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What is skill? (and why does it matter?).

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What is Skill? (and why does it matter?)

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***Abstract*- This Research-to-Practice Full Paper seeks to investigate the concept of Skill within a Competency Framework, such as that described by the CC2020 document. The notion of skill is fundamental to modern educational discourse. As educators, we strive, not only to impart knowledge, but to help students acquire the skills that they need to flourish in the modern academic and professional environments. We admire skillful practitioners and strive to become more skilled at what we do, recognising that skill is tied to an aesthetic sense - that there is something attractive and deeply satisfying about the process and output of skillful practice. Together with knowledge and disposition, the term is also used to denote one of the constituent components of competence. In computing, for example, the CC2020 document proposes curricular development models which promote skills as key ontological elements and emphasises skill acquisition as a major focus in the educational process.**

While this is undoubtedly an important, evolutionary development in discipline-based pedagogical practice, we feel that there are still foundational questions to be asked about precisely what is meant by definitional terms that form the core vocabulary of this approach. In this paper, we look at the notion of skill and provide a conceptual analysis which tries to distinguish it from other related ideas. We provide an overview of how skill has been seen historically as both a philosophical and sociological construct and what this means for using the term in educational theory. We examine how to usefully define skill, discuss the part it plays in teaching and assessment, and make recommendations for how it can be viewed operationally within a competency framework, such as that proposed by CC2020.

Keywords-competency model, knowledge, skill acquisition, demonstration

I. INTRODUCTION

The experience of teaching suggests that the acquisition of propositional knowledge is only one component of what the educator desires when facilitating learning [1- 9]. Indeed, when asked what we as teachers are trying to do with our students, it is unlikely that we speak solely in terms of imparting facts, or even relations between factual knowledge, but rather speak about wanting to encourage the ability to act in ways that demonstrate an understanding of that knowledge in practical and authentic ways, as well as build effective dispositions for working hard and for learning. Skill seems to be one of those capacities that we want to promote, and we speak about encouraging students to become skillful or skilled in particular areas of the curriculum. But what precisely do we mean by skill and how does our use of the term in an educational context relate to that in other neighbouring disciplines. In this paper, we attempt to provide a conceptual analysis of the nature and practice of skill, specifically as it arises in the context of competency theory.

There are many questions related to the concept which have a direct bearing on teaching, learning and assessment. What, for example, is the characteristic property of skill? Is it an attribute of a person, or a requirement of the task that is being carried out? What does it mean when we say that someone has a skill, or is skillful or skilled? How does skill relate to the cognitive processes oflearning, and, in particular, to knowledge? How does it relate to practice or performance? Are skills general capacities applicable to a wide range of situations or are they specific to the task at hand? What are the processes or stages involved in learning a skill? And how is it possible for a skill transferred from one context to another? Such questions not only indicate the breadth of application of the context but the lack of clear answers also demonstrates how difficult it is to develop an overarching theory.

In this paper, we do not address the issues of skill transfer, or the notion of proficiency, and only briefly attend to some of the other questions detailed above. Instead, we try to provide an overview of some of the salient points of what constitutes skill from a number of different theoretical perspectives - philosophical, historical and sociological - before looking at how this work relates to the computing education discipline. We focus on the use of the word in the CC2020 document [10] as representative of the way that the concept is being applied in Computing Education and relate it to some of the ideas discussed such as its relationship with the concept of knowledge. We suggest that the demonstrative element involved in skill, as described in the CC2020 document, is key to understanding the concept and that competency models should use this characteristic rather than some reference to "know-how" forms of knowledge.

II. SKILL FROM A SOCIOLOGICAL PERSPECTIVE

When we think about the notion of skill, we run into a significant problem with the terminology that is used, and how the definition relates to similar concepts in other aspects of educational discourse. People obviously use words like skill in an informal way in a variety of different ways and in a range of different contexts, both as a noun, and with reference to adjectives such as skillful and skilled. We talk about learning new skills, about skillful performance and proficiency displayed by a skilled practitioner. As noted by a number of authors, e.g. [11], in terms of a dictionary definition, the word has connotations of proficiency, both mental/cognitive competence and physical dexterity. However, while skill denotes the ability to do something, it also carries a sense of increasing ability and expertise. Thus, in English at least, the word carries both the sense of mundane accomplishment and of virtuosity, something that can lead to conceptual confusion.

In an early review of sociological aspects of the concept, Attewell [11] distinguished between a number of different approaches to skill, two of which are useful in the context of this paper. The first is what he termed the positivist approach, while the second takes a phenomenological or ethnomethodological perspective. In this context, positivism refers to the fact that skills are seen as amenable to quantitative measurement and that, in some sense, this measurement has an objective character independent of the observer. By contrast, the ethnomethodological approach, focuses on the experience of the individual practitioner (or group) and the way that a definition of skill is grounded in, and emerges from, the community of practice, rather than from some quasi-objective measurement process.

Examining skill from a positivist perspective, two questions are of particular importance to the educator, firstly whether skill should be treated as a measurable attribute of the person or the task itself [12], and, secondly, whether there is some kind of common scale that underlies the measurability of different skills (and if so, how it can be applied to diverse and qualitatively different areas of practice).

The question of whether the adjective "skillful" applies to individuals or to actions and associated tasks is one that also receives considerable attention in the field of epistemology. Skill appears to have a close link to intentionality in that claims about skillful action, as demonstrated by some element of success in a task, are not usually consonant with that success being due largely to luck [13]. It is highly unlikely that we would ascribe skill to a pianist who somehow managed to play a musical score by randomly choosing which piano keys to depress. It therefore seems plausible to claim that acting intentionally is a prerequisite for acting with skill. Even on occasions where the demonstration of skill appears to be separate from intentional action (such as when a goalkeeper is able to respond almost immediately, and seemingly without thinking, to a close range shot), that behaviour is grounded in, and flows from, more characteristic and intentional actions developed through practice.

With regard to the question of how to measure skill, a universal quantitative metric seems implausible, given the wide variety of complex circumstances to which we would wish to apply it in the real world. It could be argued that it may be possible to aggregate skill characteristics in similar domains of practice, to which equivalent quantitative measures could be applied, but this just pushes the problem to how to find equivalences for these larger areas. And yet, we use taxonomies and frameworks which seem to suggest that there are some broad, common, structural and dynamic features in the acquisition of skill across a wide range of different disciplines. We routinely use curricular frameworks and competency hierarchies to try to match levels of qualification between different geographical, institutional, and temporal contexts. This suggests that it may be possible to specify a set of measurable criteria, such as reliability of outcome, length of time taken, etc, which characterise or, at least, acta as some kind of proxy for, skilled behaviour. In order to arrive at some kind of objective measure, there is a need for a general assumption that the task involved is narrow and stable enough to be done under some approximation to experimental conditions. However, it could reasonably be argued that such constrained tasks would usually not be applicable to the type of skills exhibited by people in the real world. Skills, such as those that employ a variety of heuristics or contextual judgement to make decisions, are often grounded and situated in specific circumstances of use, and are simply not amenable to controlled, experimental investigation. These considerations are important in the context of this paper, and one answer is provided by the discussion of competencies in the CC2020 curricular documentation.

III. THE RELATION OF SKILL TO KNOWLEDGE

One of the most complex problems with regard to skill is how it relates to knowledge. This section is not meant to provide a complete (or even representative) view of the historical development of the subject, but we do draw out two conceptualisations of skill, one from the classical tradition and one which emerges from more modern considerations by epistemologists, both of which have a bearing on how we see the notion of skill in the modern educational setting. The first of these, which can be traced to the earliest recorded forms of philosophical enquiry, can, broadly, be thought of as seeing skill as an intellectual virtue, while its more recent counterpart sees it as a specific form of (propositional) knowledge. We give a short description of each approach before considering some of the implications of each in the modern educational setting.

A. Skill as an Intellectual Virtue

It is, of course, unsurprising that the idea of a skillful person or, perhaps, skillful work, has enjoyed a long and varied usage in almost all times and contexts where humans have needed to perform important tasks and guarantee their quality. We can start to see an attempt to formalise this in classical times, and, historically, this reaches its most important expression in the Nicomachean Ethics [14], where Aristotle makes a distinction between different types of capacities for knowledge and action, arguing for the existence of different forms of knowledge, such as *"episteme"* or theoretical knowledge, *"techne"* or craftsmanship, and *"phronesis",* that is, practical wisdom. Each of these had its own area of applicability and was associated with different ends. With some exceptions, the higher educational process in the Modem Period has tended to prioritise the delivery of theoretical knowledge, with the demonstrative sciences being given a special prominence in the curriculum (although disciplines such as Medicine and Law, as well as those associated with politics such as Rhetoric, were also important subjects in the period when universities were founded). While the Pure/Applied distinction found in Mathematics or the Theoretical/ Experimental divide which occurs in the Natural Sciences is not as stark, there was still a tension between the analytic, "Engineering Science" attitude of the European universities and more pragmatic, practical approaches. More recent educational approaches have also sought to incorporate the acquisition of relevant skills into the learning process, for example, as vehicles for the assessment of authentic learning, and as important ways of enhancing social goods such as graduate employability. These two aspects of the educational enterprise appear to relate to the first two types of Aristotelian knowledge, with propositional knowledge elements corresponding to episteme and skills corresponding to techne.

Aristotle devotes some considerable effort within the Nicomachean Ethics to discussing what have since become known as the intellectual virtues, of which, episteme, techne and phronesis are the most significant in an educational context. It is important at the outset to recognise that the term "virtue" is not to be understood in its modern, moral sense, but rather as a disposition that makes it possible for people to think, and act in a certain way, appropriate to the situation in which they find themselves. In his discussion, Aristotle introduced a number of terms which distinguish what we would now call types of knowledge and form the basis of his epistemological theory.

The first, *episteme,* is a form of propositional knowledge that is demonstrable, that is, legitimately derivable from more fundamental principles and, as such, is independent of any specific context. Given the universality of these principles, it is tempting to see this concept as a precursor of modem "scientific" knowledge, and many translations do indeed use that word. However, it should be clear that it cannot be simply identified with the subject matter and methodology of post-Enlightenment "science", which simply did not exist at that point in time. Episteme aims at the attainment of timeless or universal truth, such as that found in mathematics or metaphysics, and conveys the idea of knowledge sought for its own sake.

The second intellectual virtue is *techne.* This describes a form of knowledge expressed in terms of craftsmanship or artistry, and so is sometimes translated, in a modem context, as "technical expertise", "skill", "craftsmanship" or "artistry". This type of knowledge has sometimes been characterised as "knowing how" to do something and, since this depends on the situation in which the action is to take place, it is context-dependent, with the production of some kind of artefact as its primary aim. However, as we shall see, this translation of the Greek word raises its own problems with how that phrase is used in modem epistemology. Kemmis and Smith [15] state that it is the disposition to act in a true and reasoned way, relative to the standard rules of the discipline or profession involved. As such, it results in an instrumental type of knowledge, the reasoning involved being contextual and employed to achieve some known or designated outcome.

The third virtue is that of *phronesis,* which Aristotle defines as 'a true and reasoned state or capacity to act with regard to the human good'. It is often translated into modem language as "practical wisdom" [16], "prudence" or "practical reason" , and differs from episteme in its focus on action, rather than cultivating a more passive understanding of an idea, event or object. It incorporates the capacity for moral judgement, and cognitive understanding and insight, and, significantly, results in some kind of practical outcome. It therefore underpins the capacity to develop practical understanding and the disposition to act wisely and justly within the world. Although not a moral virtue in itself, the ability to evaluate the right end in a particular situation, and so make a wise or prudential judgement, is nevertheless aligned with the moral sense and is directed towards that same objective.

One point of debate is the distinction between the kinds of output or action that emerge from techne and that which results from phronesis. Both bring about contingent things which are subject to change but techne is primarily concerned with reasoning and acting for the end of producing something rather than its end being in the action itself, the latter being the domain of phronesis. A potter practises the craft of pottery, not just to perform the actions of creating a pot, but so that a pot is produced at the end of the process. In other words, there is a distinction made between production and action for the sake of itself. The disposition to "make something" (poiesis) which characterises techne therefore contrasts with the disposition to "do something" *(praxis)* which is the result of the process of deliberation characteristic of phronesis.

This distinction has been blurred somewhat in some modem discussions of these two concepts, e.g. (Jonsen and Toulman, [17]) and it can be argued that this has led to a loss of a distinct concept of phronesis in current discussions about the wider role of skill and judgement in education. Nevertheless, the point remains that there is a long tradition of seeing skill as a significant element in the philosophy of education. It is also the case, given that the Nicomachean Ethics is a fundamental element of the Western Philosophical canon, that techne, and hence skill, has acquired an aesthetic sense, as intellectual virtues lead, in this tradition, to moral virtues. For brevity, this idea will not be pursued here, although the aesthetics of a modem technical subject such as computing is a woefully under-researched area of study. But while the classical philosophical tradition has much to say about it, the lesson we wish to draw from the previous discussion is that skill, considered as technical excellence that seeks its end in an act of production, has a long and important role in epistemology and has informed educational philosophy in a profound way.

It is perhaps not unreasonable at this point to ask why we have provided such a level of historical background on what might be considered a somewhat abstruse area of classical philosophy. What does an appreciation of the Aristotelian notions of *episteme, techne* and *phronesis,* let alone auxiliary concepts such as *poeisi,s* or *praxis,* have to do with an appreciation of the concept of skill in the context of discussions of competency in 21 st century engineering or computing science? One reason for highlighting these ideas in the previous discussion is that they provide a framework in which knowledge is not simply understood in propositional terms. A motivating observation that we would like to make here is that a number of authors, e.g., Goldman [25], have pointed out that there are some unfortunate consequences of uncritically using the concept of knowledge that has emerged from the undoubted success of the mathematical and physical sciences in the modem era. As seen in the next section, science, as an institutional form of enquiry, has tended to prioritise abstract propositional knowledge (i.e., episteme) over the kinds of contextualised knowledge exemplified by techne and phronesis. This, it may be argued, has led to a progressive devaluation of methods of enquiry that rely on this kind of contextualised knowledge (e.g., engineering) compared to their more scientific" counterparts (e.g., physics). Indeed, it has been claimed that the success of scientific enquiry has meant that a definition of knowledge, given solely in terms of abstract propositions, has effectively replaced the broader, classical understanding of knowledge, and this has had important, and by no means, completely beneficial consequences for the education process. In view of this contention, it is important to analyse the word "knowledge" when used, for example, in the context of competency theory, to decide what kind of knowledge is being considered. Another outcome of this redefinition of knowledge is the tendency to try to reduce other forms of cognitive ability to propositional knowledge. An example of this is the popular definition of skill as "know-how". This description of skill is a common feature of educational discussion of the concept and, indeed, is the route taken in CC2020. There are however problems with this approach, as we discuss in the next section.

B. Know-That and Know-How

Having looked at the relationship of skill to (propositional) knowledge from a classical viewpoint, we now tum to a related question considered from a modem perspective, namely the current discussion among epistemologists, of whether "know-how" (or knowledge-how) can be reduced to "know-that" (or knowledge-that). This is essentially the question of whether the possession of skill can be reduced to the possession of a form of propositional knowledge about the context in which that skill is exercised. Gilbert Ryle [18] used the term "intellectualist" for those that claim the truth of this reduction, while the counterproposition is nowadays termed "anti-intellectualism" (with respect to this argument). What educational significance could this have and why is this question important? Such discussion is relevant here because the current paper is situated in the educational context of the CC2020 curricular project which uses a competency model in which knowledge and skill components are considered to be distinct (but related) goals of learning. This distinction has important pedagogical consequences in terms of how educators see the curriculum, indeed the CC2020 document talks about moving from a knowledge-centred approach to the broader conception of a competency-centred approach.

Ryle's argument against intellectualism, that skill could not be reduced to the possession of states of propositional knowledge alone, is basically that this would lead to an infinite regress. If know-how were a form of know-that, then one would have to contemplate a proposition in order to engage in any specific action. But, the contemplation of a proposition is itself an action, which would then have to be accompanied by another distinct contemplation of a proposition. And so on. This would lead to an infinite regress which would mean that no action of know-how, i.e., no demonstration of skill, could ever be manifested, which is not possible. This anti-intellectualist position was popular within epistemology in the latter half of the 20th century, being espoused as orthodoxy by the majority of epistemologists and educational philosophers, e.g. Dreyfus [19,20]. In addition, the identification of skill with know-how was common and was lent plausibility by the fact that skill is routinely ascribed through know-how ascriptions. Some languages, such as Italian and French, do not even have a designated word for skill distinct from their word for ability, or from their word for talent, and they systematically ascribe skill through attribution of know-how (i.e., through attribution which would be translated in English by statements of the form "Alice knows how to do X") [21,22] It seems plausible, therefore, that having knowledge of *"how to do something'* is a prerequisite for being skilled at doing it. Saying that Alice is a skilled programmer appears to entail that she knows certain facts about programming constructs, structural and functional elements of the language, and how to use these in practice. Indeed, the statement, *"if Alice is skilled at programming, she must know how to program",* seems almost self-evident. Nevertheless, one might object to the sufficiency of know-how for skill on the grounds that knowledge does not by itself seem enough. It may be that Bob understands how to program but is not considered a skilled programmer because he lacks some relevant ability connected with its practice. However, as noted by Pavese [22], we usually consider so-called "gradable" adjectives, such as "skilled", to quantify over degrees above a certain contextually determined threshold - in this case over degrees of skillfulness above that threshold. This contextuality matters for both know-how and skill. Saying that *"Bob knows how to program"* means that, *"in many circumstances involving the solution of a programming problem (the range of which are determined by some contextual factors), Bob knows how to solve that problem by writing a program".* But it is generally considered too extreme to demand we can *only* say that Bob knows how to program if he is able to solve all relevant problems by writing an appropriate program. Similarly, saying that Bob is a skilled programmer is true, only provided that Bob exceeds a contextually determined threshold. Attribution of skill, therefore, follows the same kind of qualification as that of know-how. Bob may have some of the know-how to program, but his lack of skill could be attributed to lack of appropriate know-how in some important areas. Nevertheless, a fuller and more rounded knowing-how to program (relative to that contextually determined standard) will entail being skilled at it (relative to the same standard). Hence, although know-how does not, strictly speaking, entail being skilled, knowing how, above a certain qualitative (and contextually determined) threshold, does.

This "Rylean" view, that we can identify skill with know-how, was commonplace in the latter half of the 20th century but it has been challenged over the last two decades by work initiated by Stanley and Williamson [23,24] who claimed that skills were better understood as "disposition(s) to know". The essence of their objection was that if it could be shown that there was no "fundamental distinction between knowledge-how and knowledge-that" [23] i.e. that know-how was simply a species of know-that, then skills would also simply reduce to propositional knowledge states. Suppose Carol knows how to do something; then this can be restated in terms of Carol's knowledge of propositional states. Carol's knowing how to play the piano is simply shorthand for Carol knowing certain propositions about the piano, the way that notes and chords are produced, the translation of musical notation into finger positions, etc. Carol knowing how to play the piano, therefore, can be restated as Carol having an answer to the question
"How do you play the piano?" As mentioned previously, this view has come to be known as "intellectualism". The argument is that, if know-how is simply a kind of know-that, propositional knowledge, and if the argument that skill (at least above a certain threshold) can be reduced to know-how, then skill is itself a form of propositional knowledge. It is true that there are some intellectualists who deny that know-how entails ability and hence skill [24], on the grounds that one may know how to perform a task but still be unable to do the actions that amount to performing it, and hence the reduction of skill *per se,* to knowledge, is not a valid inference. However, much of the work being done in this area is directed to closing this inferential gap. It should also be noted that "know-how" is only one type of what are often called forms of "transitive" knowledge. These forms also include knowledge modified by ascriptive statements which include the words "where, who(m), what, which, when and why". Knowledge, or knowing, in these transitive forms, gives rise to "knowing where", "knowing who(m)", "knowing what", "knowing which", "knowing when", "knowing why", etc. Together with "knowing how", these forms of knowledge are generally termed "know-wh" and similar issues with their relation to propositional knowledge arise.

As suggested in the preceding section, discussion of the Aristotelian classification of types of knowledge, or modem epistemological arguments about the relationship between different varieties of knowledge and skill, may seem a little archaic and somewhat removed from the everyday practicalities of educating students at university, but we would argue that there are some important issues that lie behind this discussion. An understanding of the distinctions between different types of knowledge - episteme, techne and phronesis

- is important when considering the epistemological and methodological status of subjects which do not follow a scientific paradigm. Engineering, for example, routinely deals with knowledge claims which are context-dependent and contingent. In his paper on the philosophy of engineering [25], Goldman discussed the relationship between philosophy, engineering, and Western culture. He contended that the way engineering problems are defined, and the range of acceptable solutions, depend explicitly on value judgments that are separate from the technical expertise possessed by engineers. These value judgments themselves are influenced by the expected economic, social, and political consequences that result from implementing such a solution. The assessment of these consequences is in turn influenced by the specific commercial and sociopolitical contexts within which engineering is practiced. These levels of contextualisation in the statement of an engineering problem and its solution are impossible to remove, and so the knowledge gained and used by engineers is irreducibly contingent. By contrast, scientists are perceived as impartial seekers of universally true knowledge about the way things are, and their problems are defined by nature itself, independent of their employers. Scientists, at least in popular public perception, rely solely on nature as the authority for determining correct solutions. While engineers may employ mathematical and scientific knowledge to solve problems, they make use of that technical knowledge in ways that align with the specific needs and objectives which arise within the subject. This approach may be quite different from that of mathematicians and scientists, as engineers may adapt scientific theories and mathematical techniques in unique ways that are tailored specifically to address engineering problems.

One particular aspect of engineering problems that is not usually shared by their mathematical or scientific counterparts is that they are subject to what Herbert Simon called "bounded rationality" [26, 27]. This concept, developed as an alternative to rational choice theory [28], explains the fact that, unlike in scientific or mathematical problems, decision-making in engineering is often constrained by various factors that prevent individuals from making fully rational choices. Rational choice theory assumes that individuals are rational decision-makers with complete information, the ability to consider all available alternatives, and the goal of maximising their own self-interest or utility. By contrast, the theory of bounded rationality challenges these assumptions and proposes that decision-makers have limitations in their physical and cognitive resources, as well as in their capacity to process information. Consequently, the outcome of the decision-making process is also constrained by these limitations. To overcome contextual limitations, decision-makers often rely on heuristics, or simplified mental shortcuts, to quickly evaluate and make decisions based on incomplete information. In an engineering context, this can lead to solutions that are not optimal but still viable and satisfactory within the given problem's constraints. This process, known as "satisficing," - a portmanteau introduced by Simon from the words, "satisfy" and "suffice" - involves solving problems while ensuring that the solution meets a minimum threshold of acceptability. In the context of design, satisficing represents a pragmatic approach to decision-making that recognizes the constraints typically faced by designers.

As stated earlier, Goldman suggests that there has been a devaluation of this kind of contingent knowledge derived from contextual problem-solving, in favour of the necessary, scientific and mathematical knowledge, so that the word knowledge has almost become synonymous with theoretical knowledge. This is also reflected in a similar downgrading of the term skill compared to "knowledge", with the result that the educational value of skill development has tended to be downplayed in favour of the acquisition of (propositional) knowledge.

The preceding sections were intended to provide the analytical context in which to discuss the concept of skill in competency theory, specifically the competency model used by the CC2020 document. We will therefore look at what this document says about competency in general and skill in particular.

IV. CC2020 AND THE COMPETENCY MODEL

The *Computing Curricula 2020 (CC2020) Paradigms for Global Computing Education* is a global joint project, sponsored by the ACM and IEEE Computer Society, to examine the current state of curricular guidelines for academic programmes that grant degrees in computing, and to provide a vision for the future of computing education. The work covers undergraduate programs in computer engineering, computer science, cybersecurity, information systems, information technology, software engineering, and data science. The publication of CC2020, together with the development of the curriculum visualisation tools that accompany the work, is a significant milestone in the evolution of computing education at university level, and it is anticipated that it will have an extremely positive effect on all aspects of teaching, learning and assessment in the discipline over the coming decade. One of the most important steps that was taken is to reformulate the teaching and learning process from an approach based on acquiring knowledge to one based on developing competency. This can be viewed as a shift in the philosophical basis of the educational framework from one where propositional knowledge elements, and the relationships between those elements, were seen as the primary, if not sole, constituent of the subject ontology, to a conceptual space where skills and dispositions join knowledge as first-class citizens in the educational discourse.

In order to discuss the components of competency, we give a brief outline of salient features of the model. It is worth remarking that the CC2020 document uses a structural model of competency (see, e.g., [29]). However, there are also models which focus on competence levels and competency development. As noted by Koeppen et al., [30], models of competence *structure* focus on understanding the relationships between performance in various contexts, and aim to identify common underlying dimensions. By contrast, models of competence *levels* are used to define *"the specific situational demands that can be mastered by individuals with certain levels or profiles of competencies"*. These models aim to allow criterion-referenced interpretation of individual performance and so can be used to assess and evaluate educational outcomes at a collective level. With regard to models of competency development, there are few that are underpinned by empirical evidence, and many disagree in the basic way in which the development process is conceptualised. Some models view competence development as a continuous progression, where individuals gradually move from levels of lower competence to higher levels whereas other see it as a process of steady assimilation punctuated by short periods of conceptual development and change involving a fundamental reorganisation of concepts and structures [31].

These different types of models address different aspects of competence constructs, and ideally should complement each other. However, the lack of a generally accepted representation of competency beyond the well-known structural model does present challenges for visualising the development and acquisition of skills and how this process relates to the development of other components, e.g., see [32].

The CC2020 project makes extensive use of the structural model illustrated in Figure 1. The document states that:

"There is a general agreement in educational circles that career success requires three things.

- *Knowledge-"know-what"-a proficiency in core concepts and content and the application of learning to new situations.*
- *Skills-"know-how"-the ability to carry out tasks with determined results; and*
- *Dispositions-"know-why"-intellectual, social, or moral tendencies.*

Hence, any definition of competency must connect the three dimensions within a context or task represented as:

Competency = Knowledge + Skills + Dispositions. "

(CC2020, p13)

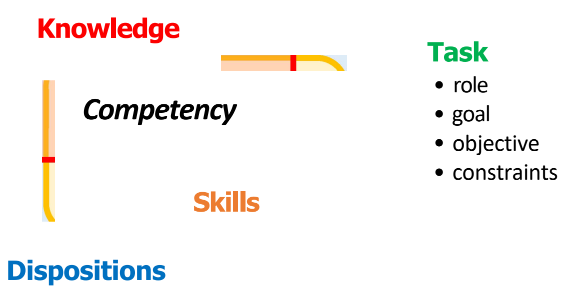

Figure 1: The Conceptual Structure of the CC2020 Competency Model (based on CC2020, p47)

The conceptual structure of competency is represented schematically by Figure 1. which is (re)drawn from the CC2020 document. It is not entirely clear whether this picture is meant to provide some kind of Venn/Euler diagram of the components, whether the two-dimensional structure of the diagram is important, and whether competency is meant to be seen as lying at the intersection of the components, as opposed, say, to being some kind of integrative concept in which the components subsist.

CC2020 describes *Knowledge* as the *"know-what" dimension of competency. It is propositional knowledge of facts and comprises the "enumerated subject matter that teachers catalog as topics in their syllabi, departments distribute and balance among the courses they develop in an academic program"* (CC2020, p48).

Skills are described as *"the capability of applying knowledge to actively accomplish a task"* (ibid). It states that *"a skill expresses an element of knowledge as acted upon with proficiency to define the "know-how" dimension of competency".* The knowledge and skill components of a competency are therefore integrated, and propositional knowledge is only understood to be useful to the learner when applied in a context *"at a level of skilfulness that is specified and observed as a level in Bloom's cognitive process".* This level of skillfulness would often be assessed indirectly through observation or appraisal of the quality of work produced. Skill is defined then as *"the proficient applying of knowledge"*

The third component of a competence is *Disposition.* The CC2020 document states that these *"frame the 'know-why' dimension of competency and prescribe a temperament of quality of character in task performance".* Dispositions are thought of as moderating factors in the application of skills and are habits and tendencies which control the affective elements (i.e. motivations, attitudes and inclinations) to use skills. It is not the purpose of this paper to discuss the dispositional aspects of competence although that, again, is an area that requires a great deal of further exploration in terms of the way other disciplines use that word. The role that is played by disposition within this competency model has been investigated by Frezza et al. [33]. While we do not wish to pursue these issues here, it is worth noting that the defining character of this component, together with the relationship between dispositions and the knowledge and skills, require further conceptual analysis. For example, a clear understanding of the concept is especially important when considering the assessment of dispositional aspects of learning. Dispositions seem to have a more holistic, personal nature than knowledge and skills, and they are built up over a period of time in which beneficial habits are developed and internalised. Assessment of these dispositional aspects of competence therefore involve both a longer-term examination of the kind of behaviour which manifests the disposition, and a more nuanced view of what is meant by measurability and how progress can be demonstrated.

The final element in a competency is the context or task that *"frames the skilled application of knowledge and makes dispositions concrete".* The task is where dispositions manifest themselves in skilled action guided by appropriate knowledge elements. Consequently, the task, or context of application, provides the place where educators can develop a pedagogy that enables student to demonstrate competency as a computing professional. There are a number of points here that should be explored, but before we do, it is worth looking at what else the document has to say about how skill should be assessed.

Given the definition of skill as "the proficient applying of knowledge", there is some indication of how assessment of this aspect could take place and the CC2020 document provides a Bloom-like taxonomy with an ordered sequence of six cumulative levels of (cognitive) skill together with abbreviated definitions. These levels are Remembering, Understanding, Applying, Analysing, Evaluating and Creating. Assessment of skill level would proceed by mapping the implementation of the task onto these levels.

V. DISCUSSION

Having given an overview of some of the fundamental issues of how we understand skill, as well as the way that the CC2020 document treats the concept, we can begin to discuss some of the implications of this view.

The first thing to state is that the CC2020 document is an exercise in curriculum development, visualisation, and mapping, not an epistemological treatise on the relationship between the different competency components. That puts it squarely within the (disciplinary-) education context. This is important because it constrains the scope of the document to addressing those issues which have direct relevance to (computing) education. In particular, there is a need to ensure that whatever structural learning units that are considered, be they knowledge elements, skills or dispositions, they must be measurable and so amenable to assessment. It means that there is an underlying positivist approach: whatever CC2020 means by skill, we must be able to assess it. That assessment might rely on subjective interpretation of criteria but, at least for cognitive skills, it cannot be wholly subjective as it is guided by levels in the taxonomy. However, a taxonomy is not a rubric, and it is not clear from the CC2020 document itself how this would work in practice.

A second, and perhaps more important issue is the use of the word "know-how" in the definition of the skill component within the competency framework. Based on the discussion in section 2.2, we would argue that there are many problematic issues regarding the synonymous use of the words, skill and know-how. However, in addition to those concerns outlined, previously, looking from the perspective of educational practice, any definition of skill in terms of know-how is almost guaranteed to reduce skill, at best, to a secondary or derived quality and, at worse, to a redundant category. Leaving aside questions of the existence of different types of propositional knowledge, if skill is just a form of knowledge, then why not simply talk about knowledge. We would argue, however, that skill is more than just a derivative form of knowledge. From an educational perspective, skill is grounded in practice; in demonstration and performance. In fact, in some senses (and again from an educational perspective), because we use effective demonstration as a proxy for understanding, which is itself a characteristic of knowledge, we should perhaps be making a claim for the priority of skill over knowledge. This would, however, take us further down the instrumentalist approach to education than we would like to go. Regardless, when moving from a knowledge-based pedagogy to a competency-based one, for the sake of conceptual clarity, it is not helpful to define independent competency components with reference to other components without very careful qualification. The CC2020 definition of skill in terms of effective proficient demonstration of knowledge is a good one provided the emphasis is on demonstration.

This will have implications for the way that course documentation is written, and assessments are drawn up. The use of Bloom's taxonomy is fine for characterising skills, but it is impractical as a means of assessment. However, a definition of skill which focusses on application serves to force assessors to focus on the contextual manner in which information is presented to them and the relevant mechanisms by which this can be done. Given the issues reported by many employers that they are looking for graduates with competencies beyond the purely technical, this would be a sensible way at enhancing employability skills.

Also, as noted by Fuller et al. [34], some concepts and structures of learning taxonomies are difficult to transfer to the subject of Computing, with "Understanding" and "Applying" causing particular problems when assigning a position in Bloom's hierarchy. One suggested alternative to this was to separate Bloom's six levels into two dimensions, "Producing" (i.e., applying and creating) and "Interpreting" (i.e., remembering, understanding, analysing, and evaluating), giving a 2D representation of competency development. However, this would introduce further complications when trying to apply the taxonomy, in a straightforward way, to the process of skill acquisition.

One interesting aspect of the previous discussion concerning the classical notion of techne is the relationship between that concept and the associated notion of phronesis, that is, between skill and prudential judgement. In both cases the exercise of these capacities requires some kind of demonstration, but the latter is not involved in production per se, but in actions which, by virtue of being "wise" actions, are ends in themselves. From a pedagogical perspective, this distinction seems to be a useful one. In an educational setting, we want to encourage and foster both the development of skill, (i.e., the ability to produce something - either a physical artefact or some kind of performance), and deliberative judgement, (i.e., actions which result in better states of affairs). The exercise of phronesis through the employment of reflective, contextual judgement should be a fundamental component of a pedagogical approach which aims at providing an authentic learning experience for students, in which they can start to participate in the communities of practice of their professions. There is also a strong link between the idea of authentic, "real-world" learning and its expression in the solution of ill-structured problems which require the use of evaluative or interpretive judgements. The requirement that actions should be justified based on the use of such judgements should be ubiquitous features not only of work-based learning environments but of more traditional modes of learning. This may require that the distinction between techne and phronesis, between skill and prudential judgement be maintained, while incorporating both within a competency framework.

It is also worth considering the relationship between performance and skill when confronted with emerging technologies, such as generative AI. It appears that such tools appear are becoming more accessible to novice learners which, given the nature of their method of operation, raises serious questions about what competence (especially knowledge and skill) will mean in a world with ubiquitous AI support. One feature of generative AI seems to subvert conventional educational objectives is the lack of explainability between inputs and outputs. Given the neural network architecture, the machine learning algorithms, which underlie tools such as large language models (LLMs), act as black boxes which connect inputs and outputs in an obscure and, in some cases, impenetrable, way. This lack of "procedurality" poses significant challenges to their use in the development of skills in areas demanding careful reflection on the operational aspects of performance.

This is not an entirely new situation. The advent of accessible electronic calculators in the 1970s, and their subsequent ubiquitous use in schools and universities, meant that much of the tedious work involved when students and professionals wanted to perform calculations was eliminated.

The direct need to understand the implementation details of the algorithm used when finding the quotient of two large numbers, or the use of interpolation techniques when identifying the natural logarithm of a number in tables of special functions, was removed. This undoubtedly had significant advantages in terms of productivity but most of the benefits accrued to those individuals who already knew how to perform those calculations. Treating the calculator as some kind of oracle by which inputs were transformed into outputs in a deterministic but wholly opaque manner led to a decrease in skills such as numerical estimation [35-36]. Significantly, there is little suggestion that calculators should be used at the earliest stages of learning arithmetic [37]. This response to technology stands in marked contrast to current controversies about use of LLMs, e.g., in the introductory stages of learning to program, where, perhaps for purely pragmatic reasons, substantial effort is being devoted to investigation about how to use the technology in the introductory stages [38, 39]. In these circumstances, it is important to know what we mean by skill when, for example, talking about the ability to program. It may be that the competency changes from being one in which skill is demonstrated by writing procedural code to one in which it is shown by sophisticated use of the tools, which includes suitable declarative capabilities in the development of appropriate prompts, as well as promoting the capacity to examine the rationality of output and carry out robust tests on anything produced in this manner. Here again, the notion of skill can be tied to performance rather than knowledge, although knowledge, especially knowledge about how to frame declarative statements about requirements, becomes more important. Moreover, given the state of research into so-called "explainable AI (XAI)" [40 - 43], it may well be the case that future AI tools will allow reflection on process as well as output.

VI. CONCLUSIONS

It is undeniable that the concept of skill now plays a much more prominent, and increasingly important, function in educational discourse, compared to its role in the previous century. There are significant social and economic drivers that require universities produce computing and engineering graduates who can apply their competencies in a practical way from the outset of their professional careers [44,45] The political pressure to enhance employability competencies to cope with changing technological environments [46 - 49] have meant that the concept of skill has become a vital part of attempts to predict and understand what higher education will look like in the coming decades. In the current climate of anxiety about the emergence of novel forms of artificial intelligence, some commentators [50 - 54] suggest that the lack of explainability inherent in some technologies may undermine the role of demonstration (and, hence, skill) in learning. However, we would suggest that, even if research on explainable AI does not result in significant changes to the black box model, it would still be the case that declarative rather than procedural competencies would be seen to be desirable. Clearly the debate about these issues will continue and, in this light, clear and coherent conceptualisations of the nature of competency, and the skill component in particular will be needed.

The CC2020 project is a major step towards creating a computing curriculum which can accommodate the needs of all in the production of computing graduates in the medium-term future. The move to a competency-based conception of what students should learn is a significant one and the concept and practice of skill will undoubtedly be at the forefront of this change. There are issues with the definition of skill in terms of some aspect of the knowledge component but an appropriate understanding of skill as the performative element in the demonstration of competence will help to distinguish the individual structural elements. While the structural model of competency does provide for this distinction, it would be useful to have a similar evidence-based developmental model of competency that showed how proficiency in the different components could be gained and tracked, specifically when talking about demonstration.

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