Sense-Making Frameworks in Computing and Engineering Education

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***Abstract*— This full paper addresses the concept of meta-narrative in computing and engineering education: the presence of an overarching meta-narrative which provides a sense of integration and some degree of connection and coherence to the elements under study. This meta-narrative should firstly provide a mechanism for discussing the fundamental entities under consideration, as well as the relationships between these and other, derived, concepts. Secondly, it should indicate what counts as valid knowledge, as well as legitimate ways of arriving at such knowledge. Thirdly, it should indicate how and where the concept of value arises in the content and practice of the subject. The meta-narrative should therefore provide a vehicle which encompasses the subject ontology, its epistemology and methodology, and its axiology (i.e., its ethics and aesthetics). In other words, the meta-narrative should provide a philosophy of that subject.**

Keywords—philosophy of computing education, philosophy of engineering education, theory, metatheory, model, framework

I. Introduction

The role of narrative within any human activity is an important and fundamental one. Human beings use narratives to try to articulate who they are, where they come from, and what they hold to be important. As such, they provide a vital mechanism by which people communicate how they perceive themselves and their relationship to the world. A narrative, therefore, is an attempt to draw out or impose some form of meaning on the experience of phenomena, and so make sense of that experience. Narratives are also used within subject areas for much the same reason: to explain how the subject has arisen, how it is constituted, what is important and how practitioners operate. In engineering and computing, these narratives and the values they enshrine inform subjects that are themselves constantly changing, and consequently dependent on a changing narrative.

A strong, overarching description of a subject which tries to make sense of, and integrate, disparate phenomena within a discipline, and provide connection and coherence to the elements under study, can therefore be seen as one of the defining characteristics of that subject area. Such articulations may take a number of different forms, depending upon the subject area, but the underlying structure can best be construed as some kind of narrative about the important elements of the discipline. Such large-scale narratives can be called "sense-making frameworks" as they provide a way for the community of study and practice make sense of the subject.

Such narratives are not necessarily required to be articulated as a linear expression of ideas. They can, for example, also be expressed implicitly in terms of a set of important problems, such as in Mathematics, with the Hilbert problems at the start of the 20th century, or Millennium Prize problems at the end, which served to guide the development of the subject [1]. A similar process can be seen with the Grand Challenges in Global Health in medicine and the health sciences [2]. They can also be carefully considered statements of important ideas such as the Great Principles of Computing, or perhaps, more prosaically, can be described in terms of a prescription for research programmes to be undertaken within the discipline [3]. It is also rare for grand unified theories to exist uncontested within any subject, and so competing or contrasting narrative elements tend to develop within any disciplinary area. In attempting to describe a comprehensive narrative for a subject, therefore, it is necessary to study different aspects so as to try to integrate them within an overarching framework that provides some degree of coherence and meaning to the phenomena under investigation.

Such a meta-narrative should, first of all, provide a mechanism for discussing the fundamental entities under consideration, as well as the relationships between these and other derived or secondary concepts. Secondly, it should give some indication about what counts as valid knowledge, as well as legitimate ways of arriving at that knowledge. Thirdly, it should indicate how and where the concept of value arises in the content and practice of the subject. The meta-narrative should therefore provide a vehicle which encompasses the subject ontology, its epistemology and methodology, and its axiology (i.e., its ethics and aesthetics). In other words, the meta-narrative should provide a philosophy of that subject.

In this paper, we describe a number of sense-making frameworks which have been applied in an educational context. We consider the relationship between concepts such as *theory* and *metatheory*, as they are used in some STEM-education fields. The concept of theory, which is the most prevalent structure in computing education, requires some explanatory substructure within a discipline, and so we introduce the sense-making framework, outlined by Sfard [4], which situates theory within a wider set of scholarly activities such as 'research" and 'discourse". We then proceed to elaborate how theory has been used within the computing education community before briefly discussing the concept of metatheory, which is used to frame and organise theories in science education. We describe the main categories that would constitute a philosophy of computing education and discuss how this could be useful in addressing some of the challenges that educators will face in the future.

II. SENSE-MAKING FRAMEWORKS

The idea of a sense-making narrative is central to the development of any academic or vocational subject. After all, making sense of the phenomena that fall under the purview of some discipline is a precondition for any ongoing scholarly activity in that area.

It should, however, be mentioned at the outset that the word "sense" here is not being used as Fregean technical terminology. Frege introduced the notion of "sense" (*sinn*) to capture the cognitive content of linguistic expressions, i.e. the way in which we understand the meaning of words or phrases. In his work, the sense of an expression refers to the mental concept or idea that it evokes in the mind of the speaker or listener, and so is not tied to any particular referent or object in the world. This was contrasted with "meaning", or "reference" (*bedeutung*) which refers to the actual object or entity in the world to which a linguistic expression refers. This is a common starting point within philosophical discussions of language and the mind. However, the use of the word "sense" and "sense-making" in this paper draws more specifically on the work of the organisational theorist, Karl E. Weick. Weick described the act of sense-making as a process by which individuals and groups frame or structure the complexity of the world which is replete with ambiguous and mysterious phenomena and experiences. Sense-making, in this context, is seen to be an emergent process involving the articulation of plausible narratives about the world, that may be tested for internal and external consistency, and which ultimately allows for greater agency.

Nevertheless, a narrative, even if combined with others into a meta-narrative, does not, on its own, provide a complete description of the sense-making process. Making sense of complex phenomena involves theorising, conceptual and empirical investigation, evaluation, and interpretation of results, and so forth. Given that one often needs to decide between different interpretations of ambiguous, complex phenomena, an important function is to explain the basis for such determinations, especially in situations where no explicit appeal can be made based on empirical evidence. In such circumstances, it is often the case that decisions are derived from value concepts taken from the community of practitioners. Such inquiry inevitably leads to the analysis of normative aspects that arise within professions and hence to a consideration of axiology and the axiological underpinning of the subject and those who study it.

A. The Role of Axiology in Sense-Making

Before investigating the idea of sense-making frameworks in detail, it is worth considering this appeal to values and from whence they are derived. In the short description of a disciplinary philosophy given in the Introduction, it was stated that a disciplinary philosophy consists of the study of the objects (whether physical or conceptual) under consideration within that discipline, the nature of valid disciplinary knowledge about those objects and the legitimate ways in which such knowledge can be derived, and the values that arise out of the study of those objects. This general characterisation of a philosophy of a subject is clearly a simplification of a more sophisticated conceptualisation of how philosophical inquiry applies within a disciplinary context. Nevertheless, even at this level, questions arise about why we include axiology – the study of how value arises and is practised – as a fundamental, intrinsic element of the philosophical account of a subject, rather than, say, just focusing on its ontological and epistemological/ methodological elements. It is not entirely clear, at first glance at least, that that the notion of value should play a central role in any systematic understanding of mathematics or physics. Indeed, one of the outcomes of Early Modern and Enlightenment philosophy was the emergence of a belief that normative or prescriptive statements are qualitatively different from descriptive statements. Consequently, propositions about values, such as those found in ethical or aesthetic judgements, cannot be inferred from facts about physical systems. The question of how, and why considerations of values emerge is discussed in section V.

B. Theory and its Impact in Engineering and Comptuing

Historically, engineering was not always a theory-laden practice, but shifts among educators in the 20th Century led to major shift in role of theory in engineering education and practice [5][6]. Such shifts in narrative were already well established when the computing disciplines grew out of engineering and mathematics in the mid-20th Century [7].

Especially considering its roots in mathematics, where theory is a dominant value, it is no surprise that in computing education, the predominant, explicit, sense-making framework has been that of "Theory" [8] [9] [10] [11] [12], and this has resulted in transformation of the subject literature from descriptive, exploratory, experience reports (so-called "Marco Polo" studies [13]) to the current point where the expectation among the community of inquiry is that work should engage with, and appropriate and extend, relevant theories from the mathematical, cognitive and social sciences [14]. In this paper, we consider the current understanding of "theory" as a sense-making framework by situating it within the narrative framework explored by the educational theorist, Anna Sfard.

C. Research, Discourse and Theory

Sfard [4] proposes a model of scholarly inquiry in mathematics education in which the concept of "theory" is related to a number of similar and prior ideas such as "research" and "discourse". According to Sfard, at its heart, research is a kind of narration or storytelling activity. Where this occurs, the activity of telling stories about some aspect of reality may mediate and improve the human activities around which the stories evolve, and so be useful to those engaged in those activities.

Clearly, not all stories constitute research; what distinguishes research stories from other kinds of narratives is the type of discourse that is used. Discourse, in this context, is a special kind of communication which can be characterised with reference to four dimensions. The first of these is the *language used* in the narrative, the so-called keywords, which form the technical vocabulary of the narrative. Secondly, there are the *data or objects under discussion* (what Sfard calls "visual mediators"). Thirdly, there is a set of *characteristic routines*, or patterns of action that appear when people participate in the discourse. These three elements give rise to the fourth defining feature of the discourse, a set of *endorsed narratives* about the subject under investigation.

Different kinds of activity generate different kinds of discourse, but when considering scholarly activity such as scientific (in the broad sense of the word) inquiry, if these narratives have a substantive degree of coherence and utility, what Sfard calls a "tight interrelatedness", then they form a theory. Once established, a theory can be extended by absorbing new narratives constructed either by logical derivation from previously endorsed narratives, or by incorporating new narratives based on subsequent observations of important phenomena.

The key property is that of overall internal consistency, i.e. there must be no pair of narratives within the theory that would mutually exclude each other's endorsability, according to the standards of the research community. Formally, this is an instrumental approach to theory building rather than a correspondence approach, i.e. it says nothing about whether there is a reality to which the theory corresponds, only that the theory is internally consistent. Of course, further empirical investigation should lead to greater correspondence with reality as well if the community considers this an impor6ant aspect of the story

One reason that Sfard situates the development of theory as an aspect of discourse rather than as a primary focus of research, is that this provides an explanation of how conflicting theories can be understood within a wider research programme. If two discourses differ in their vocabulary or in the rules by which legitimate narratives engage the community, then they will be incommensurable. Consequently, theories that emerge from such discourses may appear to be contradictory. What mechanisms are there for deciding between such theories? Sfard suggests a pragmatic approach based on the criterion of contextual usefulness. [4] An example of this approach can been seen in the a recent reframing of the definition of competency, wherein a disagreement among researchers was addressed by reframing the definitions along pragmatic lines [15].

III. The Use of Theory in Computing and Engineering Education Research

Arguably, the most important sense-making framework currently in use within the computing and engineering education research community is that of "theory". While this is a general technical expression found ubiquitously within the sciences and beyond, its use as a general sense-making term within computing has only emerged over the past two decades.

A. Theory in Computing and Engineering Education

An early review of the concept in the field of Information Systems by Gregor [16], drawing heavily on Popper's definition of theory in the context of the natural sciences, proposes that theory has four primary goals: analysis and description, explanation, prediction, and prescription (a sub-class of prediction). These, in combination, give rise to a taxonomy of five theory types:

- *Analysis*: This type of theory is either purely descriptive, or else, analyses conceptual basis of terms, but without seeking to explain causal phenomena or make predictions.
- *Explanation*: This provides some degree of explanation, but without making predictions subject to empirical testing.
- *Prediction*: This type of theory makes testable predictions but does not have a well-developed causal theory for the phenomena.
- *Explanation and prediction*: These theories provide testable predictions which are accompanied by justificatory causal explanations.
- *Design and action*: These types of theory give explicit, operational prescriptions for carrying out some experimental procedure or to produce some artefact.

Theory, in this sense, is a multivalent concept and so can be used to express descriptive, analytic, causal and predictive regularity within the investigation of some set of phenomena, all of which then act to integrate the elements of that phenomena within a wider explanatory context.

This classification of theory types has been taken up, with some revision of terminology and further elaboration, by Nelson and Ko in [17]. They made use of a dual classification scheme which distinguishes between descriptive theories, which simply describe phenomena, and operational theories, which allows for measurement and prediction. A similar conceptual analysis is performed by Szabo et al. [18] who developed a definition of theory "as a generalisation, abstraction, explanation or prediction of a phenomenon, where the phenomenon under study is learning."

B. Theory as a Structure for Explanation

The concept of theory has been extensively developed in an influential series of papers by Malmi and co-workers [5-9]. Theory is defined in this work to mean "a broad class of concepts that aim to provide a structure for conceptual explanations or established practice" [8] Terms such as 'theories', 'models', and 'frameworks' are then defined as "particular manifestations" of this general construct. This is a broad definition which allows application to a wide variety of contexts. Examples of theory include general approaches to educational knowledge-building such as constructivism, approaches to instructional design such as cognitive load theory, hierarchical descriptive frameworks for learning outcomes such as Bloom's taxonomy, as well as particular empirical and mixed methodologies in research such as the use of grounded theories, or phenomenographical outcome spaces [5,15].

The word "theory", from this definition, appears to be an abstract placeholder for any specific instance of a number of concrete theories under consideration. Two pieces of work on the same subject may use different or even incompatible explanatory theories, but they would still both be using "theory" in that sense. Similarly, two instances of theory which concerns objects or relations in the natural world, for example, could be compared using a third which relates objects which are abstract theories. It may be argued, however, that a theory about natural phenomena is qualitatively different from a theory about the relationship between abstract entities such as theories. For example, the former may well be amenable to empirical testing whereas this may extremely difficult or impossible. In the latter case. Even where, as in the case with many learning theories, the objects under consideration are themselves abstract concepts (such as motivation or proficiency or skill), consideration of theories based on these abstract notions seems to require some degree of empirical grounding. [12][19]

Since, in one sense, this is similar to the situation where a new analysis is performed using previously generated analyses, i.e. a meta-analysis (although this would depend on how the previous analyses were combined, i.e. whether this was done through aggregation of the original sets of data or simply the results), it would be sensible, in this context, to call a theory about theories, a metatheory. This appeal to a metatheory when discussing a "theory of theories" is done by

Tedre and Pajunen [20] who note that it should lead to a richer discussion of the notion of theory, although one that is not yet developed within the computing education subject area. Instead, in order to see what this may look like, we can turn to one example of metatheory in a neighbouring discipline, that of science education.

C. *Examples of Metatheory in Science Education*

If one considers the Natural Sciences, there is a historical, scholarly tradition of not only analysing natural phenomena, but analysing the methods by which natural phenomena are analysed within the discipline and what has become known as the philosophy of science is a well-developed and productive research area. Similarly, the application of forms of analysis to science education is also a productive area of investigation. Sense-making concepts such as theory, paradigm, and model play important roles in framing work conducted in science education, drawing together connections between the natural sciences and the educational and cognitive sciences. The concept of theory, in particular, is well-developed in this context. For comparison therefore, we consider a sense-making framework which has not been considered within computing education, that of metatheory.

Metatheory, i.e. an overarching framework for thinking about (psychological or educational) theories, in this case, science education, have been discussed by Schulz [21]. Drawing on psychological research, the term metatheory [22] denotes a worldview that provides meaning within a “big picture” of a subject, offering an encompassing framework under which multiple theories of development or learning are classified together based on what can be described as a shared view of human nature. In some sense, therefore, metatheory in science education is similar to "theory", as described by computing educators, in that it provides a contextual environment for considering multiple theories.

A metatheory “seeks to formulate a coherent account of, and prescriptions for, a given range of phenomena within its specified conceptual framework; it has pre-established criteria for empirical interpretation and judgments, and it directs research efforts along given lines within scientific or scholarly communities” [21]. Aldridge et al. suggested that there were four psychological meta-theories which have been applied to education, each of which presented a different view of the subject based on, or inspired by, an underlying social or scientific metaphor. These were the biological or organismic view, the mechanistic view, the dialectic view, and the contextual view.

The biological or organismic view, often associated with Piaget and fellow constructivists, sees educational and psychological development occurring through a sequence of discontinuous stages. This was augmented by others, e.g. Reese and Overton [23], who suggested that the emphasis should be on seeing development in holistic, or at least integrated, terms. They contrast this with the reductive, mechanistic model which derived primarily from the work of Galton and behaviourist psychologists such as Skinner. The mechanistic approach sees the process of learning in terms of inputs and outputs, where the inputs are provided by external factors such as the learning environment and teacher, and outputs are demonstrated in terms of modified behaviour.

As expected, the primary metaphor for this type of metatheory is the concept of a mechanism, which could be physical such as that provided by flow through hydraulic pipes but could also be computational or electronic, based on computers. The dialectic metatheory draws inspiration from the theories of Marx, Hegel, and Soviet theorists such as Vygotsky, and focuses on contradictions and conflict in the individual's dynamic interaction with the learning environment. These are taken to be primary determinants of development.

Finally, the contextual metatheory is derived from pragmatic philosophers such as Pierce, James, and Dewey, and based on the idea that human activity does not develop in a social vacuum but is rigorously situated within a sociohistorical and cultural milieu. To these four meta-theories describing psychological development, Aldridge et al., and Schulz both add what they see as a specifically educational cognitive-cultural metatheory: a metatheory which looks specifically at educational, rather than psychological development and draws on the work of Kieran Egan in educational theory and cognitive psychology [21][22].

D. *Metatheory and its Role in Sense-Making*

A metatheory, therefore, can be viewed as providing a lens through which the body of professional practitioners, or community of practice, understands the scope of the subject. It provides meaning and conceptual order for the ontological basis of the subject by giving value to certain methodological prescriptions about what constitutes knowledge and what methods would be appropriate to arrive at it.

We have provided a brief exposition of some of the forms of sense-making employed within mathematics, computing, and science education. The intention here was not to give a comprehensive account of these ideas but to illustrate a variety of approaches that have been taken, or have emerged historically within the sense-making processes in various STEM subjects.

Whatever the arguments for or against a specific metatheory, it seems clear that the analysis of the arguments themselves is not simply based on empirical data but upon reasoning about the kind of things that are under study, the way that knowledge about them is accessed and the values that are important when considering science education, i.e. on the philosophical categories of ontology, epistemology, and axiology. Consequently, the analysis of such metatheories themselves warrant a framework or structure to help ensure their consistent application and understanding.

IV. Philosophical Inquiry and Engineering and Computing Education

Having considered some of the main sense-making frameworks informing engineering and computing education, we seek to apply the categorical structure and methodology of philosophical inquiry as a unifying approach to the general process of sense-making within these fields. It should of course be noted that, within the English language at least, the word philosophy can be used in an informal sense to denote some kind of strong and integrative personal opinion about something (e.g. my "philosophy" of how to deal with too much work) or some kind personal, general approach which motivates and informs a set of actions (e.g. my "philosophy" of teaching). While there is some link between this colloquial usage and the formal process of philosophical inquiry, it is not the meaning that we will take in the rest of the paper.

Philosophy, as has been often noted, is a notoriously difficult subject to define. We can, nevertheless, still identify characteristic topics and develop categories that distinguish the main areas of study by looking at the topics which philosophers have traditionally investigated (see, for example, Russell [24]; Heidegger [25]; Putnam [26]). In the following section, we give a very brief characterisation of the subject before looking to see if this can be used to gain insight into issues in computing and engineering education.

A. What is Philosophical Inquiry

Philosophy as a subject is generally held to encompass such subject areas as metaphysics, epistemology, methodology, aesthetics, ethics, logic, as well as other specialisms such as the philosophy of mind or the philosophy of religion. If we wish to articulate a general description of the subject area, we could say very broadly that the subject of philosophy is concerned with the study of the nature of reality (metaphysics or ontology), the nature of knowledge (epistemology, but also valid ways of arriving at knowledge such as methodology and logic) and the nature of value (axiology, which includes aesthetics and ethics). While this is not a perfect summary of the subject, it useful in describing what constitutes a philosophy of an applied domain.

From a methodological perspective, a characteristic feature of philosophical inquiry, since at least the time of Socrates, is a focus on making distinctions, and analysing the differences and similarities between the categories that are so distinguished; an approach that has been applied to the subject matter of philosophy itself. This gives us a set of categories into which philosophical problems fall and which can be seen as branches of the subject. Philosophers, being philosophers, do not necessarily agree on the specifics of the classification. There is disagreement about whether philosophy is a deflationary field, i.e. the subject is too diverse to admit one definition and so it is simply the name given to collection of problems that are studied, e.g. Rorty [27], or Derrida [28], or whether the subject has some essential, foundational unity (e.g. Aristotle [29], Kant [30], Copleston [31]), or indeed, whether there is some Wittgensteinian family resemblance between the problems that give rise to the subject. Nevertheless, even if only as a descriptive classification, we can identify characteristic classes of problems which include subfields such as metaphysics, epistemology, ethics, etc, which, in turn, have their own sub-disciplines such as the philosophy of mind, or the philosophy of religion, or political theory.

A useful distinction that can be made is between intrinsic categories of philosophical inquiry 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, often from close to its inception, and which still provide much of the content of the subject. This is a useful distinction, and for the purpose of this paper, we divide the subject matter of philosophical inquiry into three broad areas, which we then use as ordering principles for philosophical problems in application domains.

The first such category is *Metaphysics*. Much like philosophy itself, the conceptual boundaries of metaphysics are hard to delineate [32]. As a subject area, 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. We can say that it is the study of what is, or what exists. For this reason, it is sometimes called "Ontology", i.e. the study of what objects and relationships can be recognised as fundamental (or at least important) in the subject area and how the non-fundamental or composite objects depend upon them. This is not to diminish the importance of those subdisciplines in metaphysics which do not fall under the aegis of ontology but just to recognise that the ultimate goal of this paper is to discuss philosophical enquiry applied to computing education. In that context, the focus on ontology is a useful one.

The second intrinsic 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 is the relationship 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 enquiry that supports the practice of almost all other fields of study. In the context of an introductory paper such as this, we use the term to include what methods of knowledge acquisition are accepted as relevant within a particular application domain. This means that it also includes other philosophical subdisciplines that would normally be counted as separate from epistemology, such as methodology, i.e. what approaches to enquiry are counted as legitimate within the application domain, and logic, i.e. the systematic study or reasoning and the methods for evaluating the validity and soundness of arguments.

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. This category investigates what values are discussed and prioritised in application areas as well as basic questions about the ascription of 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.

B. The Philosophical Method

Rather than take a structural view of philosophy, we can also, approach the subject through its methodology by asking the functional question of what philosophers do when they "do philosophy". However, providing a complete description of that method has proved challenging. Nevertheless, central to the approach is the process of conceptual analysis. This seeks to define and clarify the meanings of particular terms and concepts used in any discussion and typically involves the use of techniques such as critical reasoning, analysis, and logical argumentation, to examine and evaluate such problems in the light of other philosophical concepts and theories. Conceptual analysis (e.g. Coombs and Daniels, [33]) seeks to systematically decompose the concepts being studied into their fundamental logical constituents, determining conditions for their validity and domains of application.

One way of understanding this approach is to see the analytic approach as consisting of three components: conceptual interpretation, which attempts to provide an adequate account of a concept in ordinary language, conceptual development, which determines whether the description of the concept is suitable, and conceptual structure assessment, which determines the adequacy of conceptual structures to frame further inquiry. Alternatively, one could look at the range of perspectives that are used when framing the investigative process [34].

One example of this would be the analytical perspective which tries to investigate the logical structure of the question. Another would be the ampliative perspective which deals with the assumptions and norms that are inherent in the question form. Yet another would be the phenomenological perspective which tries to understand the subject's intentional, first-person experience of the phenomenon under question. Additional perspectives might include the hermeneutic, normative, critical, or evaluative perspectives. This is not an exhaustive list but it serves to illustrate the range of different viewpoints that can be taken when considering conceptual questions. It is important to state that, in essence, this is not an empirical methodology. While observational data may have some bearing of the way in which the concept is decomposed and modelled, it does not rely on data collection and analysis, but this does not mean that the method fails.

Gregor, building on the work of Godfrey-Smith [35] in the philosophy of science, identified four types of questions about bodies of knowledge that arise in research. The first she called "domain questions", i.e. what phenomena are of interest, what are the core problems and how does the delineate the boundaries of the subject area. The second type of question are "structural questions" which seek to examine how the sense-making structures of the subject are understood within the discipline. The third type are "epistemological questions" which seek to determine how knowledge is acquired, what methodology is legitimate and how theories can be constructed and tested. Finally, there are "socio-political questions" which concern how disciplinary knowledge is understood by stakeholders, how knowledge is applied and what the social, political, and ethical issues are with regard to its use. Each type of question can be reformulated in terms of engagement with one or more philosophical categories. Domain and structural questions seek mostly metaphysical/ontological answers, while clearly epistemological questions fall under the remit of epistemology (including methodology). Socio-political questions are questions about value and are therefore axiological in nature. This framing of questions provides for a philosophical approach to developing and evaluating sense-making frameworks.

V. Discussion and Application

The difficulties of sense-making frameworks, particularly in areas of rapid change suggest the strength of a philosophically-framed approach. Consequently, the philosophy of engineering and computing education is important as it provides a good framing structure for discussing high-level questions about meaning. This is often most easily seen through the effects when we operate from partial frameworks, e.g., the application of a framework that lacks one (or more) of the three components from philosophical inquiry: ontology (metaphysics), knowledge (epistemology), or values (axiology).

Consider theory as a partial sense-making framework in engineering and computing education. In a subject area (e.g., computing); criteria that is valuable is empirical, connected to reality. Hence meaning is often centered on the quality of generalizability or replicability; criteria applied to help ensure that the theory agrees with reality. This is quite different in education, where there is little consensus (e.g., constructivist vs behaviorist, etc.). In a physical theory, there are well defined criteria; in education, these criteria are embodied in the values of those deciding. The two competing 'values' of theory can easily confuse the application of sense-making: In one case, the quantitative, the numeric, the statistical is valued; in the other, the qualitative, the impact on varied or diverse individuals.

In a sense making framework, it can be the observer who is making the meaning; in a community that values theory, generalizable theory is the ultimate value of the experience, of the proposal in our research domains. However, in an educational system, values matter. Values are needed for aesthetics - what are ideas of elegance or beauty, as well as ethics, what is right or proper within the subject. And one does not acquire these values simply from an examination of the things or facts of the matter, nor are they uniquely constructed by the individual.

We cannot divorce values from facts, knowledge and seeking knowledge because we undertake the process of learning as embodied individuals, in a social context, from which priorities which are encoded as values automatically emerge. The point is that there is a necessary relationship between sense-making and the development of meaning making. Take for example a value common to engineering and computing: The framing of correctness with respect to context, e.g., that some values like "attention to detail" are contextual: This is an attitude valued for its contextual-correctness. At times, attention to the most fine detail is needed; at others, it is counter-productive [36][37]. Hence from a engineering and computing *professional* perspective, competence in the contextual correctness of *when* to be attentive to detail, and when not to be.

The following subsections present examples of how a philosophical approach to sense making frameworks can enhance engineering and computing education.

A. Framing the Definition of Engineering and Computing

When considering the educational goals supporting entry to and advancement within a profession, it is important to define what in fact is meant by that profession. Applying a philosophical inquiry approach would necessitate considering the three philosophical aspects: an ontological view: What is engineering or what is computing as a profession; Similarly framed is the nature of what needs to be known in engineering and computing, e.g., epistemological questions: How is engineering or computing made known? An axiomatic approach would consider what is valued both ethically and aesthetically. For example, Frezza et al present a knowledge-based (epistemological) framing of engineering [38] and computing [39], applying a pragmatic framework consistent with Sfard [4]. Their observations are that despite the valuation of theory consistent with science and mathematics, engineering and computing knowledge is distinctive. Consistent with studies of engineers in practice (e.g., Trevelyan [40][41]) from their philosophical approach to sense-making they conclude "*the best engineering answer(s) are judged pragmatically, and routinely involve social context (e.g. a company, a customer).*" An aspect of engineering formation they note is not universally recognized in accreditation standards or undergraduate engineering programs.

B. Reframing Competency to Enhance Engineering and Computing Education

Another impactful example has been the championing within the Computing Education community a move from knowledge-based educational approaches to competency-based approaches [42]. Enshrined in the recent *Computing Curricula 2020* document [43], the CC2020 committee aimed to better integrate professional needs of graduates (e.g., one of the goals of professional education). Following the values of computing education, their team began with a theoretically-framed approach. Frezza et al strove to define competency in a pragmatic manner suitable for engineering and computing [15]. Their theoretical examination began with a depressing assertion:

> *"There is such confusion and debate concerning the concept of "competence" that it is impossible to identify or impute a coherent theory or to arrive at a definition capable of accommodating and reconciling all the different ways that the term is used*." ([15] quoting [44]).

This difficulty in defining competency in a pragmatic manner suitable for engineering and computing education warranted a pragmatic sense-making approach leveraging philosophical inquiry. The research team, following a structured sense-making approach, began with theorising, follows by conceptual and empirical investigation, and concluded with evaluation and interpretation of results. Here they focused on identifying the consistent dimensions of competency from the literature that were both consistent and would support addressing the need to better integrate professional formation for students. Following a careful examination of multiple theoretical frameworks for competency, they conclude with a synthesis of approaches:

> *"We view competencies as personal qualities causally related to demonstrated proficiency or accomplishments in an area of work, civic engagement, and social participation. Competencies tell how good one is in a particular line of work, whether on a job, in a profession… Competency integrates knowledge, skills, and dispositions and is context -situated. These integral components of competency manifest in observable and tangible form within a work context."* [15]

This competency model became the foundation for CC2020, extending the community-valued lens for computing education from knowledge and skill to knowledge, skills, and dispositions that is context -situated. Identifying affective-domain learning as a key missing component (see Clear et al [45][42]) applicable to both engineering and computing education.

C. Framing AI Tool Use in Engineering and Computing Education

As another example, we consider the advent of ubiquitous access to large scale AI tools that is emerging as one of the most challenging issues in the field. Tedre has pointed out [46] that the current concern over, say, the implications of generative AI tools in elementary programming course units, while extremely important from a pedagogical standpoint, misses the wider point. The computing education community has, over the past thirty years, been at pains to point out that computing is more than just software development and that, while programming is a crucial and very successful tool, it cannot be divorced from how it is learned [47]. This process of coming to terms with the new technology is, in part, a sense-making process. Many of the wider questions about the implications of the technology for computing education engage with philosophical categories in a fairly clear way, especially the epistemological and axiological categories. Moreover, these questions often mirror those that are being asked in other neighbouring subject areas such as science or engineering education and one advantage of the use of conceptual analysis is that it provides a way of identifying common features across disciplines.

Given some of the predictions about the impact that AI will have on educational practices at all levels and across all subjects, this is a useful feature of the approach and we believe that philosophical inquiry can and should play a much greater explicit role in the sense-making aspects of computing and engineering education in the future.

D. Beyond Knowledge-based Education

The challenge on the educational horizon in engineering and computing is the shift from knowledge-based education to competency based education [42]. When applying sense-making framework to this proposed shift in education presents the challenge to realize that engineering and computing education is:

- *Ontological*: about facts, including the mechanisms of uncovering knowledge – e.g., Bloom's Cognitive Taxonomy, particularly levels 1 & 2.
- *Epistemological*: about skills (and cognitive skills) E.g., the Revised Bloom's Taxonomy.
- *Axiological*: Examining the values and attitudes implied or needed.

Education as a value-laden enterprise. It does not rely on just the ontology of the subject area(s). While there are epistemological components, and a methodology (manner) in which the approach is applied in better or worse ways. Necessarily, there is necessarily an axiological component to education, particularly engineering and computing education because there are clear and identifiable sources of values: Education in engineering and computing is for a profession - and this speaks to working within a professional community with and for society. There is also a professional need to define the virtues, or standards of the profession.

The moving target is the aesthetics, or more particularly the teaching and learning of the aesthetics within each particular subject area, and the development of informed judgement. The notion of "Engineering" or "Professional" judgement (e.g. ABET EAC and CAC outcomes in the United States) should necessarily form a critically important aspect of student learning. The argument presented here suggests that foundations and practice of philosophical inquiry, as well as its connection to argument formation, would be valuable to more developing both foundations and student competency in professional judgement as well ethics (for example, see the approach championed in [48]).

This recommendation comes with some significant challenges; as asserted, the engineering and computing educational communities significantly value theory, not philosophical inquiry. This is an expertise currently uncommon and undervalued within our community [49]. Consequently, this requires a shift in values, and an intentional shift in the means by which values are shared with students. While numerous authors agree this is needed (e.g. [50][51][52]), how such broad change in the values of engineering educators would be made and the shifts necessary in the structures of engineering and computing education needed to enable such change are broad, and beyond the scope of this paper.

VI. Conclusion

The examples presented how a more generic view of sense-making can be applied, following philosophically-informed approaches to making sense from phenomena. The five key steps to making sense of complex phenomena involves theorising, conceptual and empirical investigation, evaluation, and interpretation of results. The qualification of the completeness of the framework is based on its consideration of the three components from philosophical inquiry: ontology (metaphysics), knowledge (epistemology), and values (axiology).

This work examined sense-making as an approach that encompasses and extends theory. Furthermore, it presents the criticality of sense-making both as a tool and a structure essential to engineering and computing education; that the effective meta-narratives need engage in theorising, conceptual and empirical investigation, evaluation, and interpretation of results leveraging the components of philosophical inquiry (ontology, epistemology and axiology) as a means for guiding the application of the meta-narrative.

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