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Through the eyes of a research team: Using theory to enhance STEM Education

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***Abstract*— Computing Education Research (CER) is an example of Discipline-Based Education Research (DBER) that has developed substantively over the last few decades. This is especially true for the Uppsala Computing Education Research Group (UpCERG). In this paper, we use UpCERG as a lens to see how a conscious use of theory can enhance the quality of STEM education. This is accomplished through presenting our use of the concept "theory" in the paper and by using the theses produced by the group as a way to illustrate the increased importance of theoretical development**.

Keywords—Computing Education Research, STEM education, Theory based

I. INTRODUCTION

Interest in improving teaching and learning the STEM field is increasing. There are a number of indicators of this interest, such as an increasing number of research publications on STEM learning and teaching, more varied in their content and more theoretically robust (see for example overviews in [1], [2] and [3]); more conferences (like iSTEM-Ed); different national and international initiatives aiming to enhance STEM education (e.g. US page of STEM education resources [4]; the EU sponsored project Euro-Asia Collaboration for Enhancing STEM Education [5]; national courses in Student-Centred Learning in STEM in Indonesia and Thailand[1]) The nature of these initiatives is varied: While some of them focus on developing and disseminating good practice, others tackle the underlying theories of STEM education, looking for insights that can be developed and then shared between different settings, disciplines and contexts. By focusing the attention on the theoretical and methodological underpinnings of STEM education tools can be provided to help us to discuss why some teaching approaches are more successful than others, from the perspective of the actual learning outcome in relation to intended learning outcomes, and how insights derived from successful learning and teaching approaches can be used in new situations. The increasing interest can also be seen through a Google searches for the term STEM education research. For the year 2000, Google returns approximately 22 000 hits, for 2010 the number has increased to 166 000 hits, while for 2020 the corresponding number is approximately 37 700 000. While these numbers should be interpreted with care, but still illustrate the trend.

In this paper, we describe the Uppsala Computing Education Group, UpCERG[2], at Uppsala University, Uppsala, Sweden, with the aim of analysing how this research team has been a part of the theoretical development of computer science education. This developmental agenda serves as a lens into the theoretical development of STEM education. The empirical data for this paper comprises the theses written within the team, as they differ considerably in terms of what the roles of theories are, and why certain theories are preferred by the authors with regard to the research questions.

Research in Computing Education has developed considerably over the last 30 years, in terms of the questions addressed, selection of methodologies and use of underlying theories. Many literature reviews, taking various methodologically and theoretically perspectives, demonstrate how the field of Computing Education Research (CER) has matured as a discipline. [e.g. 6, 7, 8].

Our intent is to illustrate the development of a STEM research community and its research agenda, as a model to stimulate others to start disciplinary-based educational research within the STEM fields. We, the authors of this paper, have insider perspectives on UpCERG as we currently are active in the group.

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[1] EASTEM https://eastemproject.eu/deliverables/

[2] Uppsala Computing Education Research Group https://www.it.uu.se/research/group/upcerg

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II. Why discuss theory in STEM education research?

The term *theory* is a multifaceted and complex concept. As this is a paper in which the focus is on the use of theory in STEM education, and not on theory *per se*, we contend ourselves with providing a summary of what theory can mean, with a quote from Klette in Norwegian Educational Research towards 2020 - UTDANNING2020 [9], p 3-4], on the role of theory in educational research.

> *Theory refers to a particular kind of explanation. Leedy and Ormrod [10 , p. 4] state: "A theory is an organized body of concepts and principles intended to explain a particular phenomenon". Thus, theories explain how and why something functions the way it does. [11 , p. 7]. As pointed out by Boss, Doherty, LaRossa, Schumm, and Steinmetz [12 , p. 20]: "Theorizing is the process of systematically formulating and organizing ideas to understand a particular phenomenon. Thus, a theory is the set of interconnected ideas that emerge from this process". Following McMillan and Schumacher [13], a theory can develop scientific knowledge congruent with the following criteria: first, provide simple explanation about the observed relations regarding their relation to a phenomenon; second, be consistent with an already founded body of knowledge and the observed relations; third, provide a device for verification and revision; and fourth, stimulate further research in areas in need of investigation.*

Accepting this passage as a perspective on what a theory is, we can now turn our attention towards the role of theory, and its applications, in discipline-based educational research (DBER). Here we find inspiration in Suppes pivotal article from 1974 [14] and particularly in section 1, "Why theory?", here presented in an abbreviated way. His first argument is an *argument by analogy* from the more mature sciences (i.e. mathematics, physics) which can support the need of theory in other sciences, among them educational research. The second argument refers to *reorganisation of experience*, where Suppes offers the law of inertia replacing the Aristotelian physics as his core example. Another example from DBER is a discussion on the decline of seeing transfer as a dominating theory of teaching and learning. Suppes presents *reorganisation of experience* as his third argument. He argues that what can be found under the surface could be more complex than what can be seen at first sight. Theory offers broader explanations of a phenomenon than what could be seen at first sight. A clear example could be the replacement of the Ptolemaic worldview, with the more theoretically sound helio-centric. His final argument is that *bare empirism would be trivial*. This could, with one of his examples, be obvious for the teacher if he or she could not refer to theory, when explaining something to his or her students.

Certainly, Suppes is not alone in arguing for the usefulness of being theory-aware in educational research, but his arguments are clearly described and stay consistent over time.

DBER is in the inter-disciplinary cross-road of the STEM field and the social sciences, mainly educational research. STEM is in itself rich and multifaceted. The abbreviation stands for Science, Technology, Engineering and Mathematics, where these disciplines are interpreted in a broad way, including, for example, Computer Science. This character of STEM makes UpCERG an extremly relevant example in this paper.

The object of the students' learning is mainly to be found within the STEM field, while the research methodologies and theories of learning and teaching to a large degree stems from educational research

III. Uppsala Computing Education Research Group

UpCERG, currently consisting of approximately 14 persons (whereof 6 PhD students), has a large set of publications[3], has an extensive international network, and deploys a rich set of theoretical and methodological research approaches.

A. Introduction of theoretically robust research – the first generation

Uppsala Computing Education Research Group, UpCERG, can trace its first publications to 1996. They were descriptive in nature and mainly presented the teachers' experiences and impressions, possibly with some statistical analyses as a complement and corresponded often to what Valentine [15] refers to as Marco Polo papers.

The first PhD thesis was produced by Berglund [16], followed by the thesis of Eckerdal [17]. In contrast to the first publications, the theses of Berglund and Eckerdal applied a theoretically well developed phenomenographic research approach [18, 19] to their studies. Phenomenography is a qualitative research approach that aims to describe how something (called a phenomenon with the terminology from the approach) is understood (or experienced) within a cohort of learners, for example, how university students in IT understand a particular network [20] or the concept of evolution as understood by master students in biology [21] could be the phenomena of interest. The outcome of a phenomenographic study is a set of categories, each of which describes a certain way in which the phenomenon is perceived in the cohort.

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[3] A list can be found at `https://www.it.uu.se/research/group/upcerg/publications`

Berglund contextualised the results from his phenomenographic studies, using activity theory [22], to describe the learning of CS that took place in an internationally distributed student project. In this way, it became possible to see the learning of particular phenomena within IT, as they were experienced by the students, at the same time as the learning was seen as a part of a broader setting [23]. Eckerdal, inspired by the dualism between and, at the same time, the interaction between theory and practice in students' learning of programming, discussed her phenomenographic outcome space in terms of students' learning of fundamental programming practice. In both these theses, theory was made explicit, both in terms of focus on the CS content and in the use of a robust, qualitative, interpretative theoretical basis. With the work of Berglund and Eckerdal, the importance of grounding research in sound theoretical underpinnings became a part of the "life" and "meaning" of the UpCERG team. This introduction of phenomenography served as a platform and example for how methodologically and theoretical rigorous research could be used to gain insights into computing education.

B. *The next generation*

Building on these insights, the subsequent theses from the team had clear foci on their research questions and their contexts, while still writing theoretically well founded theses. Also, the theoretical and methodological repertoire was extended by selecting research approaches that by the authors were deemed [24] relevant for tackling their research questions.

In her thesis on students' development of an identity as a computer scientist, Peters theoretical point of departure is the work of Lave and Wenger [25] and studies how participation in a cohort effects and constrains their individual becoming and how the participants shape each other. Boustedt [26] studies possibilities to overcome the gaps between newly hired and experienced CS professionals taking a phenomenographic approach. Learning in project courses, and the possible gap between students' experiences and teachers' expectations, is the core topic of Wiggberg [27]. A method is developed focusing on capturing the students' experiences. A different perspective has been taken by Alghamdi [28], who through a set of case studies [29], studied the experience of teachers and female learners and how to enhance CS education in the context of Saudi Arabia. Daniels's [30] thesis, despite being anchored in case studies as well as action research (see e.g. [31]), still differs from the previously mentioned in that the core part of the theoretical development lies in the object of the students´ learning, in his case in understanding and developing insights in professional competencies (see e.g. [30], chapter 5.5.1) and not mainly in the methodology.

This development among the PhD students has been enhanced by rich and lively discussions in the full UpCERG team on what CER is and how it stands out as different from research in education, sociology or computer science and also in a number of publications [32, on the multitude of possible theoretical approaches; 33, on the cultural situatedness of CS; e.g. 34, on qualitative research in CS education].

C. *Current development*

The current work of UpCERG is focus of the the theoretical achievements of the earlier PhD theses, but also demonstrate a greater variation in terms of the manner in which theories and methodologies that are used. Recent development is that ethical and moral values are made visible and become important in the research in a way inspired by that advocated by Clear [35]. Anne Peter's work[4] on sustainability in computing and computing education, as well as Virginia Grande's [e.g. 36] research on role models, can here serve as illustrations. Still, what unites the current work of UpCERG is its theoretical awareness. The research questions vary between the projects and researchers but the importance of anchoring research in theory can be found in most of the publication of the last decade.

IV. Conclusions

UpCERG is been a part of, and continues to contribute to, the theoretical development in Computing Education Research. The team has a focus on evidence-based learning [37], combining empirical based research with a rigorous theoretical stance. Theory has served, as argued by Suppes [14], to offer analogies, to reorganizing empirical findings, to see the complexity and to avoid bare empiricism. Further, it has offered as a language to learn from others and to share conclusions.

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