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Editorial: Conceptualizing and Using Theory in Computing Education Research

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There has been considerable recent interest in a number of questions related to theory within computing education research. In this editorial, we summarize some of this recent interest, discuss the process in which this special issue came to be, and how papers were selected for inclusion. We end with a brief summary of each of the six papers appearing in this special issue, highlighting the relevance of each to this issue's theme.

CCS Concepts: • **Social and professional topics** → **Computing education**;

Additional Key Words and Phrases: Theory, theory use, theory definition, computing education research

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1 INTRODUCTION

In recent years, there has been considerable interest in questions related to theory in **computing education research (CER)**: what can be borrowed from other disciplines, how to build theory within CER, how to appropriately use theory, how to combine theory, whether it is necessary to use theory in reporting research or instructional designs, what we take theory to be, and many others. This special issue, one of two on the theme of "Conceptualizing and Using Theory in CER," is intended to offer insight, though not definitive answers, into many of them. In this editorial, we document some of the recent discussion related to these theoretic-related questions that have appeared in the CER literature, and describe the development of these special issues as a contribution to and continuation of this discussion.

The general and growing interest in the questions about theory enumerated above is visible in a number of literature surveys exploring the development and state of art in using theories in published papers in CER. Malmi et al. [2014] explored research papers in ACM **Transactions on Computing Education (TOCE)**, Computer Science Education, and the **International Computing Education Research conference (ICER)**, published during 2005–2011, to identify how they were *building on theoretical work* and *from which disciplines* this work initiated. Lishinski et al. [2016] complemented this work by analyzing ICER papers from 2012–2015 and found out that "A

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significantly higher proportion of articles in our sample made use of outside theory than in the results presented by Malmi et al., suggesting that the field is increasingly reaching into other disciplines to frame and interpret studies with respect to previous research in learning theory" (p.167). There are also conceptual review papers that provide overviews of theory from other domains that are likely to be useful in CER. For example, the Cambridge Handbook for Computing Education Research [2019] focuses on theory in three chapters: "Learning sciences for computing education" [Margulieux et al. 2019], "Cognitive sciences for computing education" [Robins and Margulieux, 2019] and "Motivation, attitudes and dispositions" [Lishinski and Yadav, 2019].

Other papers focus the analytic gaze more narrowly. For example, Luxton-Reilly et al. [2018] focused on the programming education literature, and identified – among many other results – papers that *model student understanding in introductory programming*. Similarly, Computer Science Education published a special issue "Advancing Theory about the Novice Programmer" in 2019 that included "comprehensive literature reviews across several areas of interest, including K-12, higher education, sociocultural and cognitive factors" [Margulieux and Morrison, 2019]. Malmi et al. [2019] explored *domain-specific theories* in CER, Szabo et al. [2019] investigated *how learning theories are adapted* in the computing education research communities, and Malmi et al. [2020] explored theoretical development in CER concerning *emotions, affects, attitudes, beliefs, or self-efficacy* in teaching and learning programming.

There are also several papers that focus attention on a single theory or related family of theories, with an implicit or explicit argument that such theories have been underutilized, misunderstood, or inappropriately applied within CER, which serves as a rationale for the authors to provide an overview of the theory (or family of theories) and the impact that additional and/or appropriate use of these theories might have for CER. Tenenberg and Knobelsdorf [2014] took sociocultural learning theories as its focus, and Prather et al. [2020] focused on metacognition and self-regulation theories, to give just two examples.

The use of theory has also been an explicit requirement of publication in several of the important venues in CER. From the very beginning of the conference series, ICER has solicited papers with "A clear theoretical basis, building on existing literature in computing education, computer science, and other related disciplines." Koli Calling conference has explicitly called for theoretical papers that "formulate, extend, apply, critically evaluate, or otherwise discuss theory for the purpose of improving computing education or computing education research." Computer Science Education calls for "submissions that are situated in the computing education research literature and draw on diverse theories and research methods, including those that borrow from allied fields such as educational psychology, cognitive science, and the learning sciences." And ACM TOCE instructs that "[p]aper authors are strongly encouraged to frame their research in terms of one or more learning theories [that] can be accomplished, for example, by motivating research questions or hypotheses with the help of learning theory, or by interpreting results in terms of learning theory."

While the arguments above support using theories to guide research, this view is not without its critics or problems. Nelson and Ko [2018] argued that our field must have space for developing new educational designs even though such designs may lack an explicit theoretical framework. They also emphasize that CER should focus more on developing domain-specific theories in preference to applying general theories of learning. Our own experience as ICER program chairs has also revealed that evaluating the appropriate use of theory is frequently a challenge for reviewers in our field, partly a result of the diversity of ways that researchers in CER carry out and report research; as with many other social sciences, there is no single, shared, and hence taken-for-granted theoretical paradigm in CER as is often the case in many of the physical sciences [Kuhn, 1962]. One of the underlying reasons is the terminological confusion in the literature, where terms such as, theory, theoretical framework, theoretical model and model are frequently used in papers and there is no clear definition and established practice of use of these terms in the CER context. CER papers also use a wide variation of theories [Malmi et al. 2014; Szabo et al. 2019] and only a fraction of them can be considered theories with an established name, e.g., constructionism, cognitive load, self-regulation, metacognition. Moreover, the literature in social sciences is rich and many theoretical terms cover multiple different versions of theories; there are different conceptualizations of, for example, metacognition and self-regulation. As found in Malmi et al. [2014], much research in CER applies or adapts theoretical developments or models presented in individual papers, e.g., grounded theories or statistical models, and builds its arguments simply on this secondary literature. For a reviewer, it may not be straightforward to judge whether such arguments form a clear theoretical base.

This general interest can be considered as a part of the process of a maturing discipline, which seeks to build stronger arguments for research designs, better describe and interpret empirical findings, and develop more effective instructional tools and interventions. Broadly speaking, these can be achieved in several ways, applying general theories from other disciplines (particularly the social sciences) in our research settings, adapting such general theories and theory-based instruments to computing education contexts, and developing domain-specific theories of CER that emerge from interpreting empirical findings in computing education contexts.

It is against this background of interest and broad discussion of theory in CER that this special issue came about. Not only do we each have an interest in many of these issues individually, but we have pursued these in ongoing discussions between the two of us whenever the opportunity has arisen for face to face or electronically mediated conversations. We explicitly began to talk about "what next for theory in CER" at the start of the pandemic in a series of Zoom conversations. We quickly realized that as rich as the discussion was between the two of us, that it would be even better if others from the community were involved; it is only within the context of the larger CER community that these questions around theory are meaningful and timely. We brainstormed a number of different formats in which a larger discussion on theory might happen, imagining the commitments and contributions associated with each, converging on a special issue of a CER journal as being the best fit for our experience and availability over the time required. We chose ACM *Transactions on Computing Education* as our first journal to target because of our past history with this journal (Josh served as Co-EiC and Lauri as Associate Editor), the ACM's commitment to computing education in general, and the ACM's ongoing efforts to make its publications as globally accessible as possible. Moreover, *Computer Science Education* had just recently in 2019 published a special issue "Advancing Theory about the Novice Programmer" overlapping partially the theme of our anticipated special issue. Therefore, we put together a proposal that we sent to then-Editor-in-Chief of TOCE, Chris Hundhausen, who gave his approval in October 2020. This proposal included a two-phase reviewing process, the first phase involving the submission of extended abstracts, reviewed by the two of us as guest editors and from which invitations to submit a paper would be made, followed by submission and review of complete papers. Within days, a Call for Papers was posted on the TOCE website in the ACM Digital Library (https://dl.acm.org/journal/toce) and we were disseminating the call to colleagues and email lists.

To our surprise and delight, we were overwhelmed by submissions, receiving 78 extended abstracts when we had expected 20 or fewer. Because we had not anticipated receiving this number of papers, we had cast the net broadly in our Call for Papers. Part of our rationale for doing so was that from our prior experiences both in editing TOCE and overseeing the submissions for ICER'17, we anticipated that many submissions were likely to be out of scope (of TOCE and/or the special issue) or outside the genre norms of scholarly discourse in CER. Part of our surprise was that this was emphatically not the case, with all but a few of these submissions appropriately themed and articulated in the context of computing education research. In addition, and relearning a lesson that our ICER Program Chair experience had already suggested to us, authors' interpretations of what we were seeking were even broader than our own interpretations of what we had been soliciting. To put this another way, in the diversity of papers that we received, we recognized that not only had we originally had a somewhat hazy and ambiguous sense of what we were seeking from authors, but that our words in the Call for Papers could quite reasonably be taken to mean differently than what we took them to mean. And some of these alternative conceptions were as worthy of consideration as ours. As a result, this large number and diversity of papers required the development, after the receipt of the submissions, of explicit criteria that we could use for making fine-grained distinctions between the submissions. This would then serve as a rationale for which we would take responsibility and also that we hoped the Editor-in-Chief would endorse, since by ACM policy, a journal's EiC is authorized as the individual to make publication decisions. This rationale was also something that we needed to communicate to authors, particularly those who we were not inviting to submit full papers but who are nonetheless important contributors to these Special Issues on Theory and to the CER community more broadly. And finally, we communicate this rationale here, to our readers in this editorial and the special issues.

We undertook the abstract reviews as follows. First, we jointly developed a categorization scheme for the "type" of paper (e.g. meta-discussion of theory, conceptual review of a theory, empirical study + use of theory, . . .), with a final ontology of eight types. We developed this ontology based on our past experience in reading and reviewing CER papers and a quick skim of the 78 papers shortly after the submission deadline. We then separately evaluated all of the papers, categorizing and commenting on each. In doing so, we also developed a sharper sense of what distinguished the categories. Following our individual evaluations, we met and talked through all of the papers one at a time, discussing how we categorized each one (sometimes differently, usually the same), and what we took the anticipated contribution to be of a full paper consistent with the abstract. What emerged from this discussion was an emphasis on anticipated papers that do not look like "regular" empirical research papers such as what ACM TOCE typically publishes, papers that (in general) skillfully use theory. These are papers that on the one hand already stand on their own in the TOCE review process, and on the other are not emphasizing something "new" about theory that we came to see as a necessity in order to appear in this special issue. Instead, we were drawn to papers that discuss innovative theoretical approaches for CER, that give new insight into theoretical approaches already used in computing education, and/or that provide a meta-theoretical discussion about new ways to conceptualize theories and their use in the field. From this discussion, we narrowed our focus to 17 abstracts for further scrutiny. If we were to invite the authors of all 17 abstracts to submit full papers, we wanted to find out if it was possible to accept as many of them as met the TOCE publication criteria, or were close enough so that they could do so within a relatively short revision period. Given the current limit of 12 papers per issue, we approached Chris Hundhausen about the possibility of having a second special issue on the same theme, to which he gave his assent.

We then did another round of separate evaluations of these 17 abstracts, rereading, reclassifying, and re-evaluating each abstract. At this point, we also decided to track the discipline and theory for those papers that discuss specific theories for use in CER. Our purpose was to ensure a broad range of coverage and that we were not overly emphasizing any particular theoretical or disciplinary orientations. We then met and talked through these 17 papers, one paper at a time. This involved the usual triage: first those papers we had separately rated as "Yes, let's invite a full paper submission," then those we had both determined were "No, let's not invite," with most of our time spent on those papers where our separate judgments diverged. The discussion allowed us to learn much more deeply the strengths and weaknesses of these proposed papers, and also to make sure that we were not having too many papers with similar themes and approaches. This brought us to 13 abstracts that we invited for full submission.

While authors completed their full submissions, we lined up a set of reviewers for the anticipated papers. Our plan, which we were able to implement, was for each submitted paper to be reviewed by at least one author of another submitted paper to the special issue, and at least one review from a CER expert who had not submitted to the special issue. Complete papers were received for all abstracts invited for submission, and we followed the TOCE review process, assigning three reviewers for each paper. This assignment was informed by first distributing anonymous, updated abstracts of all papers to all reviewers and seeking review preferences based on their expertise and interest. Reviewing abstracts also allowed reviewers to identify potential conflicts of interest. Throughout the entire review process, we followed the Conflict of Interest Policy for ACM Publications (https://www.acm.org/publications/policies/conflict-of-interest), removing the individual with a conflict (including each of us as guest editors) from any further role in the review and recommendation for the conflicted paper. Of the 11 papers that were submitted, two were conflicts of interest for us, and were assigned by the Editor-in-Chief to other guest editors who remained anonymous to us. When assigning reviewers to papers, we also provided a one-page reviewer guideline (which we also provided to the anonymous guest editors for their reviewers) detailing how to interpret and use the standardized TOCE review form, developed primarily for reporting empirical studies, since the special issue papers were primarily not reports of empirical studies.

On receiving the reviews, our role was to make recommendations to the Editor-in-Chief for which papers to accept and our reasons why. To carry out this responsibility, each of us read all papers and their respective reviews independently, and formulated in writing our recommendations with rationale. We then (synchronously) talked through our recommendations and rationales until we reached consensus. During these discussions, we wrote down points that had not been articulated in any of our separate rationales that emerged in the discussion together. We then used these notes (individual and collective) to draft our decision recommendations and rationales, which were sent to the Editor-in-Chief for approval. These same recommendations and rationales were sent to the authors by the Editor-in-Chief (who included their own cover letter), and blind-carbon-copied to each of the reviewers. Of the 11 papers that were submitted and for which we had no conflict of interest, eight were conditionally accepted to these special issues, the conditions of acceptance made explicit to authors. Authors had another 30 days to complete their revisions, which we checked against the specified conditions of acceptance. All eight papers were accepted. In addition, both of the conflict of interest papers were accepted based on recommendation of the anonymous associate editor(s).

With ten papers accepted, the two "position paper" editorials that we have each written individually, a "dialog paper" between a subset of the authors, and a joint editorial introducing the issue, we found ourselves just beyond the paper limit of a single special issue. We also noticed that the papers seemed to have a "natural" bifurcation, with six of the papers focusing in-depth on one theory (or small set of related theories) and its implications for CER, while the remaining papers treat theories at the "meta" level as explicit objects of discussion, e.g. how researchers orient towards theories, use theories, combine theories, and similar. The papers in the "one-theory" group appear in this first special issue, while the papers in the "meta" group will appear in the second special issue. In the balance of this editorial, we provide a summary of each paper in this first issue.

Loksa et al.'s paper "*Metacognition and Self-Regulation in Programming Education: Theories and Exemplars of Use*" discusses two important and related skills, metacognition and self-regulation, which have a long history in the general education literature. The authors have carried out a systematic review of the computing education literature of how these theories have been leveraged in programming education research. The foundational theories, Flavell's theory of metacognition and Bandura's Social Cognitive Model of Self-Regulation are not specific to education, but they have been often combined to build theories of **self-regulated learning (SRL)** of which the authors discuss Zimmerman's model of SRL and Pintrich's SRL theory which have been widely used in computing education research. The paper presents several exemplary papers on how these theories have been used to inform research questions, study design, data collection with related instruments and/or interpretation of results. Following this, the authors present two domain-specific theories, Xie et al.'s theory of instruction for introductory programming skills and Loksa et al.'s theory of programming problem-solving which also build on metacognition, and four other SRL theories, which have been leveraged in other fields, but not in computing education research. The authors discuss their observations of how the theories have been used and give their recommendations on how they could be better utilized in the future.

In the paper "*Cognitive Load Theory in Computing Education Research: A Review*", Duran, Zavgorodniaia, and Sorva discuss in depth how **Cognitive Load Theory (CLT)** has been used and applied in computing education research. CLT has been one the most frequently used theories in CER, but this usage has a number of issues that the authors consider more closely. They begin with presenting the main concepts of the theory, working memory, elements and schemas, as well as intrinsic and extrinsic load. This is followed by the history of how the theory has evolved, especially explaining the role of germane load which is defined in different ways in the old and new versions of the theory. They present the critique in the CLT literature concerning the old version, as well as open issues in the whole theory. This scholarly introduction to the theory is followed by a systematic mapping of the computing education research literature where the authors have explored how these two versions have been cited and used in almost 300 papers published since 2010, when the new version of CLT was published. The findings reveal many shortcomings in both citing and using the theory, and the authors provide recommendations for future research which help mitigate those problems. Overall, this paper is an excellent summary of research in computing education which builds on CLT. Its recommendations are valuable for anyone considering seriously using CLT. However, the recommendations are also worthwhile guidance more broadly for researchers in computing education on how to avoid caveats in using theory.

The paper "*Dual Process Theories: Computing Cognition in Context*" by Robins focuses on a family of theories from the cognitive sciences captured under the rubric "dual process theories." This paper is noteworthy in providing an overview of this family of theories heretofore overlooked in CER and discussing how these theories can help to provide fresh insight into a number of historical concerns within CER and CE more generally. Robins explains that a number of theoretical contributions from the cognitive sciences over the last century have coalesced in hypothesizing two inter-related but qualitatively distinct cognitive systems that impact thinking and behavior. One system is typically characterized as fast, associative, and automatic while the other is slow, conscious, and rule-based. Robins details what it is about these systems that leads researchers to consider them sufficiently distinct as to be different cognitive systems while at the same time indicating that there is considerable cross-talk between these systems. Having laid this theoretical foundation, Robins then takes up a number of topics that have been of enduring interest in CER, including novice-expert differences, notional machines and mental models, programming strategies, and the relationship of code reading to writing. Robins shows how the language and concepts from dual process theories can provide insight into these concerns and suggest new avenues for additional empirical research studies.

Kao, Matlen, and Weintrop's paper "*From One Language to the Next: Applications of Analogical Transfer for Programming Education*" is focused on the learning of subsequent programming languages after a first one has already been learned. They characterize this situation as an instance of the general problem of how learners transfer conceptual material from one situation to another. This thus makes available to computing education researchers the key theoretical insights from cognitive science concerning *analogical transfer*, which the authors summarize both to articulate its conceptual features and to introduce a precise language that they then use in the balance of the paper. Moving from the domain-general, the authors summarize three domain-specific theories of language-learning transfer from CER and review a wide range of empirical studies of language-learning transfer in CER in relation to these domain-specific and domain-general theories. The authors point out that these empirical results show that prior programming language learning can not only facilitate but also interfere with subsequent language learning. As a result, the authors provide a nuanced account of how elements of these theories of analogical transfer can provide specific guidance for the design of instruction for learning a second (and subsequent) programming language, highlighting the importance of *comparisons* and *perceptual cues* in this instructional activity.

Michaelis's and Weintrop's paper "*Interest Development Theory in Computing Education: A Framework and Toolkit for Researchers and Designers*" addresses students' interest and motivational factors to study computing. The authors present current interest development theory, which defines interest as a developmental motivational variable that can refer to two aspects of interest. Situational interest is a psychological state of heightened attention and focus in relation to some content or activity, while individual interest is a relatively stable disposition to re-engage with that content or activity. Central questions in this context concern what activities can trigger interest and how it could be maintained over a longer period. The authors present a model, Integrated Interest Development for Computing Education Framework, which integrates three key dimensions of interest, Knowledge, Value, Belonging. They discuss each of the dimensions separately providing a theoretical base for each dimension and key factors which can influence interest within computing education contexts. Moreover, they discuss examples from computing education research addressing these factors. After this in-depth discussion of their framework, the paper addresses the challenge of measuring interest and how this could be carried out with validated instruments or theory-based interviews. The paper concludes with implications for future research.

In the paper "*A Sociocultural Perspective on Computer Science Capital and its Pedagogical Implications in Computer Science Education*," by Vrieler and Salminen-Karlsson, the authors describe the development of a domain-specific concept, Computer Science Capital, and use it as a basis for reflection on instructional design and teaching practice. The most important theoretical conception that is drawn upon and explicated is Bourdieu's sociologically-oriented theory of capital that relates access to resources (economic, social, cultural and symbolic) to an individual's social location and mobility. The emphasis on sociological theory—rarely used in CER—provides a nuanced account useful for reflecting upon problems of diversity and inclusion in computing education. In using a sociocultural conception of the constitution of individual sensibilities and actions in relation to computing, quite different than what might be obtained in using theories that are more psychologically focused, the locus of instructional intervention shifts from primarily individual interventions (e.g. reducing cognitive load, enabling analogical transfer) to those that are more social in nature. This is facilitated through the use of a set of reflective questions about the social and cultural resources that students and the instructor collectively bring to the forms of participation that currently exist within the classroom, and how these might be changed so as to produce more diverse and equitable learning contexts.

We are very happy to present these high quality contributions to our field. We hope that they will be valuable resources for researchers, opening new avenues and perspectives on teaching and learning computing to enrich future work in CER. Enjoy reading!

Josh and Lauri

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