

Research Agenda for Computer Science Education

Asra Anjum ¹, K. Sindhu ², Akshith Nag ³

³Assistant Professor, Swarna Bharathi Institute of Science & Technology, India, E-mail: asraanju@gmail.com.

¹Assistant Professor, Swarna Bharathi Institute of Science & Technology, India, E-mail: karlapudisindhu516@gmail.com.

²Assistant Professor, Swarna Bharathi Institute of Science & Technology, India, E-mail: Nag.686@gmail.com.

Abstract:

Research in computer science education (CSE) is the focus and subject of this article. We begin by defining CSE research and its goals in order to set it apart from other types of educational research. Our goal in reviewing the current landscape of CSE research is to classify previous studies into overarching themes that capture the wide range of contributions to the field. Additionally, we assess every grouping, drawing attention to potential advantages and disadvantages. We contend that previous research investigations have neglected to include the educational philosophy that forms the basis of their findings. The outcome is that educators lack the "pedagogical content knowledge" necessary to address learning's cognitive and educational challenges. We wrap off by outlining some ground rules for CSE studies, with an emphasis on how they could be better integrated with the theoretical frameworks of fields like psychology, pedagogy, and curriculum studies.

Introduction:

A review of existing computer science education (CSE) literature shows that the effort to date has largely been in a few important, but relatively limited areas (such as descriptions of courses, development of tools, and computer aided learning). In contrast, long-established scientific disciplines such as physics and chemistry possess a large body of literature concerned with education in those disciplines. Specific problems which arise in the teaching and learning of these subjects have been thoroughly researched, and there is a long tradition of pedagogical research specifically relevant to each discipline. Many computer science educators have no formal training in education. As a result, the field of research tends to be grounded in the technology, rather than in the pedagogy or didactics of

computer science. In this paper we attempt to categorise the CSE literature and highlight some areas whose expansion and consolidation would provide a solid foundation for both future research and the development of innovative teaching techniques and tools which support and enhance computer science education.

What is CSE?

Computer science is a rapidly changing and increasingly diverse academic discipline. Relevant issues for research concerning the teaching and learning of different parts of this discipline are even more diverse. This paper will not provide a unique definition of research in computer science education; nevertheless it is necessary for the further discussion, to offer some general pointers to our understanding of what constitutes the discipline. Computer science - a diverse and developing discipline Computer science might be a problematic phrase in and of itself. Informatics and information science are two other names that might be used. The meanings of these terms have evolved throughout time and between nations, languages, academic institutions, and professional groupings. One reasonable and flexible way to describe computer science is as a set of related scientific fields that focus on data storage and processing in a digital format. Perhaps some will argue that this umbrella term is too broad and propose splitting the field into more specific areas of study. To put it another way, there are separate scientific fields that deal with the social and psychological aspects of computer use in organizations and society, as well as the technical parts of building computers and computer systems. This is in contrast to computer science and informatics, which focus on the same technical aspects. Communication, media, mathematical modeling, information copyright law,

etc. are adjacent fields of study. This study takes a more tolerant stance, but it will focus on the academic and scientific aspects of computer science rather than its craft-like nature.

What CSE is not

Computer science, pedagogy, and sociology scholars throughout the world are devoting more and more time and energy to studying the role of computers in the classroom (Boyd-Barrett & Scanlon, 1990; Oettinger, 1969). It is important to note that this kind of work differs from computer science education (CSE) in that its primary emphasis is on using technology to enhance the teaching and learning of disciplines other than computer science. Studying computer science as a theoretical academic discipline and studying it as a practical training program are roughly opposite ends of the spectrum. The academic field of computer science is the main topic of this article. Subject specific educational research. A number of topics related to the instruction and comprehension of scientific disciplines in the classroom have a long history of academic inquiry, including but not limited to the application of pedagogical concepts. While the name "didactics" is used to describe this kind of study in France, it is known as "subject didactics" in Germany and the Nordic countries (Gundem, 1998). Contrast this meaning of didactic with the more common English meaning of a teacher-led lecture style of imparting knowledge. Accordingly, we've decided to designate this multi-faceted field of study as subject-specific educational research. Thus, the field of study known as computer science education (CSE) would conduct research on computer science education from a subject-specific perspective

The aim of CSE-research

The main motivation for educational research in computer science education, as in all subjects, is to improve the quality of the teaching and learning of the subject in schools and universities. To be able to measure the success of this work, one needs to agree upon what constitutes an improvement. In particular, what is good teaching practice? How do we best facilitate the students' construction of knowledge? The findings of existing studies attempting to answer these questions are just as diverse as would be expected,

considering the diversity of the individuals (ie. students, teachers and researchers) involved in them.

Pedagogical content knowledge

The good teacher needs, of course, to master the subject matter of his or her discipline well, but this is not enough. It is essential that the teachers have what is referred to as *pedagogical content knowledge* (Gess-Newsome & Lederman, 1999).

Educational research should not mainly aim at prescribing successful methods of teaching – although this can provide useful guidelines for fellow practitioners. The aim should rather be to describe the different ways in which students come to understand, or not to understand, the subject matter. These descriptions, accompanied by knowledge of general pedagogical theory, epistemology and solid subject knowledge will make the foundation for answering the traditional *didactical* questions of *why, what, how* and *for whom*. Why should this subject matter be taught as a school subject, which topics do we find appropriate for such a subject and how do we best facilitate the construction of the desired types of knowledge. The *for whom*-question forms an important background for answering the other three. It is essential to keep these questions and their answers in mind. This goes for each individual teacher as well as for policymakers and educational researchers.

The Identity of CSE as a Research Discipline

As Ferguson claimed about the history of technology in the seventies, computer science education has "all of the appearances of an academic field, yet it is difficult to find in it a discipline or conceptual framework that guides the work being done in its name" (Lewis, 1999a).

What then might constitute a common denominator for CSE as a research discipline? We will see that both the various academic connections to other established disciplines and the wide variety of relevant research methods ensures that the traditional constraints constituting a research discipline do not apply here. A possibility is to say that it is the common goal that connects the corners of the field. We can claim that what makes research in CSE an autonomous academic

discipline is the aim to provide the knowledge needed to help our computer science teachers and lecturers attain *pedagogical content knowledge*.

“State of the Art” in CSE

Current Cutting Edge of Computer Science and Engineering Comparing articles published during the last twenty years with those published within the last twenty years on the subject of computer science education reveals a startling absence of pedagogical theory or references to previous research and discoveries. In light of these findings, it is clear that future studies in computer science education need a shared definition and framework for comparison. We break down the many types of computer science education research papers into their respective sections and talk about the impact of each. Based on this study, we have identified certain categories that might benefit from being enlarged. We believe that this would greatly enhance the field's overall strength and advancement. Novel, unproven concepts There have been a number of publications outlining novel approaches to education that spark conversation but fail to provide any proof (empirical or otherwise) of the approach's efficacy. Several examples may be found in the literature on programming education, such as implementation-independent pedagogic techniques (Ford, 1984), program designs (Soloway, 1985), and mathematical constructions (Elenbogen & O'Kennon, 1988). Researchers, particularly those interested in comparing old and new approaches, might use some of the presented unique concepts as a springboard for their own investigations. This category also includes publications that detail the development or current status of very advanced educational software, particularly that which is claimed to possess intelligence comparable to that of a human being. These articles show us how, once vexing implementation issues are finally resolved, computer science education might be improved in the future. While this kind of study may not seem beneficial to educators right away, it may be a great resource for guiding future studies and sparking interesting new ideas. Battlefield updates Many of the papers presented at computer science education conferences, such as SIGCSE and ITiCSE, are authored by instructors who have actually taught the subject and draw heavily on their own experiences in the

classroom. Many of them have had issues with students who do not meet expectations or with the high rates of failure and dropout in their first year classes. Depending on based on gut feelings or suggestions from coworkers, they have subsequently introduced a new approach to the course material. According to Carbone and Kaasbøll (1998), a conference paper is used to assess the change's impact depending on the student's response, the lecturer's perception of its effectiveness, or, sometimes, the outcomes of the final test. Many suggestions for improving the instruction of a certain subject are provided in these articles. The development and improvement of computer science education depend on the exchange of pedagogical concepts and practices. A small number of these works also make reference to pedagogical theory, but many of them are founded on solid computer science theory (Allen et al., 1996; Bauer, 1979; Berglund & Daniels, 1997; Dietrich & Urban, 1996; Koffman & Wolz, 1999; Smith & Rickman, 1976). It wasn't until 1976 that many of the issues detailed in 1996 were really recognized. Furthermore, there are clear challenges to doing an empirical evaluation of such courses. Not only would it be costly to run two courses at once and compare the outcomes, but such methods would also be morally questionable, since they may disadvantage students in one of the courses. It is very difficult, if not impossible, to assess the impact of specific changes because to the large number of modifications throughout the courses, even when comparing between years is available. Some publications even go so far as to claim their approach is the best way to help students succeed. Attempts to provide evidence for such statements do occur from time to time (Clark, 2000; Koelling & Rosenberg, 1996; Meertens, 1981), but these arguments and personal reflections are usually inadequate. Analysis of concepts Additionally, some articles use theories of natural language learning (Murnane, 1993) or epistemological frameworks such as constructivism (Ben-Ari, 1998; Hadjerrouit, 1998). The results of the research are never examined in the broader context of these supplementary or associated ideas, even though these references are sometimes referenced in the beginning parts of the paper. Nevertheless, the debates that these publications start and the conclusions that they reach are significant. They provide the groundwork for studies that will test and investigate the ideas, as well as their relevance to

computer science curricula. Artificial Intelligence and Educational Computing Predictions that the widespread use of personal computers in classrooms will completely alter the nature of education have persisted since the late 1970s. Another argument in favor of computer science curricula is the influence and potential of online learning tools, interactive multimedia, and instructional software. Intelligent tutoring systems, in which a computer "learns" the student's thought process and then provides feedback and instruction based on this, have emerged as a result of AI research (Chalk, 2000; Pirolli, 1986; Polson & Richardson, 1988; Sleeman & Brown, 1982). Providing very advanced computer-mediated learning and dynamic individualization of education has been the driving force behind this study. Unfortunately, computers lack human qualities like intuition and common sense, so research in this area has not yet achieved many of its major goals (such as making the system accurately diagnose errors, adapting to user needs, drawing conclusions, and solving domain problems). This research also raises the issue of having automated standardised tests to save work and to avoid the highly biased results from a human teacher reviewing the students' work (MacNish, 2000; Seffah et al, 1999). Dissimilarities between experts and novices A large number of studies have been carried out that aim to describe the different ways in which experts and novices master problem solving situations or picture the tasks they meet in computer scientific areas (Batra & Antony, 1994; Kahney, 1983; Soloway & Spohrer, 1986; Wiedenbeck, 1985). With an eye on establishing a standard for rookie accomplishment, these studies provide valuable insights into the disparities between experts and novices. To educators and instructors, this data is of paramount educational significance. Field Experiments There is also empirical research that analyzes student code, conducts interviews with students trying to solve a specific issue, or focuses on certain programming phenomena. Some papers study a specific group of learners, such as students with no programming experience (McIver, 2000), or students learning a particular language (Eisenstadt & Lewis, 1992; Putnam et al, 1986; Van Someren, 1985). Others target particular programming constructs such as conditional statements (Sime, Green, & Guest, 1973), teaching techniques for particular constructs (George, 1996; Good, 1999), or

student programming errors (Pea, 1986; Soloway & Spohrer, 1986) There are also studies that aim to describe the mental models or individual understanding students seem to have concerning programming or systems design (Bhuiyan, 1992; Booth, 1992; Brooks, 1999; Holmboe, 2000; Petre & Blackwell, 1999). These studies all examine the behaviour and responses of students tackling real programming problems, to learn about the difficulties students have when learning to program. This type of research provides a firm basis for improving teaching techniques, and the creation of effective tools for teaching programming. This is a category which could usefully be expanded in order to strengthen the field of computer science education.

Learning from others

We need to reframe the conversation around research needs such that it opens up more and more opportunities. We need to stop limiting scholars and start looking for methods to expand their horizons (Lewis, 1999b) Research in education Due to the intrinsic relationship between the content and epistemology of a given academic field, subject-specific educational research will always vary among disciplines (Gundem, 1998). Still, researchers in computer science education might glean some helpful hints about where to direct their future efforts by perusing the breadth of published work in more established domains, such as science education, mathematics education, and the teaching and learning of foreign languages. In response to the first of the didactical essential questions, which is, "why should computer science be taught as a school subject?", another intriguing area for educational study has emerged: the establishment of the academic domain that will be addressed in this particular school subject. According to Driver et al. (1996) and Sjøberg and Kallerud (1997), this kind of study aims to understand the academic area of science and its impact on the daily life of the general public. This is the main argument in favor of including a given topic into the curriculum at a certain grade level. This was briefly discussed in the part before on the de-emphasis of computer science to basic computer literacy. Computer science education (CSE) research, like research in scientific education more recently, aims to prove the subject's inherent worth as a field of study

(Jenkins, 1996; Millar & Osborne, 1998). Understanding how students grasp certain concepts has always been a crucial component of field-specific education research (Ryder et al., 1999; Sierpiska, 1994). Booth (1992) and Navarro-Prieto and Catmas (1999) are two examples of CSE studies that have focused on this same topic. This sort of study is crucial in assisting educators in acquiring pedagogical topic knowledge, thus I hope to see more of it in the years to come. Exploring how different epistemological beliefs influence the way a subject is taught and learned is another area that may be explored in educational research. When studying and describing learning processes, whether in a classroom or elsewhere, it is essential to have a solid theoretical foundation. Anderson et al. (1996), Hennessy (1993), and Säljö (2000) all indicate to a change in the emphasis of this sort of study away from constructivist perspectives and toward contextual learning and sociocultural dimensions of learning. Separate yet related fields of study As we have shown, there will be many methodological and conceptual similarities between subject-specific educational research and a number of other fields of study. Mental health, education, and knowledge are the cornerstones of French didactics. However, its own unique theoretical framework has emerged. ("Gundem, 1998) At least two lines of inquiry into human psychology have established strong ties to the field of computer science. There has been, and continues to be, research into the mental processes involved in understanding how computers work and how to program. It is to be expected that the epistemologically grounded studies outlined earlier would rely on broader psychological and educational discoveries. Cognitive science refers to a large corpus of study that has established a quite distinct connection between computer science and psychology. Artificial intelligence (AI) is a product of research into how computers might mimic human intellect by studying human reasoning, knowledge building, and problem-solving techniques. The creation of "intelligent" educational systems is the focus of CSE-related research in this field. One thing that all the psychological work that has affected CSE so far has in common is that it seems to have been motivated by economic motivations, including reducing human error and boosting productivity in the computer business. I hope that in the future, when they

are trying to teach the next generation of computer scientists, computer science educators would take a closer look at the literature on general pedagogical theory and psychology. Computer science research may also benefit from work in related fields. For example, the fields of human-computer interaction (HCI) and computer-supported collaborative learning (CSCL) are home to a substantial amount of research. The effects of the user interface on the user's thought processes are the focus of this research (Littleton & Light, 1999). Since the majority of a computer science student's work will take place in front of a screen, this also offers crucial feedback to the field of computer science education from a meta-perspective. Many studies on the use of computers in the classroom, which typically investigate various approaches to incorporating digital tools into lesson plans for a variety of disciplines, run parallel to this but are very never linked. Research in CSE and other academic fields may undoubtedly benefit from the contributions made in these two domains. Perhaps it's even more so.

Thoughts for the future

What are/should be the main areas and methods of research in CSE?

To establish research in computer science education as an academic discipline, it is imperative that the wide range of relevant issues is covered. At the same time, it is important to keep some common ground in order to achieve a feeling of identity and belonging within the field. The common ground outlined in the present paper is the common aim of most subject specific educational research – i.e. the facilitation of pedagogical content knowledge for practitioners.

Research methods relevant for carrying out this research will vary considerably, depending on the focus of the individual project. We have established that subject specific educational research is linked with several originally very different research traditions. A researcher in this field must be capable of border-crossing and be able to utilise the advantages that lie in the enormous selection of resources available.

Still it is important to keep in mind what Feyerabend (1975) implied in stating that "anything goes" for scientific research. Anything is possible or applicable

as long as it is well founded in empirical results or in theoretical argumentation. The future work of CSE must have a stronger connection to the theoretical frameworks of education-related disciplines such as pedagogy, epistemology, curriculum studies and psychology.

Who do we expect to pursue these issues?

"... research on learning is usually conducted in departments of educational psychology, whereas research on teaching is usually conducted in departments of curriculum and instruction. Unfortunately, there is often far too little contact between researchers concerned with the two topics." (Shuell, 1993)

Close collaboration between computer scientists and researchers in educational science, psychology, epistemology and related fields is imperative. With such collaboration, we can adapt what is already known to our own subject specific concerns, and build on existing educational research in meaningful and productive ways.

There is a need for more dedicated researchers in CSE, since the majority of work done in the past has been done by computer scientists reflecting on their own teaching practice. In more established educational research, like science education research, there is also an overwhelming majority of scientists doing the work. The difference is that these have usually converted into educational researchers with a solid knowledge of their subject matter. The studies carried out are not based on their own teaching practices so much as on other teachers' practices. The field has grown into an academic discipline of its own with its own faculty positions – sometimes located in a school of teaching and learning and sometimes in their old department. They represent – one might say – the state of the art in pedagogical content knowledge.

Conclusion

So far, there has been a fruitful environment where teachers are exchanging strategies, resources, and ideas to better computer science education globally. But for now, it looks like the computer science education research community might benefit from shifting their emphasis. Future studies may be more grounded in reality if more comparative assessment

and empirical study were conducted. There needs to be more of this kind of effort to disprove the notion that computer science education research is only a vehicle for "teachers to write papers" and to make the argument that computer science education research deserves academic respect as a field.

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