *business skills*. The last is a *catch-all* for characteristics valued by employers that don't fit anywhere else. Detailed descriptions are provided for 120 *skills* at up to seven levels, corresponding to the seven levels of responsibility. Competency in a particular skill at a specific level requires repeated, successful demonstration, in a real-world environment, over an extended period, of (the bulk of) both the activities defined for the skill at that level **and** the responsibility characteristics for that level. Ensuring graduates have developed competency against the SFIA framework should ensure their enhanced employability.

As an example of using an existing framework for assessing skills, the SFIA framework for product testing can be considered [235]. Using the attributes listed in the SFIA framework for testing on a programming project, the instructor could decide that:

- Level 1 (Follow): Achieved if the student tested the project according to cases provided by the instructor,
- Level 2 (Assist): Achieved if the student wrote and used a unit test script,
- Level 3 (Apply): Achieved if the student created unit tests that were based on the project requirements and created a map between the tests and the requirements document, and
- Level 4 (Enable): Achieved if the student created and followed a protocol of unit testing, regression testing, and integration testing throughout the project development.

The SFIA framework supports non-binary and binary assessments where all students should achieve a particular responsibility level for a skill.

5.3 Other Assessment Considerations

Assessments typically take place in conjunction with courses enrolled by students, which can have unfortunate consequences. Assessment occurs when a competency element is introduced to a student, not when the student has gained sufficient mastery and is applying that element. Assessment closely tracks student grades, not student achievement of competency. Using a portfolio-assessment approach can thus correct such assessment timeline errors.

When left to themselves to assess their students, educational programs might set lower thresholds on achievement, allowing their progress to succeed in assessment benchmarks while their students fail. Having standardized thresholds, e.g., established and assessed by external entities, for all educational programs would help to eliminate these issues. In addition, when set by professionals, these thresholds will make students better prepared for initial work placements and long-term careers. However, some might view such externalization as an infringement on faculty freedom in the classroom, making it unpalatable. Some of the approaches the BCS uses in the UK, such as RITech [22], might help counter this criticism.

It would be helpful for educational institutions to invest in automated tools for managing student portfolios and assessments, especially for skills and dispositions through multiple courses, with student traceability and privacy guarantees. Such tools could aid in understanding the development of competencies in students while also meeting the *burden* of assessment needed for program accreditation.

5.4 Section Summary

This section explored assessing the CC2020 notion of competency as comprising knowledge, skills, and dispositions. Skills and dispositions continue to pose challenges as they are not as easy to evaluate using traditional approaches that focus purely on knowledge. In addition to the proposed techniques, this section explored the use of professional skills frameworks, such as SFIA and iCD. These frameworks enjoy a pair of benefits: industry requirements have driven them, and academic settings can adopt them.

6 COMPETENCY AND ACCREDITATION

Software systems govern and control most aspects of modern society, including critical infrastructure sectors such as transportation, medicine, electrical power grids, secure elections, communications, and defense. Yet, despite this criticality, in most countries, there has been little will to implement certification or licensure of computing professionals, driven by several complex reasons mentioned earlier in this report and expanded in the next section.

An alternative model is to promote voluntary accreditation of programs. However, whether a mandatory licensing scheme or a voluntary accreditation scheme, it must be based on assessments designed to ensure that graduates are ready for work and long-term careers in the computing profession. Competency-based assessment becomes key to effectively achieving these goals, discussed as follows.

6.1 Certification/Licensing

The discussion in Section 3 showed clearly that in many non-computing fields, entry to the profession has strict regulations requiring a degree from an accredited program, followed by certification/licensing via tests or other evaluations. Furthermore, for several of these fields, the degree program requires students to complete one or more work experiences, where success means clearing some minimum level of performance in these practical components before qualifying for the degree. Standards are often set at the governmental level and enforced by accrediting or licensing organizations. Institutions typically implemented these standards as the public recognized the need for competence in these fields.

In computing, although there have been some attempts at certification, these have been limited in scope or have failed. In the US, for example, in 2009, the IEEE, the National Society of Professional Engineers, and the Texas Board of Professional Engineers agreed to sponsor the development of a Professional Engineer exam in software engineering [237], which they offered in 2013. Unfortunately, this examination never became popular and was discontinued in 2018. In addition, in 2002, the IEEE Computer Society developed the Certified Software Development Professional (CSDP) certification [126] with testing based on the Software Engineering Body of Knowledge (SWEBOK) [25]. These were eventually replaced by the Professional Software Engineering Master (PSEM) [128] and the related Professional Software Engineering Process Master (PSEPM). However, these certifications are knowledge-based rather than competency-based, which does not reach the quality needed for professional practice. After the Professional Engineer licensing exam failed, there was some discussion in the literature as to why it is so difficult to impose standards on computing professionals and whether it is still worth doing.

There has been more progress in the UK towards awarding professional designations to computer professionals, for example, the status of *Chartered Engineer* and *Chartered IT Professional* based on assessments of professional skills that are similar to the professional knowledge expressed in CC2020. The European Engineer (Eur ING) [96] serves a similar purpose in mainland Europe and the wider European Union. The UK Governments National Cyber Security Centre also certifies the competence of cybersecurity professionals [178]. One should note that engagement in these professional registrations is entirely voluntary and thus has not become the norm.

Licensing has not yet occurred in software engineering, according to Parnas [182], due to a lack of agreement on capabilities required by software engineers, a lack of legislation, and a lack of recognition posed by the dangers of poorly written software. Parnas argued that earlier approaches to licensing were based on bodies of knowledge, which were doomed to fail because the knowledge in this computing field changes far too quickly. Landwehr et al. [151] list capabilities analogous to the skills component of competencies that software engineers need to be able to do, which teachers should embed into the curriculum. They also noted that capabilities are fundamental and less prone to rapid change, unlike the current bodies of knowledge.

Seidman [208] argued that computing is not truly a profession in the sense that engineering is. He noted that there is wide variation

globally regarding whether computing programs must be accredited and whether computing is a part of engineering. Seidman also rightly pointed out that the people in the computing field may also be unwilling to be viewed as professionals because that would imply accountability for their work and responsibility for failures. In a recent article, Kamp [145] echoes the theme of liability for IT work by noting that companies and workers that produce software, unlike any other safety-critical profession, are not subject to product liability in most countries, a situation that he finds unacceptable. Requiring computing workers to hold liability insurance would likely lead to requirements for licensing or completing an accredited program.

6.2 Industry and Computing Graduate Readiness

Typical program-level accreditation of computer science programs, such as that done by ABET, is for the program itself, not for the program graduates. In other words, such accreditation does not include evaluation of the graduates in terms of competencies. Thus, the review of individual competency falls to employers. A long-standing perception, though not entirely well-founded, is that computer science graduates, even from accredited programs, are unready for employment or only prepared for lower-end jobs and are not being provided with the rapidly-advancing skill sets needed by computing professionals. However, the Executive Summary of the Shadbolt Review [210] in the UK rebuts this notion that there are general problems with computer science graduates:

In many areas, the performance of Computer Science graduates from English HEIs is outstanding, and the majority of graduates go on to fulfil important and rewarding jobs. The review recognizes that there is much that is good about Computer Sciences as an academic discipline and its graduates. [...] Although we have uncovered some challenges around employment outcomes for a number of graduates, it is significant that Computer Sciences as a discipline is not alone. *Shadbolt* [210] ¶ 2.1

The executive summary emphasizes that the problem appears to be a misalignment between the supply (of graduates) and the demand (for graduates). Finally, the body of the report describes that people can do more to improve graduate skills and work readiness, recommending that higher education work with employers foster more significant opportunities in degree programs to provide hands-on education that enhances computing skills.

6.3 Competency-Based Computing Education is Critical

As stated and seen in Section 3, competency-based education and assessment have become increasingly important in other practice-based fields, such as healthcare and education, but computing has been slow to adopt this model. However, there has been progress. As noted earlier, recent curricular reports in computing have focused on competency-based learning: IT2017 [204], CC2020 [48], IS2020 [143], and DS2021 [71] curricular reports. CC2020 itself owes

a great deal to IT2017, as well as other competency-focused curricular guidelines such as the Software Engineering Competency Model (SWECOM) [127] and the Global Competency Model for Graduate Information Systems programs [240]. As a result, CC2020 can potentially be more influential than its precursor, Computing Curricula 2005 [144].

One of the prime drivers for introducing competency to computing was in IT2017 [204], and elaborated in CC2020 [48], is to ensure that graduates have better preparation for employment. Specifically, the dispositions developed and promulgated in CC2020 intend to address the perceived lack of *professional skills*, reported by Shadbolt [210]. The observation about graduates lacking adequate technical skills is misplaced because it reflects an (unrealistic) expectation that computing graduates should have the preparation for the *particular* set of technologies deployed by each prospective employer. Although unrealistic, academicians could alleviate this lack if graduates were to have some significant work experience – regardless of the specific technologies to which they have exposure. Furthermore, using one set of technologies in depth may prepare graduates to learn other, possibly idiosyncratic, technologies used in different work contexts.

Assessing competencies in universities supplements rather than replaces the practice in industry of testing job applicants on knowledge and performance. Companies will not and should not depart from testing job applicants unless there is some independent assessment of applicants. No matter how strong a computing program may be, there will always be students who graduate with minimal competence. Companies will also need to train employees on their technologies because it is unrealistic and impractical for colleges and universities to teach specific technologies when those technologies change constantly. What is important is how quickly graduates can learn the new technologies, whether they properly apply theory and best practices when using the technologies, and how well they interface with the stakeholders at the company and with the product.

There is no consensus about licensure or certification for computing professionals or how much liability a programmer or a company has for its product. Therefore, it is unlikely that the current state will continue as technology becomes even more embedded in society and software flaws create even more expensive and deadly results. Furthermore, if the call for more accountability in computing grows, who will guide the development of the standards and certifications? The authors argue that professional societies and accrediting bodies must consider the computing landscape.

The following five items need consideration when implementing a competency-based program assessment.

- (1) Is there a consistent and global meaning of competency in computing?
- (2) Are there standardized assessment measures?
- (3) What role does student performance have in program assessment?
- (4) Are assessments binary or non-binary?
- (5) Is competence part of the core undergraduate education, or is it supplemental?

The following subsections elaborate on these five points.

6.4 A Global Meaning of Competency

Accreditation standards, computing programs, and curricular recommendations must use the same terminology and language regarding the expectations of graduates. CC2020 provides one candidate definition for competency as knowledge, skills, and dispositions. It is still early to tell whether computing programs are adopting the CC2020 terminology within their curricula and related assessment. On the other hand, accreditation bodies do not explicitly use competency terminology in their criteria. Even though reference to specific knowledge, skills, and dispositions is implicit in many aspects of accreditation criteria, agencies could make the wording more explicit and organized to help ensure it addresses competence.

The misalignment of accreditation standards, computing program design, and curricula recommendations for the computing community is problematic. It sends mixed messages to the computing community about what is essential and what is not. It creates a misalignment of terminology and expectations of what graduates must achieve by graduation. Such misalignment in definitions and expectations creates a higher than the desired variance in graduates' quality and readiness for the job market.

Expanding on CC2020, this report defines competency as knowledge, skills, and dispositions applied within a specific computing context *and over an extended period*. The ISO/IEC standard, 24773 [137], sets out competence as:

Competence involves the ability to apply knowledge and skills [...] to achieve a successful result on an ongoing basis [...] applying sound judgement, making correct decisions, applying the appropriate skills and knowledge and making use of relevant professional attributes. *ISO/IEC24773* [137] §5.5

From this definition of competence, it is clear that both knowledge and skills are fundamental, as are sound judgement and *professional attributes*. The first two are already part of the CC2020 model, and the last two seem to correspond to the CC2020 dispositions. However, what is missing from the CC2020 model is *achieving a successful result on an ongoing basis*. That is, competency – according to ISO/IEC 24773 – requires both (successful) *repetition* and *reproducibility*. Whether such a level of competence is a plausible expectation from a new graduate is discussed further in Section 6.8.

6.5 Standardized Tools for Assessments

The lack of standardized assessment measures is a significant issue in the current assessment model used by computing accrediting bodies. However, this issue will be more critical in a competency model because many instructors lack experience in assessing skills, especially dispositions.

As mentioned in Section 5.1, one tool for assessing dispositions is building a portfolio that provides evidence of a student's accomplishments. Teachers and program evaluators need to understand how to measure dispositions across a portfolio and confirm that a particular program considered for accreditation assesses competency in a reproducible and consistent manner. This method requires transparency and some *standard approaches* against which evaluators can measure the program's assessment strategy. Including such standardization would require training program evaluation personnel, which would require a significant effort. Furthermore,

programs will need the logistics to evaluate student performance at internships and other workplace experiences; the BCS Registered IT Technician provides one such standard [20].

There are existing models of professional skills frameworks that accrediting bodies can use to develop assessment standards, as discussed in Section 5.2. An essential determination of whether a framework is appropriate for assessment standards is whether it allows for assessing an individual's competence against the skills described in that framework.

Another approach to developing assessment standards is to look at tools employers use to evaluate worker performance, particularly for promotion or advancement. For example, the “act of judging or deciding the amount, value, quality, or importance of something, or the judgment or decision made” is one dictionary definition of assessment [38].

6.6 Accreditation on Assessment of Student Performance

Several program accreditation bodies, for example, ABET [4], focus on continuous program improvement. Continuous improvement involves a feedback loop that includes an assessment of student performance. However, the evaluation can be based on a representative sample of students rather than on all students. Therefore, actual student performance is not always used for program accreditation purposes, as long as the program demonstrates that the program is using the results in the continuous improvement cycle. For example, a competency-based assessment would include assessments of all graduates of the program to show that all are achieving an appropriate, well-defined baseline of competency.

Computing can draw on the current practices of other disciplines. For example, in engineering and education undergraduate programs, the program's mission is to ensure its graduates can pass the licensure examinations. Therefore, accreditation of those programs focuses heavily on student outcomes and requires that programs ensure that graduates achieve those outcomes. For example, CAEP [59], which accredits teacher education programs in the US, defines knowledge-based and performance-based standards to assess students. Assessment of students can occur in several ways, such as state licensing exams, other external exams, and student teaching evaluations. Similarly, in US undergraduate nursing programs, the Commission on Collegiate Nursing Education [52] requires that programs demonstrate an 80% pass rate on licensing and certification exams and an employment rate of 70% a year post-graduation. Computing can follow this example even without a formal licensure process.

An important question is whether measurements of student success are objective or subjective. A recent report from the Council for Higher Education Accreditation [58] surveyed a substantial number of institutional and program-specific accrediting organizations in the United States regarding the credibility and effectiveness of student learning outcomes being assessed and evaluated. For programmatic accreditation, the survey identified standardized tests (including licensure exams and certifications, such as Praxis, ETS Major Field Tests, etc.) as the single most widely used source of evidence of student achievement. Such assessment measures are objective because they are conducted outside the institutions and

apply the same criteria to all assessed individuals. However, program accreditation bodies also reported that internal or local (and, consequently, more subjective) measures, such as graduation/retention rates and job or graduate school placement rates, are the second and third most widely used assessment mechanisms used to evaluate student learning outcomes and achievement. Therefore, using local or institution-specific assessment measures may raise a range of concerns regarding the credibility and validity of the assessment outcomes.

Maintaining a high and consistent level of student outcomes measured using a validated and independent set of objective standards could complement the current continuous quality improvement approach. It could also address concerns about the credibility of student outcomes assessments reported by the programs. From another perspective, standards-based assessment of student outcomes achievement will not only provide additional credibility to a program's evaluation, but it will also enable each student to obtain their set of credentials.

6.7 Need for Non-binary Assessment and Accreditation

To what extent is the current competency-based education model and subsequent accreditation preparing graduates for the job market? Are programs barely satisfying the requirements of current accreditation systems preparing students for the job market? The computing domain is evolving quickly, so what are the minimum competence levels students have to achieve to work in specific subdomains? As competencies are defined too broadly, assessment results also vary tremendously. Program accreditation tends to be binary; a program is either accredited or not accredited. Given these variances in definitions of competency, it would make sense for accreditation to be on a non-binary scale, i.e., how well a program is accreditable rather than whether it is accredited or not.

While conducting an assessment, either at the program or student level, it is essential to allow such assessment activities to provide meaningful information for usage in a continuous improvement cycle. Unfortunately, many assessment activities use criteria that yield binary results, that is, whether some entity has passed the assessment. However, a non-binary outcome of assessment can produce better corrective actions to make programs comply better with the standards or criteria. For example, a learning outcome assessed as pass or fail could receive better judgment using a higher-order scale to provide more substantial insight into the intensity of passing or failing. Such concentration could directly affect the corrective actions to achieve compliance.

The same holds for accreditation bodies that still adopt a binary outcome for accreditation. Even though accreditation actions could have shortcomings, their binary result does not differentiate between outstanding institutions and those barely passing accreditation requirements. Even worse, it does not distinguish between institutions that narrowly failed accreditation criteria and those distant others far from the bare minimum accreditation requirements. On the other hand, a non-binary system may help provide the professional community with better insights into the trust status of the entity under accreditation. However, adopting a non-binary view of accreditation will be challenging to many accrediting bodies and

their criteria, as it significantly diverges from current approaches and standards.

6.8 Competency May Be Supplemental

Assessing competency in computing currently occurs at the undergraduate program level, typically before students graduate. However, many non-computing fields use the model that competency is achieved only after post-graduate industry experience (see Section 3). This model might also apply to computing programs in the future. In this scenario, undergraduate programs and accreditation would instead be focused on *capabilities* rather than competencies (cf. Section 2.3.1 for the distinction between these two terms). Competencies would then become supplemental to the undergraduate degree.

Currently, in the US, computing program accreditation through ABET is split into several established computing sub-disciplines – computer engineering, computer science, cybersecurity, data science, information systems, information technology, and software engineering – and general computing. The competencies for programs for each variety of computing would vary, though they share some common aspects enunciated in the General Criteria [4]. A problem in computing is that these sub-disciplines have no clear distinction as many engineering disciplines have. For example, it is improbable for someone from electrical engineering to be competent in civil engineering. However, computing has multiple instances of students graduating with information systems degrees and becoming hands-on cybersecurity professionals. Perhaps one way to handle this would be through specialized, optional assessments so that students graduating in information systems could demonstrate their qualifications to be cybersecurity professionals.

In terms of possible models, some aspects of micro-credentialing are possible, which would be credentialing, more specifically, the competencies with which a graduate leaves a program [191]. Therefore, there could be an accreditation model that may or may not link to professional registration. This model would also provide quality assurance for a set of processes whereby a university selects the micro-credentials it offers and has a process by which students can evidence their related capability.

For example, a student could graduate with an undergraduate honors computing degree and be a certified mobile application developer. Such credentialing could also be additive, where the student first graduates from an accredited degree program and then develops competency in a particular area. The professional accreditation of capability would be typical for all graduates of a given program. However, the accreditation of competencies would be more individual, based on what the graduate has done. That is, did the graduate do a placement or internship? What was the content of their final year project or thesis? Have the students held a part-time job? These and other experiences could develop graduate competencies in differing ways.

Within the computing discipline itself, professional registration is supported in some but not all jurisdictions (See Section 4). For the jurisdictions that do not support professional registration, competency is evidenced on an individual experience basis or via an alternative approach. As discussed in a recent article, “Experienced

and aspiring computing professionals need to manage their qualifications according to current market needs. That includes certification achievement as well as formal education, experience, and licenses” [223, p. 58]. Licenses include a variety of micro-credentials such as Salesforce Certification, the various Microsoft certifications (e.g., Microsoft Certified Professional), Certified Information Systems Security Professional, ITIL Certifications, and the various Cisco certifications (e.g., Cisco Certified Network Professional, Certified Scrum Master, etc.). The acceptance of such certifications varies globally; even the value placed upon such schemes in the US is not consistent across the computing professions [223]. Furthermore, accepting certifications to represent competency faces several challenges, including lacking a related taxonomy [191]. For example, there appears to be some consistency regarding expectations from a baccalaureate graduate. However, how can one understand the equivalencies between the various certifications, which are evidence of professional practice? Significant consideration of such certifications is beyond the scope of this work. However, it is interesting to note that evidencing professional competency by such schemes is also not universally accepted, and the level of acceptance appears to depend upon professional specialism and jurisdiction.

6.9 An Example of a Competency-Based Accreditation Standard

The UK’s Institute of Coding (IoC) [34] proposed a novel accreditation standard [34] based entirely on a professional skills framework, SFIA [232], rather than on any content-based curricular recommendations.

An accreditation approach requires three components: meeting a standard, an (accreditation) approach that ensures that a program delivers that standard, and a benchmark assessment method against which a program’s assessment strategy measures the required levels of achievement.

The IoC standard is simple [35] and based on the SFIA framework. See Section 5.2 for an overview of SFIA. In the IoC standard, graduates with a bachelor’s degree need to demonstrate *competency* against at least one SFIA skill at SFIA Level 3 and to have the underpinning knowledge for three other skills at Levels 3 and 4. However, there was no limit on which skills should be demonstrated or underpinned, as all the skills in SFIA are relevant to the computing or IT employment sectors. This situation provides maximum flexibility to the professional degrees that could acquire accreditation against this standard.

Since demonstrating competency includes demonstrating the behavioral characteristics for SFIA Level 3, which were equivalent to the CC2020 dispositions [32], demonstrating competency at SFIA level 3 satisfies all eleven CC2020 dispositions. Furthermore, the demonstration of the behavioral characteristics meets the mandatory UK benchmarks and outcomes [28]. The proposed IoC accreditation process is also straightforward [33].

The underlying assumption is that the program must include an integrated work placement or internship sufficient to allow the repeated demonstration of activities and behavioral characteristics over an extended period to develop genuine competency. So, the first element of the process is to check that the program includes significant real-world experience opportunities for students.

The formal accreditation checks that the program's competency assessment matches the benchmark assessment. The accredited element is the competency assessment, not the delivery of specific skills. There is no restriction on which area of computing is chosen - by the student - for the demonstration of competency; this allows students in the same program with differing real-world opportunities to demonstrate competency in different skills.

The benchmark assessment scheme, against which one measures a program's assessment, has two parts, one for the technical achievements [26] [201, section 6.3] and the other for the behavioral characteristics [27]. A worked example is available at [29]. The assessment scheme assumes the existence of some student portfolio that accumulates evidence of the experience. Checking a program's assessment against the benchmark requires sampling a range of portfolios and checking whether the program's review aligns with the benchmark assessment, with any differences being justified.

7 RECOMMENDATIONS

Section 2.1 notes that there are many locations around the world where computing graduate unemployment and underemployment could be lower. Section 2.2 sets out one of the fundamental driving forces behind accreditation regimes: to ensure graduates are prepared for future professional roles, thereby promoting their employment and reducing their under-employment. Section 3 considers a range of "professional" disciplines other than computing, concluding that competency/capability is essential for the fields explored and often embedded in the corresponding accreditation regimes. Section 4 currently reports that competency is not widely a part of accreditation regimes for computing, and Section 5 illustrates that assessment of competency is feasible. Finally, Section 6, by articulating some of the opportunities and challenges encountered when embedding competence, shows that, although there has been some exploration of embedding competency in computing accreditation regimes, this has yet to occur in a comprehensive and systematized manner in any of the locations explored.

Although there is no general requirement for licensure in computing, it is nevertheless a genuine professional discipline in which poor practice can have significant and potentially severe consequences for others. Given the various efforts to embed "competence" within accreditation regimes for computing, this section suggests how one might harness accreditation schemes to enhance competence and improve professionalism in computing graduates.

The authors present five recommendations, the first essential to embed competence within accreditation regimes. The second and third recommendations support this fundamental goal. In contrast, the fourth and fifth recommendations set out areas where this research suggests having a broader exploration in the wider community as future opportunities. For example, this effort might occur either within individual accreditation jurisdictions or for global accreditation practice under the auspices of the international accords discussed in Section 4.2, or even for the role of accreditation itself.

7.1 Recommendation 1: Models for Professional Accreditation of Computing Programs

The extent to which one might embed competence into the relevant accreditation regime varies between domains and jurisdictions. For computing, Section 4 discussed how various approaches have been applied to support the development of different elements of competence. Sections 5 and 6 outline multiple ways to assess competency and embed it within accreditation.

The evidence from other disciplines (Section 3) is that accreditation can be an appropriate vehicle to help institutions develop their students' competence. However, while some attempts are beginning to embed competency in accreditation regimes and progress is being made in the computing discipline (Section 4), there was little evidence of a complete systematic approach to achieving this in any of the schemes considered. To embed competency in the accreditation of computing disciplines fully, the first question to be addressed is how to build a "competence-focused" accreditation scheme for the field. There seem to be (at least) two possible models for accrediting computing degrees to prepare graduates for professional computing roles.

- (1) Ensure the development and assessment of a range of underpinning qualities. Identify high-level generic learning outcomes that develop, for example, working in teams, communication, and problem-solving. This approach would seem to fit well with the CC2020 focus on the *dispositional* aspect of competence.
- (2) Assess real-world competence and appropriate computing skills for degree programs genuinely intended to prepare students for the profession by graduation. In keeping with the CC2020 model, competence would require demonstrating knowledge, skills, and dispositions based on real-world experience gained during the degree.

For bachelor's degree programs providing the educational component for CITP, the BCS employs model #1 [20]. Alternatively, the Institute of Coding in the UK has proposed model #2, discussed in Section 6.9. This effort is a preliminary study as indicated in the introduction (Section 1, and there may be other candidate models from other jurisdictions that are also worth consideration.

However, whichever model is adopted, the developed scheme should avoid the temptation to specify a (long) list of competencies (comprising skills, knowledge, and dispositions) that graduates "must" demonstrate. Although superficially attractive, such an approach runs the significant risk of becoming a *conjunctive tick-list*, whereby a single omission should result in *failure*. Any list-based approach - whether for generic competencies, dispositions, or some other set of "transferable" skills - would therefore need a careful application in a real-world scheme.

7.2 Recommendation 2: Promote Industry Engagement for Workplace Competencies

This recommendation is one of two implementation approaches intended to support the delivery of recommendation 1 discussed in Section 7.1; the other is recommendation 3 in Section 7.3, building strongly on Section 6.2.

Universities, computing departments, individual academic faculty, and accrediting bodies can aim to develop graduates who meet industry expectations better by building capability and competency within delivered programs. However, ISO-24773 (Section 2.3) emphasizes that competency requires “repeated successful application of knowledge and skills in a professional context”, rather than (just) in the classroom or laboratory. Section 3 illustrated such an approach is common in some other disciplines, and Section 6 further expanded upon the potential.

Course design and delivery could promote competency development by repeated exposure to practical/authentic assessments for individuals or teams of students [196], and by strengthening accreditation requirements. However, in addition to contributions within the university environment, industry also has a crucial role. Effective industry-academia collaborations exist in several jurisdictions. For example, the ACM/IEEE Computing Curricula 2020 [48] highlights the potential benefits professional advisory boards and work-study, cooperative, and internship programs can provide for learner development and further refinement of competencies.

Another example is that in the UK, where the option to choose to study a paid year-long industry placements as part of four-year baccalaureate degree programs is the norm. For context, in the UK, such an industry placement occurs between the second and third year of study for computing. Other applied baccalaureate degrees have had a standard option since the 1960s. The proportion of students who choose to study this optional year varies by a university; however, at some universities, it can be as high as 80-90% of all students studying a computing program. The further expansion of such placement schemes, other students-into-the workplace schemes, and industry-into-academic schemes was one of the recommendations from a recent governmental report [210]. Research into year-long placement schemes has highlighted that completing a placement tended to increase the likelihood of finding high-skilled employment, reduce the length of time to find a job, and result in higher graduate salaries [216]. Other successful related initiatives include the undergraduate and postgraduate degree apprenticeship programs in UK [130, 236], live projects [45, 67, 157] and the co-op programs in Canada [119]. Hence, the authors recommend that professional body accreditation regimes build upon these successes and further promote competency-building and graduate work-ready enhancement initiatives.

Furthermore, Section 3 highlights that in *some* disciplines or jurisdictions, experts recognize full professional competency only following appropriate practice-based experience, development, and critical reflection. Hence, the work experience obtained by extended industry placements, internships, and work-study programs within the computing discipline, may be competency building. Business and industry are arguably among the primary beneficiaries of this competency building. The other beneficiaries are the learners themselves. Therefore, the authors recommend that business and industry become more active in collaboration with academia, mainly via extended (and ideally paid) placements, as well as internships and supporting work-study programs and similar activities.

7.3 Recommendation 3: Instill Competency in All Computing Programs and Curricular Recommendations

This recommendation is one of two implementation approaches, complementing recommendation 2 discussed in Section 7.2, intended to support the delivery of recommendation 1 made in Section 7.1. It builds strongly upon Section 6.3 and Section 6.4.

The internet, globalization, and, more recently, a pandemic broke down national barriers regarding computing jobs. The curricular guidance available within different jurisdictions (e.g., [20, 48, 196], etc.) together with the various international computing accords (see Section 4.2) seek to promote parity in computing education. The impact of these various standards and guidelines has been positive. To date, however, competency has not been formally embedded in any of the accords, and its embedding in the curricular guidelines is mixed. Hence, there may be variations in the competencies evidenced by graduates from different universities in a jurisdiction and between graduates from various jurisdictions. This situation is not helpful for prospective employers of graduates.

Competency-based curricula can help students, faculty members, and institutions have a more standardized way to compare themselves to others. However, instructors and researchers may have problems applying taxonomies, creating competency models, or understanding how they relate to the cognitive domain of student learning. Kiesler et al. [147] helped reduce the stigma of competence modeling, where the knowledge domain cannot correctly frame the high-order skills needed in some computing courses.

Using competency and taxonomies in computing could serve as a basis for standardization and curriculum design. Building a competency-based program would mean that courses become fundamental building blocks of the whole program. Any course change would need to guarantee that students can acquire the same competencies, even with a change of programming language, focus, instructor, or teaching strategy. Unfortunately, some faculty members in higher education institutions might find this to be an imposition on their freedom and expertise regarding adding/changing courses or course content.

Competency-based curricula can help students have better job prospects because they will have the competencies sought by the industry. The computing community can benefit from instilling the use and creation of competency-based programs. Such programs are flexible, so students can find the competencies they need before they graduate. Students' flexibility in doing courses abroad or transferring from one institution to another makes a case for each program to state its competencies. This method would make it more straightforward to compare academic programs to one another. The role of industry to offer guidance on what students should know and do upon graduation could be strengthened. There already has been some experimentation with this type of approach, for example that the ABET accreditation criteria already emphasize [4] and RITTech accreditation in the UK supports (as was discussed in Section 4). This approach makes a stronger case to use competency to measure outcomes instead of generalized knowledge [187].

7.4 Recommendation 4: Encourage Accrediting Bodies to Enforce Competency in their Standards

This recommendation builds upon the previous recommendations 1 and 3, discussed in Sections 7.1 and 7.3. Recommendation 3 focuses on curricular guidance. This recommendation focuses on accrediting bodies considering competency within accreditation. It builds strongly upon Sections 6.3, 6.4, 6.7, and 6.9.

One goal of accrediting bodies is to validate the exit standards of a particular degree, i.e., what learning will be evidenced by all graduates regardless of their route through a program. This validation may occur by considering the competencies achieved. An accreditation standard that enforces or requires competency-based curricula or outcomes would percolate throughout the higher education institutions.

Some countries (e.g., Brazil and Russia) use a top-down approach whereby the government determines a list of competencies needed by a particular degree program, as reported in Section 6.1. Other countries, such as the US, leave this to be implemented at different levels. So, governmental accreditation of a program is neither needed nor perceived as valuable, and the accreditation process transfers to bodies that define their standards.

Including competency in an accrediting body standard could make their accreditation process and results more relevant. When an accrediting body decides whether to accredit a program, the decision is typically binary, i.e., whether a program is accredited or not. Programs vary considerably: for example, some computing programs have a more theoretical approach, preparing graduates for a research-oriented career path, whereas others have a more hands-on approach that would better prepare students for the general job market of computing careers, yet others fall somewhere in the middle. It could be possible to map these alternatives to standard skill profiles. Libraries of such skills profiles already exist [234], which teachers could use, modify, or extend. An example of this appeared in Section 6.9.

7.5 Recommendation 5: Encourage Accrediting Bodies to Assess Student Performance

This recommendation highlights an opportunity for accrediting bodies to move beyond accrediting programs of study and to start accrediting the demonstration of competencies by individual graduates. It builds strongly upon Sections 6.6 and 6.5, offering a more explicit alternative to the approach in Section 6.9.

The mismatch between the stated program outcomes, degrees, GPAs, and the actual competencies of graduates has become a concern for a broad range of institutional and program-specific accrediting bodies [58] and by employers [183, 213]. Explicit inclusion of student performance in the program-specific accreditation criteria could work in tandem with the previous recommendations to reinforce the importance of competencies in the computing curricula. Furthermore, this could make the programs more accountable for the quality of graduates they produce and would provide a meaningful way for the accrediting bodies to evaluate these programs. Equally, including the requirement for student performance assessment in the accreditation criteria would help improve the credibility and strengthen the validity of existing methods for student learning

outcomes assessment performed by individual programs, which generally use locally-created assessment instruments.

Teachers could implement the assessment of student performance in various ways. For example, some other fields require an evaluation performed in a practical setting. For instance, most teacher education programs require evaluation of student teaching after a period of immersive practice spanning several months. In addition, undergraduate nursing programs in the United States must demonstrate an 80% pass rate on licensing and certification exams.

There is currently no consensus about which approach(es) to student performance assessment might fit best for computing accreditation programs. Hence, the authors recommend further research, discussion, and evaluation of the approaches for assessing competence in computing. In turn, experts could implement this approach to accreditation requirements and expectations. Indeed, part of this discussion could focus on whether individual students rather than programs should be accredited.

7.6 Implementation Recommendations

While there are numerous ways to implement the recommendations in this report, this section suggests several possible approaches that emerged during the working group's deliberations.

- To achieve all the recommendations in this section so that computing degree programs can produce “professional” graduates, it is essential to perceive computing as a profession more than a discipline. Furthermore, stakeholders should be encouraged to seriously discuss the merits of requiring licensing to practice computing as a profession.
- To support recommendation 3 (see Section 7.3), assessment approaches for competency should be developed and shared within the academic community, enabling faculty members to explore alternative approaches to those they have previously employed.
- To support recommendations 3 and 4 stated in Sections 7.3 and 7.4, accreditation bodies should develop effective practice reports that are useful to capture the variety of ways in which computing programs implement competency-based education models.
- As an extension of recommendations 2 and 3 stated in Sections 7.2 and 7.3, advisory boards for computing programs could benefit from education regarding the merits of competency-based education can enable students to have better workplace readiness when appropriately implemented. Advisory boards need greater involvement in defining competencies in academic programs. It is also essential to be sensitive about the competencies major employers of students from given programs expect.
- To achieve recommendation 4 (see Section 7.4), accreditation bodies should start an active conversation about embedding competency-based education with accreditation guidelines and expectations.
- To achieve recommendations 3 and 4 (see Sections 7.3 and 7.4), accreditation bodies should align their requirements with curricular guidelines from the academic perspective,

and all curricular guidelines referring to computing should include reference to competency-based education.

- Whenever referring to competency-based education, as discussed in Sections 7.3 and 7.4, it is critical to refer to benchmark references offering clear definitions and proven good practices for achieving competency-based education because many disparate definitions exist.
- To support recommendation 5 discussed in Section 7.5, given the diversity of how computing programs around the world operate, accreditation bodies could consider constructing a standardized international joint assessment for the degree of achieved competencies of computing graduates.

Regarding the second item, there are research opportunities to catalog and document good assessment practices and to develop and deliver training and professional development to support and promote competency assessment practices. These activities would benefit both early career colleagues and more experienced academics.

8 CONCLUDING REMARKS

This section reflects on this report, reviews its curricular recommendations, addresses bodies of knowledge, and provides insight into the projection of future work.

8.1 Collecting Thoughts

This study provides an overview of competency-based learning in computing from the perspective of accreditation agencies and their standards. In addition, the work poses three questions about professional accreditation and competency, computing accreditation and competency, and how computing accreditation agencies can promote competency-based learning in computing. After exploring the meaning of competency, the authors gathered evidence related to the first two queries and then provided some guidance on assessing competency beyond knowledge. Finally, the work concludes with recommendations and suggested implementation forms supporting the third query.

This report focuses on understanding competency in general and in computing contexts. The competency triad of knowledge, skills, and dispositions is not always understood, even by computing educators, who are knowledge experts. Thus, graduates from computing programs often face challenges in knowing how to apply their knowledge as a skill and why they do such work as a set of dispositions. Unfortunately, computing accrediting agencies have not addressed competency as a holistic and foundational concept as have other accrediting bodies. Perhaps this work and its derivatives will foster greater understanding and commitment to these agencies to promote a competency-based philosophy in their standards and criteria. With 95% of program graduates entering the workplace, all computing accrediting agencies are incumbent to encourage and promote competency with a greater emphasis on skills and human attributes (dispositions).

The authors' research experience culminates with five recommendations. The first promotes establishing models or examples of computing professional accreditation schemes that systematically consider competence. In addition, since preparing students for the workplace should be a prime purpose of computing degree

programs, such programs should involve industry engagement for workplace competencies. This approach forms the second recommendation. The third recommendation is to include competency as a core component in official curricular recommendations by worldwide professional organizations to help promote competency as a central theme in all computing programs. The fourth recommendation suggests including all aspects of competency (including, for example, the three dimensions of competency) in accrediting agencies' standards and enforcing those standards when implementing the accreditation process. Finally, the fifth recommendation is to encourage accrediting agencies to find ways to assess actual student performance rather than simply indicating whether students received exposure to specified topics. Adherence to these five recommendations, taken collectively, would ensure that competency becomes the foundation for computing accreditation processes.

8.2 Bodies of Knowledge

An enduring challenge in curriculum development is to balance the wisdom embodied in the various bodies of knowledge available for subjects like computing with the growing clamor for student-centered pedagogy that develops competence rather than just knowledge. Given relevant bodies of knowledge, the temptation can be to build a discipline-based curriculum. Eryaman [90] may be referring to high school discipline-based curricula but parallels university teaching when he writes:

A discipline-based curriculum [...] encourages teachers for specialization, depth of content knowledge, and integrity to the conventions of their discipline.

Indeed, a traditional approach to designing a university computing curriculum can consider the latest body of knowledge that closely matches the school's interests, filtering that body of knowledge by the capabilities of faculty and what it already teaches.

Since the focus is on knowledge, the accompanying assessment strategy is likely based on Bloom [23] rather than a more appropriate learning hierarchy (e.g., Simpson [214] or Miller [164]) that emphasizes repeated practice that underpins real-world competency [30]. Additionally, educators often address *employability* by including some *employability skills* into a curriculum without consideration of domain integration. But, again, the focus is entirely on knowledge and tends to produce graduates who *know what*, rather than having developed any professional competency so graduates *can do*.

Neither all students nor all employers are the same. Many students will thrive in a knowledge-oriented curriculum and emerge as graduates whose strength is to *think* rather than *do*. However, while some employers can take thinkers and develop them into competent doers, many need doers from the start. Furthermore, some students may not thrive under a knowledge-focused curriculum designed to produce thinkers because they are fundamentally more practical – teachers must educate them to be doers rather than thinkers. Hence, this work explored ways to shift the emphasis from curricula for thinkers to those who are doers. Instead of focusing on the content of a body of knowledge, the learning emphasis should be on developing competencies comprising all three dimensions of knowledge, skills, and dispositions that afford opportunities for repeated practice.

8.3 Transforming the Future

In advancing computing competency in accreditation, exploring ways to teach and assess skills and dispositions would be worthwhile. Teachers and students would benefit significantly from realizing that becoming a professional requires more than knowledge. In addition, seeking innovative methods such as interdisciplinary approaches for evaluating skills and dispositions would encourage accrediting agencies to make the recommended changes toward competency and foster professionalism. Hence, academia must become more proactive in promoting competency-based learning in all computing programs worldwide. In doing so, computing accrediting agencies will become more active in advancing competency-based accreditation.

There is optimism that competency-based curricula and accreditation will become the educational norm in baccalaureate computing programs. However, further research and experimentation related to competency-based computing education must continue to overcome challenges. Such research would support wider adoption whereby competency-based learning and teaching become the pathway for student engagement, professional accreditation, and productive placements in the workplace. Such a framework would transform computing as a profession.

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A PROFESSIONAL ACCREDITATION IN NON-COMPUTING DISCIPLINES

This appendix summarizes accreditation standards for several non-computing professions. The authors examined the standards or criteria for each profession, particularly from the competency standpoint. In many countries, entry into critical professions is regulated at the national or regional government level and typically involves a mix of program-level accreditation and individual certification/licensing. For most professions, the candidate should attend an approved or accredited educational program, which may include required internships or other workplace programs. In some professions, candidates should also pass exams or evaluations to obtain a license to practice.

Along with Table 3 in the main body, Tables A.1, A.2, A.3, and A.4 in this appendix summarize the details collated by the working group.

Table A.1: Accreditation of programs for medical discipline

Country	Brazil	Chile	Egypt	Russia	Canada & USA	UK
Sources	[167, 168, 205]	[54, 54, 55]	[83, 104, 252]	[215, 258, 261, 262]	[153][53]	[105–110]
Individual recognition/certification?	Yes	Yes	Yes	Yes	Yes	Yes
Institution/School accreditation?	Yes	Yes	Yes	No?	Yes	Yes
Program accreditation?	Yes	Yes	Yes	Yes	Yes	Yes
Accredited degree required?	Yes ¹	Yes ²	Yes	Not clear ³	Yes	Yes
Length of program (years)?	6	7	frn	4-6	frn	5
Curriculum defined by	Govt ⁴	Govt	Govt	Govt (Medical Chamber)	Prof (AMA) Body	Prof (GMC) Body
Competency evidenced in program?	Yes ⁵	No ⁶	Yes	Yes	Yes	Yes
Post-study experience required?	Yes	No	Yes ¹	Yes	Yes	Yes
Individual assessment necessary?	Yes	Yes	Yes	Yes	Yes	Yes
Recognition/certification needed for licensure?	Yes	No ⁷	Yes ⁸	Yes	Yes	Yes
CPE/D required? No	No	No	frn	Yes	Yes	Yes

⁰ Note that *frn* depicts *further research needed* to indicate a response.

¹ Doctors who qualify overseas may complete an exam

² Although for most subjects, accreditation is voluntary, it is mandatory for medical education

³ Development of accreditation processes appear to be in progress

⁴ Competency based accreditation defined by the National Education Minister

⁵ Internship in National Health System

⁶ Knowledge-focused - competency not specified at all

⁷ A paper saying that the practitioner passed the test (EUNACOM) is needed before all hiring

⁸ License to practise based on having gained an Egyptian medical degree, although there is a route for overseas physicians

Table A.2: Accreditation of Programs for Nursing Discipline

Country	Brazil	South Korea	United Arab Emirates	Russia	South Africa	US	UK
Sources	[158, 189, 250]	177, 190, [118, 150]	[11, 155, 241, 246]	[101, 163, 177, 203, 260]	[217–219]	[9, 159, 176, 220]	[229, 230]
Individual recognition/certification?	No ²⁴	Yes ¹¹	Yes ¹²	Yes	No	Yes ¹⁴	No
Institution/School accreditation?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Program accreditation?	Yes ⁴	Yes ⁵	Yes ¹	frn	Yes ²	Yes ³	Yes
Accredited degree required?	Yes ⁴	Yes ⁵	Yes	frn	Yes	Yes	Yes ⁶
Length of program (years)?	4	4	at least 3	4	4	4	at least 3
Curriculum defined by	Federal government	Korean Accreditation Board of Nursing Education	UAE Nursing and Midwifery Council	Ministry of Health	South African Nursing Council	state regulations & Boards of Nursing	Nursing and Midwifery Council
Competency evidenced in program?	Yes	Yes ⁷	frn	Yes	Yes ⁸	Yes ⁹	Yes ¹⁰
Post-study experience required?	No	No	Yes ²⁵	frn	No	No	No
Individual assessment necessary?	No	Yes ¹¹	Yes ¹²	Yes	Yes ¹³	Yes ¹⁴	No ²⁶
Recognition/certification needed for licensure?	Yes ¹⁵	Yes ¹⁶	Yes ¹⁷	Yes	Yes ¹⁸	Yes ¹⁹	certification?
CPE/D required?	Yes in some states	No	Yes	Yes ²¹	No	Yes ²²	Yes ²³

⁰ Note that *frn* depicts *further research needed* to indicate a response.

¹ The Scientific Committee for Education is commissioned by the UAE Nursing and Midwifery Council to set unified standards for nursing and midwifery education

² Accreditation of programs is through the South African Nursing Council

³ Programs must be approved by the state Board of Nursing, otherwise graduates cannot take the NCLEX exam. Programs also can be accredited by CCNE or ACEN; this is required in many states. Nationally, about 88% of BS in Nursing programs are accredited [176]

⁴ Nurses must earn a bachelor's degree issued by an institution certified by the Ministry of Education

⁵ Korean Accreditation Board of Nursing Education accredits nursing programs

⁶ Nurses must earn a bachelor's degree issued by an institution certified by the Nursing and Midwifery Council

⁷ Must assess *core nursing skills* each year of program

⁸ One of the requirements to be registered as a professional nurse, besides graduating from an accredited program is *has been assessed and found competent in all exit level outcomes of the programme* (from the Regulations document)

⁹ ACEN requires end of program student learning outcomes, with measurable levels of achievement. The outcomes are competency based. Both ACEN and CCNE requires NCLEX pass rates above 80%, which is knowledge based

¹⁰ Students must be assigned academic and practice assessors to confirm achievement of proficiencies and outcomes

¹¹ Under the auspices of the Ministry of Health and Welfare, administered by the Korea Health Personnel Licensing Examination Institute. Accredited programs must document pass rate

¹² Exam, Ministry of Health and Prevention

¹³ Individuals must be assessed by an assessor registered by the Council: "the learner must be assessed and found competent in all learning outcomes of the programme, in line with the assessment criteria outlined in the qualification registered on the National Qualifications Framework". 60% of the formative clinical assessment must be done in real life situations.

¹⁴ NCLEX-RN exam

¹⁵ Must be registered with the regional professional council that has jurisdiction in the state where they practice (Law No. 7.498/1986)

¹⁶ Must be licensed by the Ministry of Health and Welfare

¹⁷ Either the Ministry of Health and Prevention (MOHAP), the Department of Health -Abu Dhabi (DoH) or the Dubai Health Authority (DHA) depending on where the candidate plans to practice

¹⁸ Nurses must register with the South African Nursing Council. In addition, student nurses must also register.

¹⁹ yes, through the state Boards of Nursing

²¹ Every five years, all medical professionals including nursing are required to receive training and reexamination.

²² many states require continuing education credits to renew the license

²³ Revalidation every three years requires CPD and reflections

²⁴ Competence is evaluated in the program level

²⁵ For foreign nationals only

²⁶ Unless educated outside the UK

Table A.3: Accreditation of programs for teaching discipline

Country	Brazil	Chile	Egypt	Russia	South Africa	US	UK
Sources	[56, 188]	[51, 171]	54, [180]	[46, 259]	[72, 172]	[12, 59, 184, 185, 193, 249, 254, 255]	[73–77, 224]
Individual recognition/certification?	No	No	Yes ¹⁶	Yes	No	Yes ¹¹	Yes ¹⁹
Institution/School accreditation?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Program accreditation?	Yes ¹	Yes ²⁰	frn	Yes ²	No	Yes ³	Yes ⁴
Accredited degree required?	Yes ¹	No	No ⁵	Yes	No	Yes ⁶	Yes
Length of program (years)?	4	8 Sem	frn	5	4-5	4 ⁷	At least 4 ⁸
Curriculum defined by	Natl. Committee for Education	National Commission on Accreditation	National Authority for Quality Assurance and Accreditation (NAQAAE) in Egypt	Ministry of Education of the Russian Federation	frn	By the individual states. Also by CAEP and AAQEP for accredited programs	UK Dept for Education
Competency be evidenced in program?	Yes	No	Yes ⁹	Yes ¹⁰	No	Yes and No ¹¹	Yes ¹²
Post-study experience required?	No	No	frn	No	No ¹³	Yes ²¹	Yes ¹⁴
Individual assessment necessary?	No	No	Yes	Yes	Yes	Yes ¹⁵	Yes
Recognition/certification needed for licensure?	No	No	Yes ¹⁶	Yes	Yes ¹⁷	Yes ¹⁸	Yes ¹⁹
CPE/D required?	No	No	frn	Yes	No	Yes	Yes

⁰ Note that *frn* depicts *further research needed* to indicate a response.

¹ A governmental body, the National Committee for Education, does the licensing using a national curriculum guideline

² Through the Ministry of Education of the Russian Federation.

³ States must approve teacher education programs, which is separate from accreditation. Accreditation is through CAEP or AAQEP. Accreditation is not required in most states and less than half of the programs are accredited.

⁴ Through the UK Department of Education.

⁵ Teachers in Egypt can graduate from many types of programs. A large portion of them graduate from dedicated colleges of Education that graduate teachers with specialisations in various domains.

⁶ All states require students to graduate from state approved programs. A few states, such as New York, require that students graduate from CAEP or AAQEP accredited programs.

⁷ Most states have a *fast track* degree path for people with degrees and job experience in other fields.

⁸ Candidates with teaching experience need complete only the assessment program (12 weeks)

⁹ The national standards for education specify general competencies for graduates of Education colleges, not for other programs. General competencies include those pertaining to attained knowledge attained, technical skills, cognitive skills, and other general and transformation skills.

¹⁰ Yes, evaluated via portfolio. The portfolio includes a knowledge based test, a video of a lesson and a set of real world scenarios involving student situations.

¹¹ State licenses require a variety of assessments - some states require only knowledge based tests such as Praxis, but some states have added competencies. Accredited programs must assess students based on knowledge and competency.

¹² Assessment is completed by a practice related portfolio coupled with other assessments which address the academic dimension of the related training program.

¹³ An Advanced Certificate can be obtained for teaching math and science.

¹⁴ After obtaining initial Qualified Teacher Status, a teacher can apply for positions as an early career teacher and follow a two-year induction program which includes two assessment points. Upon completion the candidate becomes a fully qualified teacher.

¹⁵ Specifics of the assessment varies by state.

¹⁶ Through the Egyptian Ministry of Education, based on a test.

¹⁷ Upon completion of an education program, a prospective teacher must register with the South African Council for Teachers by submitting a diploma and transcripts.

¹⁸ Licenses are controlled by individual states.

¹⁹ Qualified Teacher Status, through Dept of Education.

²⁰ An Accreditation Agency accredit programs, checks if the program they advertise is being followed

²¹ not in all states and requirements vary by state, usually years of experience or completion of graduate work

Table A.4: Accreditation of programs for legal discipline

Country	Brazil	Chile	Egypt	Russia	England(UK)
Sources	[189] [190]	[54]	[175]	[14–16, 238]	[199]
Individual recognition/certification?	Yes	Yes	Yes	Yes	Yes
Institution/School accreditation?	Yes	Yes	Yes	frn	Yes
Program accreditation?	Yes	Yes	Yes	Yes	No ¹
Accredited degree required?	Yes	Yes	Yes	Yes	Yes ²
Length of program (years)?	5	5	4	frn	3 / 1.5 ⁵
Curriculum defined by	Govt	Institution	Govt/Institution	pending ⁶	Prof body
Competency evidenced in program?	Yes ³	No	Yes	frn	No
Post-study experience required?	Yes	Yes	Yes	Yes	Yes
Individual assessment necessary?	Yes	Yes	Yes	Yes	Yes
Recognition/certification needed for licensure?	Yes	Yes	Yes	Yes	Yes ⁴
CPE/D required?	No	No	frn	No	Yes

⁰ Note that *frn* depicts *further research needed* to indicate a response.

¹ Institutions must self-certify that they cover the required syllabus.

² May be undergraduate, or postgraduate for graduates from other disciplines.

³ Competency based accreditation defined by the National Education Minister.

⁴ A few specific areas of legal practice do not require professional registration, including will writing and estate administration, family law, intellectual property and employment.

⁵ Three years for undergraduate, 1.5 for postgraduate

⁶ Proposed by the government in 2021, not yet approved