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In search of a philosophy of computing education.

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In Search of a Philosophy of Computing Education

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***Abstract*— In this paper, we present a preliminary description of the field of inquiry encompassed by the philosophy of computing education. We first attempt to identify a general framework for investigating characteristic questions of a philosophical nature that arise within the STEM application domains. We describe the categories such questions fall under and use the philosophy of computing to illustrate this process. We also consider an alternative approach to identifying philosophical issues within a practical field, using the philosophy of education as an example. We consider the related subject of the philosophy of engineering education and see how this has recently emerged as an object of study in its own right. We investigate the similarities and differences between this field and the philosophy of computing education, and provide an initial description of the latter subject area. We also discuss how it relates to the subject referred to as Computing Education Research. Finally, we draw some conclusions about why there is this puzzling, apparent lack of interest in current work in this area, and suggest reasons why the pursuit of philosophical inquiry into computing education should be an important aspect of scholarly study in the subject.**

Keywords—philosophy, philosophy of computing education, philosophy of engineering education, philosophy of computing, philosophy of education.

I. Introduction

The subjects of mathematics, computing, engineering, and the physical and biological sciences have all given rise to well-established and vibrant research communities which investigate the philosophical problems raised in those fields. In addition, the STEM disciplines all have established research communities whose focus is on the philosophical implications of the educational processes in those subject areas. However, if one searches for "*philosophy of computing education*" in, say, Google Scholar, there are no papers with this term in the title, and only one that uses it as a keyword/phrase. This contrasts with thousands of hits for terms such as "*philosophy of mathematics education*", "*philosophy of science education*" and hundreds for "*philosophy of engineering education*" and the "*philosophy of technology education*". This is an unexpected observation and raises the question of why this is the case? Is the field of Computing Education, alone amongst its peers in the STEM subjects, bereft of topics which require philosophical investigation, or are there other factors which may explain the apparent lack of interest in these topics?

This paper investigates the role of philosophical inquiry in computing education. We consider the way that philosophical ideas have arisen in the subject domain of computing, as well as those that emerge from the philosophy of education. We examine whether the intersection of these two areas provides a basis for a distinct philosophy of inquiry, of or within, computing education theory and practice. To do this, we consider the educational traditions in neighbouring academic fields and examine whether there are distinct problems that are posed in the education of computing students which are distinct from those that arise in the practice of mathematics, science, engineering, or technology education. An important question is whether the philosophy of computing education is effectively subsumed within the ambit of its more established STEM cousins, or whether it is useful to distinguish it from, say, the philosophy of engineering education, because of its characteristic subject matter or some distinctive methodology. For example, are there distinct epistemological issues that exist within computing education, by virtue of its reliance on abstract notions of information in software, that are different from those found in the engineering disciplines? Does a pedagogy based on the concept of computational thinking differ in kind from more established approaches based on abstract mathematical thinking? Does the scientific method provide a good pedagogical underpinning for the development of competencies in computing? And how do issues, such as these, relate to the university computing curriculum, e.g., as expressed in the CC2020 document?

We begin this paper by examining the nature of philosophy and philosophical inquiry. We could say, very broadly, (and with one eye on later application) that the study of philosophy concerns the nature of reality (metaphysics), what we can legitimately know about that reality (epistemology, but also valid ways of arriving at knowledge such as methodology and logic) and the concept of value that arises from these considerations (axiology, which includes aesthetics and ethics). This is undoubtedly a gross simplification but characterising the subject like this gives us a set of categories into which philosophical problems can be placed and from which a taxonomy can be developed. We make a heuristic distinction between what may be called the intrinsic categories of philosophical investigation - metaphysics, epistemology, axiology - and extrinsic application domains such as mathematics, natural sciences, engineering, education, etc. This is not a hard and fast division - some areas of philosophy such as the philosophy of mind or the philosophy of language would generally be defined as areas of intrinsic interest to philosophers rather than application domains. Nevertheless, it allows for a description of the philosophy of applied areas as the study of problems in those fields which fall under the intrinsic categories. We provide examples linked to computing and education, before examining the discipline of computing education in the same manner.

II. What is a "*Philosophy of Something*"?

Before we discuss what constitutes the subject matter and methodology of the philosophy of computing education, it is useful to examine what characterises the subject of philosophy itself. This, however, is a notoriously difficult problem, e.g., see [1]. Nevertheless, although the history of the subject has shown a remarkable degree of diversity in the development of ideas and methods, we can still determine some aspects of basic subject matter and methodology that have remained central to the philosophical enterprise over the past twenty-five centuries. A characteristic feature since at least the time of Socrates, is a focus on making distinctions, and analysing the differences and similarities between the categories that are thus distinguished, a mode of inquiry that has been applied to the subject matter of philosophy itself. This gives a set of categories into which philosophical problems fall and which can be seen as branches or subcategories of the subject. Philosophers rarely agree on the specifics of the classification. However, even if only taken as a descriptive typology, we can identify characteristic classes of problems which include subfields such as metaphysics, epistemology, ethics, etc, all of which have their own sub-disciplines, such as the philosophy of mind, or the philosophy of religion, or philosophy of politics.

When discussing philosophical questions in specific application domains, we can identify two general ways in which they arise. The first is by taking a "top-down" approach in which a subject area is analysed using a number of prototypical philosophical categories. This provides a structural view of the philosophical issues that appear and is natural when dealing with abstract or theoretical aspects of a discipline such as the natural sciences or computing. The second way is to take a "bottom-up" approach in which practical questions that arise naturally from within the subject domain are analysed using what might be described as "the philosophical method". This can seem more natural in, for example, the social or educational sciences where practice is often a key feature of the subject, but is frequently messy and inherently contextual, making a top-down analysis difficult.

Another basic distinction that could be made is between intrinsic categories of philosophical study and those that arise in its areas of application. By intrinsic categories, we mean those areas of study that have characterised the field of philosophy from its inception, and which still provide much of the content of the subject. This distinction will be useful and, for the purpose of this paper, we divide up the subject matter of philosophy (or the focus of philosophical inquiry, which we take to be the same thing) into three broad areas, which we then use as ordering principles for philosophical problems in application domains.

The first category is Metaphysics. Much like philosophy itself, the conceptual boundaries of metaphysics are hard to define [2], but it includes the study of essential properties and substances, the theory of universals, the identification and classification of causes, modality and ideas about necessity and contingency, the nature of the mind and its interaction with the body, free will and determinacy, and space and time. As a somewhat simplistic overview, we can say that it is the study of what is, or what exists. For this reason, and with an eye to application areas in the sciences, we prefer the term *Ontology*, i.e., the study of what objects and relationships can be recognised as fundamental (or, at least, significant) in the subject area, and how non-fundamental or composite objects depend upon them. While this definition of ontology is technically inadequate, it captures the main elements of what we need in the rest of the paper.

The second "intrinsically philosophical" category is *Epistemology*, i.e., the study of knowledge, its nature, scope, sources, and limitations. Epistemology examines how we acquire knowledge, what kinds of knowledge are possible, what the relationship is between knowledge and belief, and how we can distinguish between true and false beliefs. Because it seeks to examine the nature of knowledge, it provides a foundation for understanding how we can make reliable claims about the world, and so is a fundamental area of philosophical inquiry that underlies the practice of almost all other fields of study. In the context of this paper, we use the term to include what methods of knowledge acquisition are accepted as relevant within a particular application domain. For our purposes, this also encompasses other philosophical subdisciplines that would normally be counted as separate from epistemology, such as methodology, i.e., what approaches to inquiry are counted as legitimate within the community of study, and logic, i.e., the systematic study of reasoning and the methods for evaluating the validity and soundness of arguments. Again, this definition is open to objection, but suffices for the purposes of the paper.

The third intrinsic category of philosophical study is *Axiology*; the study of the nature of value, its generation or recognition, and the functional role of values within an area of discourse. Axiology investigates what values are discussed and prioritised in application areas as well as basic questions about the attribution of significance or meaning. This is clearly a fundamental process in any human enterprise and it encompasses a number of well-known philosophical subdisciplines. These include ethics and aesthetics, as well as social and political philosophy, cultural criticism, some aspects of the philosophy of religion and the philosophy of law. For the purpose of application, we can focus on the first two of these. Ethics is the subcategory of axiology that investigates questions of morality and what actions and behaviours are morally acceptable. It seeks to provide a framework for making moral decisions and evaluating actions and behaviour that occur in the world. Aesthetics, on the other hand, is the subcategory concerned with ideas about beauty, art, elegance, and expertise or virtuosity. It considers how one evaluates these concepts and how, for example, one can legitimately discriminate between examples of good and bad production or practice. In terms of application, it considers what kinds of things within a subject area are considered stylish or elegant, as well as seeking to analyse the experience of beauty from the perspective of someone engaged in that area.

These three categories are similar to those described by Ferré ([3], as cited by Heywood, [33]) except that we have denoted metaphysics by the term ontology, and have chosen to include methodology as a subfield of epistemology.

Given this classification of philosophical subdisciplines, what characterises a "philosophy of X", where X is some subject domain, is that X is analysed under one or more of the categories - ontology, epistemology, or axiology. The ontological category frames investigation into the fundamental elements of the subject, their causal processes, the relationships that constituent entities, be they physical or conceptual, have with each other at various levels of analysis, and how these can be represented and modelled within the application domain. The epistemological category encompasses questions of how knowledge is discovered, created, and justified, as well as the legitimate modes of inquiry that are accepted within the subject area. The axiological category situates questions about the values, whether ethical or aesthetic, that emerge from the subject, are articulated by its practitioners, and which inform its practice.

In his 1999 essay on the *Future of Philosophy* [4], John Searle compared and contrasted the areas of philosophy and the natural sciences. Both, he suggested, were, in principle, universal and aimed at truth, but there were important differences in the methods used to address problems, the style of solution and the presuppositions that underpinned the statement of those problems. Philosophical questions tend to have three related features that were not shared by their scientific counterparts. Firstly, they dealt with questions for which no satisfactory nor systematic way to address them had been found. This may be due to the underlying subjective nature of the phenomenon being studied which is not reducible to scientific measurement. Secondly, they tended to be "framework questions", dealing with large frameworks of phenomena rather than specific individual questions. As such, they deal with the big picture that characterises our experience of the world. Thirdly, they are typically concerned with concepts and the relationships between them and the world they represent.

III. The Philosophy of Computing

To illustrate some of the points, we give a brief overview of the Philosophy of Computing, following the survey of philosophical topics in Computing and Information Technology given by Brey and Søraker [5]. They identify five main application areas in which philosophical inquiry has been used, namely, the theory of computing, computer science, artificial intelligence, the internet and new media, and the ethics of computing and information. There are a number of accessible introductions to this area such as that by Floridi, [6].

The theory of computing deals with the essential nature of computation, what it is, and what are its limits. A fundamental open question is what constitutes computation. Is it a physical process of moving electrons or other particles around a mechanism, or is it the manipulation of information? This question is closely related to others about the nature of information and impinges upon questions about semantics and the concept of meaning ascribed to the results of such processes. Turing's definition of computation in terms of an abstract machine [7] is one attempt to model this but Church's Lambda calculus [8] would be an alternative, and there are arguments. e.g., Sloman in [9], that these abstract, mathematical descriptions do not adequately capture the real-world operational characteristics of computation on physical machines. Other ontological questions concern the nature of information, its relation to data, and the representations, conceptual and physical, of both, e.g., in formal and natural languages [10]. Epistemological problems also arise when considering the concepts of computability and complexity that seem to place significant limits on the decidability of computations. These raise questions about the nature of scientific knowledge, and whether there are forms of knowledge that are not accessible through empirical observation and experiment [11].

Brey and Søraker take philosophical inquiry into computer science to be the analogue of similar attempts to understand the philosophical underpinnings of other scientific and engineering disciplines. This includes the analysis, interpretation and clarification of key assumptions, central concepts, methods of study within the subject, and their relation to other scientific disciplines, and to society as a whole. For example, an important area within computer science is software engineering which concerns the design and development of software and its application to problems in science, commerce, and society in general. Again, there are ontological questions about the nature of software artefacts, as well as epistemological issues about the methodology of software creation, as well as its verifiability, given the level of complexity of the resulting artefact. There are axiological issues with respect to the values inherent to the engineering of ethical systems. There are also "structure vs function" issues that arise within large data models. Indeed, the way in which software represents the real-world leads to the specifically computing-technical sense of the word "ontology" as the sub-field dealing with the formal representation of knowledge or information about a particular domain, for the purpose of modelling. The role of information is also central in the study of both information technology and the broader field of information systems.

Similarly, important methodological questions arise about the relationship between rationalist theories of design and hermeneutical theories of the relationship between human beings and technology based on insights from Continental philosophers and social theorists [12]. This concern with the way that people use technology also informs the field of Human Computer Interaction, which draws heavily on cognitivist approaches to psychology, themselves informed by information processing approaches in the philosophy of mind. In recent years, situated and embodied theories of cognition have also been applied to these subject areas.

Historically, the earliest interaction of philosophers with computer science was through the field of cybernetics and artificial intelligence. The literature on these subjects, and the record of philosophical engagement with the problems that arise, span almost all areas of philosophy. Examples range from the metaphysical and ontological investigation into the nature of consciousness, questions about subjective experience in the philosophy of mind, the philosophy of language, epistemology, logic and methodology, ethics, and many others. Nor has the traffic been one way; computing has furnished conceptual models that have been enthusiastically appropriated by philosophers (e.g., Turing's "Test" [16] and Searle's Chinese Room [17]). More recently, machine learning, natural language processing, computer vision, scheduling, and robotics, have all presented use cases for valuable areas of interdisciplinary research, the frequency and scope of which is only increasing. In this area, more than any other, any attempt to provide a comprehensive review of the philosophy of artificial intelligence in this paper would prove hopelessly inadequate due to the fast-moving pace of the field. As these areas have matured over many years, we would draw attention to the fact that different flavours of artificial intelligence research now exist, (e.g., symbolic AI, connectionist AI, expert systems, ...) each with their own ontological, epistemological, and axiological questions. An accessible introduction to this area is [18].

One of the biggest and most profound social changes that has occurred over the past thirty years is the emergence of the

Internet/WWW as a ubiquitous user technology, and the pervasiveness of the individual and communal experiences that this has afforded. These changes have been felt in every aspect of life, and the technology has had, and continues to have, immense impact on political, economic, academic, and cultural spheres as our online, "virtual life" in cyberspace becomes ever more integrated into our physical activities. While less advanced, and, at the current time, with more uncertain long-term effects, the emerging fields of virtual reality and immersive technology, also have the potential to revolutionise social exchange between individuals and groups, and to redefine notions of space, proximity, and presence, beyond the physical environment, e.g., [19].

These rapid and seemingly irreversible developments have brought with them a host of challenges which are addressed by philosophical as well as scientific and technological inquiry. As with much in the field of Computing, the concept of information is often prominent in these discussions, with its attendant epistemological problems. However, the technology also presents ontological questions about the nature of virtual reality, and the experiences found therein, both in its single- and multi-user form. There are also axiological questions concerning the ethical content of that experience, its impact on human society, as well as its aesthetic value. The internet has also promoted the emergence of new forms of collaboration which are novel both in terms of process and content. While there have always been concerns about the ability of small groups to manipulate public opinion and affect the political process, the centralisation of power, and associated control of technology, in the hands of a few giant companies that make up "Big Tech", gives greater concern. The speed and dissemination of misinformation through social media also raise ethical issues about the influence of malicious agents and the ability of society to respond to active attacks, e.g., [20].

The issues raised by both the development of AI and the rise of the Internet illustrate that those axiological concerns - questions of value in both the ethical (e.g., see [21]) and aesthetic domains (see, e.g., [22]) - play an important role in assessing the impact of computing technology in any context. The term "computer ethics" was first introduced by Maner [22] and has now become a part of the mainstream university computing curriculum, e.g., [23, 24]. As a subject area, it ranges across all aspects of applied ethical inquiry, such as the social implications of privacy, security and cybercrime, intellectual property, digital censorship and freedom of expression, and issues of sustainability, equity, and moral responsibility in the virtual world. Similarly, the relatively new field of computing aesthetics combines computer science and art theory to study the relationship between technology and aesthetics. It is concerned with the ways in which digital technologies and computational processes can be used to create and analyse aesthetic objects and experiences, such as digital art, video games, and interactive installations.

This brief (and clearly incomplete) review serves to establish that interesting and important philosophical questions arise in the domain of Computing, answers to which would inform and guide technical research in the subject.

It is important to note that the problems and issues described above are not primarily scientific or technical questions, in the sense that there is no application of the scientific or experimental method which would provide an answer to them. This is where the philosophical method, i.e., conceptual analysis and modelling, can be of significant service, particularly in clarification of the problem(s) that is (are) being faced and a framework for further exploration.

Computing, as a discipline, because of its development, stands astride three historical traditions, or characteristic modes of inquiry, namely the mathematical, the scientific and the engineering traditions, each of which contributes to the ways in which computing problems are understood and addressed [28]. Mathematics, as a field of study, is concerned with abstract concepts and logical reasoning, and involves the use of symbolic notation and technical language to describe and manipulate abstract objects such as numbers, as well as more complex patterns, and conceptual structures. It is not tied to the physical world, but rather provides a framework for understanding and describing it.

Mathematical concepts and theorems are not based on empirical observation or experimentation, but rather on logical reasoning and deductive proof, and the knowledge that is provided is not contingent on immediate context but rather upon the initial assumptions. Science, in contrast, is concerned with the explanation of physical phenomena based on empirical observation and inference. The scientific method involves making observations, formulating hypotheses, testing those hypotheses through experimentation or observation, and drawing conclusions based on the results. Unlike mathematical theorems, scientific explanations are contingent upon the empirical input into the theories, and are subject to revision and falsification based on new evidence. Engineering, as a discipline uses scientific and mathematical methods to design and construct solutions to real-world problems. However, it is not simply applied science [25, 26]. Unlike the logico-deductive model of mathematics, or the empirical-inferential model of science, engineering is characterised by a pragmatic instrumentalism based on contingent value judgements, and is subject to the physical and design-based specifications of the problem and the accompanying constraints. It produces solutions to problems which are recognised as "acceptable" in the context in which those problems arise. [27].

Computing, as has been said, stands astride these traditions of inquiry [28, 29]. From mathematics, it inherits ontologies and methods to deal with abstract notions, such as that of information and algorithmic process. However, it also draws, in part, on the scientific method used in the natural and cognitive sciences, and applied to the results of empirical investigation. From engineering, it is shaped by contextual, heuristic problem-solving under both technical and non-technical constraints. As we will see, there is a sense in which the methods of the philosophy of education in a discipline, follow from those in the philosophy of the discipline itself. Consequently, we should expect all of these approaches to be represented in a philosophy of computing education. Before we get to this topic, however, we first investigate what educational philosophy means in its general sense.

IV. The Philosophy of Education

Philosophical concepts abound in the educational sphere. For example, ideas about ontology necessarily underlie discussions about curricula, while epistemology lies at the heart of any appreciation of the learning process. Moreover, in recent years, the axiological notions of value and ethical judgement have been given prominent consideration within the educational community. In this section, we give a brief tour of some of the philosophical issues which occur in the educational context, and which will be of interest when we discuss the philosophy of computing education. We note that some philosophers of education, e.g. [30], refer to the existence of "two cultures" of educational research: Anglophone and Continental.

The Anglophone tradition in which the academic study of education within universities established itself in the context of teacher education. This is characterised by a robust, practice-based approach which makes use of disciplinary knowledge in history, psychology, cognitive theory. In contrast, the Continental European tradition, exemplified by the emergence of the subject in Germany ("*Erziehung*"), took, as its aim, the development of the virtuous person with rational autonomy. In Europe, education as a discipline established itself as an academic subject in its own right, with its own forms of inquiry that integrated theory and practice. In German this is known as the discipline of "*Pädagogik*", with similar words found in other languages, such as the Swedish "*pedagogik*". These two academic traditions give rise to different perspectives on the subject which is reflected in the types of philosophical questions that are emphasised.

It should also be noted that, because of the practical nature of much of the educational domain, the philosophy of education is not commonly approached by explicit reference to the intrinsic categories of philosophy mentioned earlier. Activities such as teaching, assessing, certifying competence, etc, are all connected to human interaction at a fundamental level and the many of the problems that arise require practical and, often, contextual solutions. As such, it is more common to see philosophical problems emerge from reflection on experience gained from within this practice. In addition, the irreducibly human element of teaching and learning means that, while epistemological problems are central to the subject area, axiological questions concerned with ethical and aesthetic values in the learning process, are also prominent. In this section, we give a short review of the philosophy of education and, following introductory texts such as Moore, [31], we look at some of the philosophical ideas that have informed and influenced general educational theory and then proceed to give a brief survey of issues concerning knowledge and the curriculum, teaching, the way that the concept of value emerges in the educational process, and the relationship of the education system with the rest of society.

According to Moore, the problems of the philosophy of education deal primarily with resolving real, substantial problems that arise from educational practices, with the main focus being on achieving conceptual clarity that can enhance theory and practice. This pursuit of clarity involves analysis of educational concepts as well as scrutiny of the various theories of education that have been proposed.

Philosophers of education are concerned with the investigation and evaluation of what is said about education by those who practise it, and by those who theorise about it. Education is seen as a complex and interrelated social phenomenon that occurs at a range of hierarchical levels. The lowest of these is the set of practical activities such as teaching, motivating, advising, etc. Those engaged in these activities, primarily teachers, use a specific vocabulary (e.g., terms like "learning", "knowledge," "skill") which themselves form the basis for higher-order activities, such as educational theorising, which is itself the initial stage of the development of educational theory. The theorising may make general, though empirically testable, claims about education practice, in which case, they can be evaluated by the methods of the social sciences. Alternatively, the theorising may focus more on providing normative advice and recommendations for those engaged in teaching. Sometimes these pedagogical theories will be narrowly focussed, especially when concerning specific disciplines (e.g., theories about how to teach programming in computing) but sometimes they will be of such scale as to aim to provide comprehensive prescriptions for the educational process.

General theories of educational practice often depend in a fundamental way on other broader philosophical approaches (e.g., pragmatism, constructivism, perennialism, essentialism) and hence constitute a theme in the philosophy of education. As Moore points out, these general theories are not theories about education (which would be the remit of the social sciences) but theories of what education ought to be or how education should be done. Such a normative theory, i.e., one that expresses how a thing should be, assumes that there is a desirable end, and in the case of education, this almost always relies upon some further general assumptions about human nature, which are themselves philosophical in nature. It is important, therefore, to distinguish between general theories of education that have been put forward by philosophers (e.g., Plato, Rousseau, Dewey, etc) and actual philosophies of education.

General theories of education tend to suggest that the educated person would be one who had acquired some kind of worthwhile competence. However, the use of the word "worthwhile" here clearly indicates some kind of axiological basis found in society, which uses the educational process to transmit these cultural values. The body of valuable knowledge and skills that is taught constitutes a curriculum, although one should distinguish between different aspects of curriculum, such as what is taught, how it is taught, why it is taught. The "what" can be thought of as part of the ontological basis of the curriculum, the "how" deals with epistemology (and methodology), and the "why" with axiology.

The social aspects of education also have an impact upon its philosophy. Education is not just an individualistic enterprise but contributes, in part, to the ordering human society. As Moore states, "*Education may be seen as one of the devices which society employs to preserve its present integrity and its future survival*" [31]. This social phenomenon is, of course, studied in a range of social science disciplines by sociologists, political commentators, as well as historians, and results in social theories about education. However, the characteristic feature of the philosophy of education is that it is concerned with normative theories; consequently, the social theories are often ideological in nature. Such theories may bring in notions of equality and democracy, freedom and authority. Such issues warrant extensive discussion and while fascinating, it is not our purpose here. Nevertheless, it should be appreciated that this "bottom-up" approach of identifying aspects of the educational process, and then focussing on specific questions which can be investigated using the philosophical method, is not in opposition to the "top-down" categorical framework, but is another way of framing the set of issues that can (and should) be addressed.

V. The Philosophy of Computing Education

In the preceding sections it was seen that the discipline of Computing, and that of Education, both give rise to a range of distinct, domain-centred areas of investigation that are expressions of more general questions about philosophical subject matter, and which can be usefully addressed using the methods of philosophical inquiry. Therefore, it is natural to ask, certainly for computing educators, whether there are specific theoretical and/or practical topics in computing education (taken in its broad sense) that give rise to questions that can be profitably addressed from a philosophical perspective. If so, what are they, and how can we use them to characterise the philosophy of computing education?

Note that, the question being addressed here is not simply whether there are any philosophical problems that should be addressed in the domain of computing education, with its attendant curricula, teaching methods and assessment processes. An examination of any published computing curricula, e.g., CC2020 [23], in the light of the philosophical categories of ontology, epistemology and axiology discussed earlier, reveals many such examples. An appreciation of ontology provides the conceptual foundations for knowledge representation which then provides a framework for identifying necessary and desirable elements of competence within the computing curriculum, as well as underpinning a description of the network of relationships between those competences. Similarly, an understanding of the distinctions between different types of problem-solving methodologies, e.g., computational thinking and how this differs from other types of heuristic approaches, have clear epistemological underpinnings. Moreover, ethical concerns about information security and data protection, as well as the practice of software development, are embedded in most computing courses.

The issue, therefore, is not simply to enumerate potential philosophical questions in computing education (as important as this may be), but to try to see if there is some characteristic feature of computing education which gives its philosophy a focus which is different from, say, the philosophy of engineering education. Mathematics (taken in its broadest sense to include applicable domains such as statistics), the natural sciences, as well as engineering and technology, could all point to similar questions about elements of their curricula, their characteristic methodologies, and concerns about ethical problems that flow from the practice of the subject, and which students would be required to understand as professionals in that area. The philosophy of computing education shares the majority of these concerns. What is it, therefore, that distinguishes a philosophy of computing education from that of other STEM disciplines? One approach to answering this question is to examine a similar process that has taken place in which engineering educators have tried to characterise the philosophy of engineering education and distinguish it from that of science education.

A. The Philosophy of Engineering Education

Looking at recent development of the philosophy of engineering education, e.g. [32 – 36], we see that a number of fundamental issues arise as the subject emerges. The first of these was the discrimination problem, i.e., whether there is a philosophy of engineering education that is distinct from a general philosophy of education, on the one hand, and more established philosophies of disciplinary education (such as the philosophy of science education or the philosophy of mathematics education) on the other. If this is so and the distinction can be clearly defined, then a second problem emerges, namely, to identify the characteristic questions and methods that arise within the subject area. Finally, there is the issue of what relevance the answers to the previous two questions have for the discipline itself, i.e., how a philosophy of engineering education would impact upon the engineering curriculum.

The discrimination problem for engineering education is dependent on the discrimination problem for the subject of engineering as a whole, in that, for there to be a distinct philosophy of engineering education, it is necessary to be able to discriminate engineering as a discipline from other STEM disciplines, primarily applied science. This is usually done by observing that the process of rational engagement with problems within engineering is different to that which takes place in modern science, which usually leads to a focus on the contingency of engineering knowledge and praxis [37] and its relation to design. Wulf [38] famously stated that "engineering is design under constraint." Dias [39] articulates this discrimination problem in terms of the establishment of engineering identity. Specifically, he claims that engineers are currently facing three "identity crises", each of which (from the perspective of this paper) can be viewed as an issue in one or more of the three intrinsic philosophical categories discussed earlier.

Firstly, there is the epistemological crisis of whether engineering knowledge is theoretical or practical. The second, ontological, question concerns the role with which engineering professionals identify - that of scientist, designer, or manager. The third, axiological, question relates to how the engineer interacts with the outside world through ethical issues and the aesthetics of design. All three crises have implications for engineering education, as different answers lead to different perspectives on what engineering is, and how it should be taught. Pawley [40] reports three different but common conceptions of the subject amongst a small group of engineering teachers - that of applied science, technological problem-solving and artefact-making. Frezza et al [FIE 2013] identifies purpose (goal) and manner (method) of knowledge application and generation as distinguishable characteristics that distinguish engineering from science and applied science.

Ontological questions about engineering are themselves reflected in epistemological ones: if engineering is just applied science, then this, presumably would mean that the appropriate methodology to use would be a variant of the scientific method. Yet, as pointed out by Goldman [37], "*Engineering is contingent, constrained by dictated value judgements and highly particular. Its problem solutions are context sensitive, pluralistic, subject to uncertainty, subject to change over time and action directed*." This suggests that a philosophy of engineering should be as much Pragmatic as Platonic, and, consequently, this should be reflected in its educational approaches and methods. Engineering and engineering education cannot be divorced from science and mathematics as both subjects provide a vast array of theoretical and practical tools with which to address problems within the engineering domain. However, they also cannot consistently be reduced to the application of science and mathematics. The subjects lie in different knowledge domains with different ontologies, methodologies, value systems, i.e., they have different underlying philosophies.

One example of this is the concept of bounded rationality [41,43] which has a significance in engineering that it does not have in science and mathematics. Developed as a counterpoint to rational choice theory [44], bounded rationality proposes that decision-making is limited by various factors that prevent individuals from making fully rational choices. It proposes that decision-makers are limited in their physical and cognitive resources and information processing capacity and so can only make decisions within those limitations. They often rely on heuristics, or simplified mental shortcuts, to quickly assess and make decisions based on incomplete information. The results of this, in an engineering context, can be a solution which is suboptimal but still workable, and hence satisfactory within the remit of the problem. This process of solving problems, subject to the solution meeting a minimum threshold of acceptability, is called "satisficing", and in the context of design, it can be seen as a pragmatic approach to decision-making that acknowledges the problem constraints that are often faced by designers.

It is worth saying, perhaps, that this view of the nature of engineering as primarily a design discipline, while common and increasingly popular in academic circles, has not gone completely unchallenged. The philosopher Mario Bunge [45], for example, proposed that engineering be understood as a specific kind of applied science, the latter being characterised by the application of scientific principles to the design of technology.

B. Towards a Philosophy of Computing Education

What implications does the previous discussion have for outlining a philosophy of computing education? We wish to take a dual approach here. On the one hand we do not wish to suggest that the subject area is independent of the problems and methodological concerns that computing education shares with its neighbouring STEM disciplines; this route would cut the subject off from the very problems and methods that it inherits from mathematics, the natural sciences and engineering. However, we do wish to argue that the philosophy of computing education, while overlapping with these subjects in many places, has a distinct core which distinguishes it from the philosophies of education in the other STEM disciplines, and so can be considered a subject in its own right.

Identifying topics within the field of disciplinary education that arise from, or are informed by, consideration of the philosophical categories of ontology, epistemology, and axiology is reasonably straightforward, and many follow from the requirement that professionals have some appreciation of the nuances of philosophical questions within the subject itself. We can identify ontological questions that arise concerning the foundational structures and processes of the subject, epistemological questions about the status of disciplinary knowledge and the appropriate methods which lead to its acquisition, and axiological questions about what is, or should be, valued in these disciplines. For Computing, its disciplinary philosophy will make its presence felt in its educational philosophy in the same way. For example, computing graduates need to understand the different perspectives on abstract information, and how this affects the application of the subject to real-world problems. Any high-level conceptual analysis of this topic, be it in the context of programming, distributed information systems, machine learning or information security, will lead to ideas about the process of abstraction, the essential nature of information and how it can be transformed from one medium to another. The use of conceptual models to elucidate structure and function in such discussions is unavoidable, as is the selection of appropriate representations.

If the unique subject matter of the philosophy of computing introduces philosophical elements to computing education, its inheritance and shared content with more established STEM disciplines also contributes to the range of problems under philosophical examination. So, for example, if we consider the computing subdiscipline of software engineering, it shares many of the epistemological and methodological concerns of physical engineering. Software systems often operate in uncertain and evolving environments, where requirements can change, and new information can emerge over time. Uncertainty and incompleteness make it difficult to achieve a complete understanding of a system, leading to potential gaps in knowledge and hence in design. Such systems may exhibit emergent behaviour, making them difficult to fully understand and raising questions about the limits to which a formal specification can be made. Software development often involves choices between different design approaches, which have sets of requirements which cannot all be optimised simultaneously, with the consequent need to understand concepts such as satisficing. Different stakeholders may have different interpretations of system requirements or priorities, leading to varied and contradictory interpretations of the requirements. Software development, as a professional process, relies not only on explicit, codified knowledge but also on implicit and tacit knowledge, which is difficult to articulate or transfer to others. The expertise and intuition of experienced software engineers play a crucial role in capturing and transferring this knowledge. Clearly, many epistemological and methodological questions arise, but it would be possible to replace the phrase "software system" with "physical engineering system" and the text would be equally correct. The philosophical considerations that apply to teaching physical engineering (often) therefore apply, with appropriate changes, to the teaching of software engineering.

Similarly, a comparison between the ethical issues faced, say, by artificial intelligence researchers [46] and those engaged in the natural sciences [47] reveals that both share a range of similar concerns about research accountability and transparency, e.g., the black-box nature of some machine learning algorithms can make it difficult to understand and explain how the outputs of experiments are causally connected to given inputs. In their study of the ethics in scientific research, Weinbaum et al. [48] identified ten ethical principles which they grouped into three categories - ethical scientific inquiry, ethical conduct and behaviour of researchers, and ethical treatment of research participants - that would be normative in scientific research. While the third category would not generally be applicable in AI research, the first two are clearly important and this provides yet another example of shared philosophical concerns among educational research in STEM subjects.

Turning to questions and issues that arise from the philosophy of education, we see that almost all of the issues discussed in the general educational setting can be translated to the specific domain of computing education. These include questions of ontology, of epistemology and methodology, of ethics and the nature of aesthetic value in the subject area. Following the approach taken in engineering, a philosophy of computing education should follow the distinctiveness of computing as a discipline. With one foot in the engineering domain, all the issues about designing under the constraints of bounded rationality and the need for an understanding of satisficing apply to software engineers, just as much as to, say, mechanical or civil engineers.

Finally, we would argue that what distinguishes computing from its neighbouring STEM disciplines is its focus on abstract information: its representation, its manipulation and its application to real-world. This lends a specific nuance to any philosophical discussion which is not found in other disciplines and which should inform the practice of the philosophy of computing education as well as its expression within the computing curriculum. This is a significant issue, and much more could be said about it. For now, we simply suggest, for example, that the low-cost reproducibility of abstract information has profound implications for the ethical and aesthetic basis of the subject.

C. The Relationship with Computing Education Research

One question that may be asked concerns the relationship between the philosophy of computing education and "Computing Education Research" (CER), e.g. [49 – 53]. We take CER to be an inclusive term which encompasses the rigorous study of computing education from a number of perspectives. These would include the philosophy of education, as well as the empirical study of educational topics in computing, through the methods of the natural, cognitive, and social sciences.

VI. Conclusion

We have argued in this paper that the philosophy of computing education is a subject which is of substantial importance to computing education. It provides robust methods for conceptual analysis of the key concepts in the subject domain and serves to identify and clarify problems that lie at the heart of the discipline. We are left, therefore, with the question of why the term "philosophy of computing education" does not appear more commonly in the wider computing education research literature. Part of the answer may lie in the reticence of engineers generally, and those computing educators attracted to the engineering and design perspective of the subject, to engage in philosophical speculation on the nature of the discipline. It was only in the last quarter century that the philosophy of engineering education has developed into a subject of specific attention and engineering as a discipline has had a much longer history than computing. The philosophical challenges to defining an engineering identity continue to support formulations of engineering identity that connect engineering practice and education (see [27,41,54,55]).

Computing, as a subject, has only emerged from its STEM precursors in the last seventy years, and is only just coming to the point at which existing characterisations of the academic discipline, and that found in the profession, are being questioned. (Comparatively) Recent developments that make the discipline a ubiquitous feature of modern life, such as the widespread use of microprocessors and the software that makes use of them, the development of the massive networks such as the Internet, and current advances in AI, have changed the perception of the subject. It is no longer possible to see Computing purely as a subdiscipline of mathematics, or electrical engineering. This inevitably leads to challenging questions about the foundation of the subject, what characterises its practice (and its practitioners) and how the knowledge, skills and values that form the subject may be transmitted to a new generation of computing professionals. A coherent philosophy of computing education would have much to say about these issues. Moreover, it is clearly the case that Computing, as a subject, is not currently bereft of work being done in the philosophy of computing education field. It hides in plain sight in much of the rigorous work that is currently done under the term "theory" in Computing Education Research. The methodological analyses of Tedre et al. found in, say, [49], and the attempts to clearly justify the basis of the curricular components described in the CC2020 documents [23], and the pervasive appearance of ethics as part of the standard university curriculum all testify to the existence of a robust interest in the philosophical issues that underlie much of the technical work done in computing education.

When trying to articulate why the philosophy of engineering, and by extension, a philosophy of engineering education, was important, Heywood (in [33]) quoted Bechara and Van de Ven [56] on the importance of a philosophy of science:

"*Many of us are practitioners – not philosophers – of science. We don't think much about ontology and epistemology so that we can get on with the craft of doing research instead of talking about it. But underlying any form of research is a philosophy of science that informs us of the nature of the phenomenon examined (ontology) and methods for understanding it (epistemology). Whether explicit or implicit, we rely on a philosophy of science to interpret the meanings, logical relations, and consequences of our observational and theoretical statements*".

The same is true for computing educators. A strong philosophical basis for our subject would promote conceptual clarity and allow the fundamental presuppositions of the discipline to be examined, and compared with other STEM counterparts. This process has proved useful for the engineering community and it would be expected that similar benefits would accrue in the case of computing professionals.

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