Describing Computer Science Education Research: An Academic Process View

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Abstract

Changing conditions in universities include using new teaching models, and new technologies. The integration of new technology into computer science (CS) and Information Technology (IT) education programmes is often accompanied by studies which aim to understand and improve the teaching and learning process. How we evaluate the potential of emerging technologies and integrate them into teacher education has clearly become increasingly important.

Regrettably, many of the studies conducted by CS and IT education researchers have been criticised for ad hoc experimental processes and lack of research rigour. This paper advocates the development of an applied research framework for educational research in order to enhance the development, deployment and understanding of educational innovation in scientific disciplines.

To develop a framework we have made a survey of some of the corpus of research activities in CS education with the aim of extracting and analysing the underlying principles that contribute to a valuable study of an educational context. Development of an applied research framework has the potential to ensure that studies of educational settings are more complete. This is valuable, since it assists other researchers in understanding the context of the study, thus enabling them to interpret the results and decide how the results might be relevant to their course settings. Such guidelines can also provide a foundation for teacher training programmes that address course design and evaluation of teaching practice.

INTRODUCTION

Research addressing innovation in educational processes in computer science (CS) is increasingly important as educators attempt to understand how learning takes place. Most efforts are centered around answering some version of the following question.

> How do students come to understand concepts and gain the ability to apply concepts and technical/practical skills in computer science? How should the education environments of the future be structured in order to optimize the effectiveness of the "learning experience"?

Investigations that collect and analyse data which yield insights into the impact of innovation in course implementation are in a clear minority in conferences and journals aimed at CS academics. Instead many educators concentrate on describing their course context and teaching practices in an anecdotal manner. One result of this trend in publications is a perception by many practicing teachers that domain specific educational research in many areas, such as computer science, is not a serious endeavour and that the results have little relevance[10].

Education is a complex undertaking comprising elements such as staff, tools, technologies, learning theories and assessment methods; to name just a few. The inter-relationships between these elements are complex, and often hard to describe. Developing an explicit framework within which to structure domain specific educational research activities seems an important next step for CS education research. The advantage of an explicit model is that it can be subjected to criticism, evaluation and refinement.

One goal of a research framework should be flexibility combined with the ability to assist investigators as

they integrate research methods from such disparate disciplines as sociology and pedagogic theory. Thus, the framework we develop here encourages the view that the selection of study methods should be subject to *problematisation*, so that the pros and cons of different approaches are made explicit. Explicit guidelines and established research frameworks will make the study of CS education more easily understood by both practitioners and critics. Thus enhancing the practical impact of studying how learning environments function for teachers at all levels.

The remainder of the paper is structured as follows. Our first section discusses related research initiatives and further motivates the need for adopting a rigorous research framework in applied education research. This is followed by a section presenting what we mean by rigorous applied research in education. We use this discussion to introduce some aspects that we feel are central to researcher-centric research activities. A graphical representation of a researcher-centric view of applied educational research is then presented and explained. The paper terminates with a discussion of our conclusions, aims and plans for future work.

RELATED WORK

CS education research is established, but not mature. Specific CS literature which supports this claim includes reported studies such as that of Daniels et al.[9], Holmboe's work reported in[11] and panel discussions on the topic at the ACM SIGCSE conference[10, 8].

Bootstrapping the skills and abilities of individuals who want to learn techniques and approaches to CS education research has been addressed by some researchers[17]. A more general discussion of how academics view their discipline and practice within their discipline[15, 3] is also partly relevant in establishing a background to our work.

Related work on high level models and the practice of research and research cultures for higher education can be found variously in the works of Prosser and Trigwell[16], Becher[3], and Pescolido[15]. However, these works do not specifically target the academic researcher striving to understand CS education research as a multi-disciplinary endeavour.

How to focus on studies that contribute general understanding of processes and techniques within teaching and learning has been raised by Ahlgren[1], where he categorizes three types of study that can generate useful data when trying to study educational processes. This work, however, falls short of defining a methodology for research. It concentrates on specifying specific types of experiments that the author feels generate useful data.

Other relevant efforts in characterising educational research activity include constructivism[6], and action research[19, 14]. The focus of action research described by Newman[14] provides a model that is relevant, but more general and high level than the types of practical framework we propose.

Constructivism is important in modelling the processes that students follow in establishing understanding and has been promoted in the CS education research context[4], but does not provide the more general framework for applied CS education research that we are seeking. Rather it is one of the pedagogic theories that we are attempting to integrate into a complete research context.

Swepson[18] concentrates on the issue of separating research ideals and methodology in order to increase the practical value of research. This also has a strong resonance with the aims of our research, but falls short of proposing a model for how the separation should be achieved.

We conclude that what is not provided by the current corpus of literature is research which aims to help teachers, the majority of whom have a CS academic education, to get a grip on what CS ed. research is about, the activities involved and the relationships betweeen them.

Our aim here is to bridge the gap between learning theories and social science data analysis techniques and practical educational research in our discipline (Computer Science). Through this, and future, papers we hope to develop, test and publicise a more complete view of what CS ed. research involves. We hope that this will help more researchers to do real investigations" and understand why this is a serious research area. The also aims to framework also provides teachers with the tools and a practical methodology with which to evaluate their teaching practice and measure the benefits of innovation.

A STRUCTURED APPROACH

The theoretical foundations for investigating educational contexts and processes in established pedagogic theory[1] present a view of educational processes and research methods which often has limited relevance and accessibility to CS education practitioners.

One way to combat this is to develop research procedures that are more intuitive to scientists and which

[1]see Langerth et al.[12] for an excellent survey and the foundations of a theoretical model. Additional process techniques are discussed by Nash[13], and structured research discussions in Holmboe[11]

are suited to managing in depth studies of educational settings within computer science. This would help to bridge the gap between ad hoc teaching practices and high level educational theory. There are two benefits of this. First, it becomes easier to explain the role of education research in scientific disciplines. Second, an established research method/framework (the applied education analog of the "scientific method") will assist the recognition of computer science education research as a serious and valid research activity.

The role of this paper, is to identify the key features of one such model in order to strengthen the claim that a structured approach to applied education research provides practical insights that enhance teaching practice and teacher education in CS. Studies of educational settings draw on techniques from social science and educational theory, combining them with the curriculum content specific to computer science. The proposed framework describes how to integrate these elements and create investigative approaches in which general educational principles are combined with domain specific knowledge of curricula, tools and the context of learning.

AN EDUCATIONAL RESEARCH MODEL

Design and elaboration of the context of studies in educational methods for computer science can be investigated from the perspective of applying and adapting existing theoretical models from educational theory literature. Candidate abstractions for educational study design include those of Langerth et al.[12] and Holmboe et al.[11]. However, the direct application of these study techniques to the design of studies in computer science education is problematic. A large part of the problem is the generalist and theoretical nature of such frameworks, which makes them complex and often difficult to apply in practice.

We approach defining an applied framework by identifying the key elements of the educational setting and educational research process (from a researcher-centric perspective). This is the implicit research meta-structure underlying the design and presentation of studies in teaching evaluation and innovation in Computer Science.

The intention of the descriptive research model we have devised is to give a practical applied view of the education research process centered around the aspects most vital to the teacher/researcher in computer science (or perhaps any other scientific field). Using the model helps CS Ed researchers to design more complete studies of educational contexts.

The diagram in figure 1 provides a researcher-centric view of the teaching and research environment in which subject and topic based studies take place. It shows how technologies, students, teachers and researchers are related in the context of an investigation into educational innovation and enhancement. The diagram should be interpreted top to bottom, with the course cloud as the focus of activity. Course related activity can be divided into two broad categories, **influences** and **evaluation/research**.

Influences on a course

The influences on a course are classified as follows, **tools**, **stake-holders** and **education theory**.

By **tools** we mean tools and technologies used to realise aspects of the course environment. Examples of tools are course web sites, laptop computers, computer based teaching products and wireless networking.

Stake-holders refers to the community which have an influence on the content, form and approach taken in designing a course. This category is also intended to capture implicit aspects of the course context such as the expectations of administrators, staff, students and teaching assistants with respect to the course.

Teaching staff, whatever their background, have ideas about how to teach. These ideas might be implicit[2] or explicit [3]. The ideas which form the basis upon which an attempt to create a productive learning experience for students (implicit or explicit) is represented by the **education theory** box.

The tools, techniques, student and staff expectations, and ideas about how to implement an effective learning situation all have an influence on a course and help to define the context of a course instance. We represent the instantiation of a course by the bold arrow linking the course cloud to a rounded box representing a given course instance.

Educational research?

When we investigate an educational setting there is some aspect of what happens in the course context that we wish to learn more about. We denote this the **focus of interest**.

[2]Implicit concepts of teaching and learning approaches tend to be based on prior experience and observation of senior staff. Many teachers with implicit teaching models tend to respond to the question "Why do you teach your classes in that way?", with statements like "This is how I have always taught and I think it works well."

[3]Explicit adoption of teaching and learning models in course design tends to be characterised by comments such as "In this course I will use a combination of peer learning and problem based teaching hoping to encourage students to engage in deep learning activity"

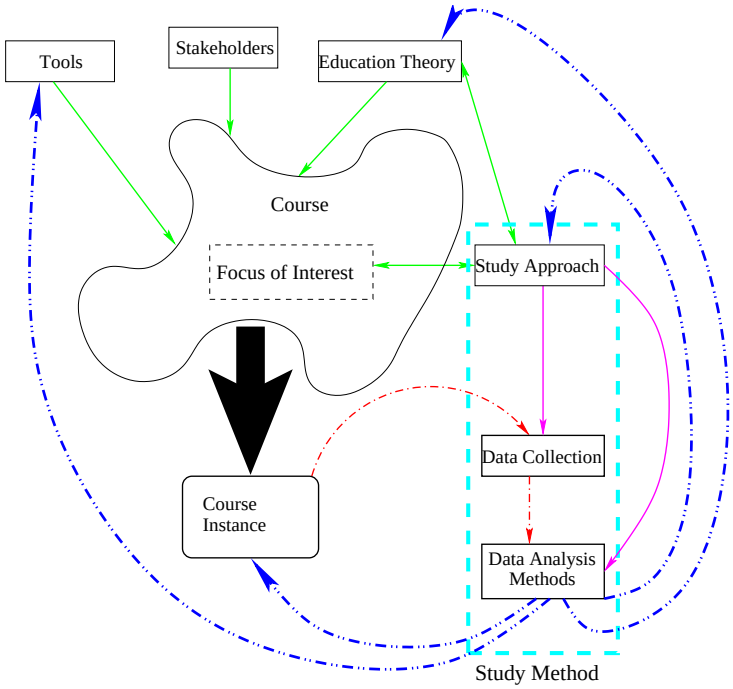

Figure 1: Applied Educational Research

In the absence of a **focus of interest** there is no research. This is, for example, the case in standard courses which are taught without any intention of assessing the impact on students of any aspect of how they are conducted. However, with modern trends towards course evaluation this siutation is becomming increasingly rare.

A course instance is considered to be unique, since precisely the same combination of expectations, individuals, technologies and approaches to the teaching process will never occur again. The **focus of interest**, on the other hand, tends to remain the same over several course instances in most studies. For example, researchers may try to determine how concepts can best be communicated to different classes of learner over many instances of a course.

Investigating a **focus of interest** requires additional types of activity. Namely, **study approach**, **data collection** and **data analysis**. Feedback based on data analysis influences many of the inputs to a course. The heavy dotted arrows show this reverse flow representing the influence of feedback on subsequent course instances and educational research studies.

The choice of **study approach** depends on both the ideas about teaching and learning and the **focus of interest** itself, since the investigative techniques must be suited to the aspects of the learning situation being investigated. **Data collection** techniques are then chosen which provide data relevant to the desired insights into the teaching and learning setting.

Techniques used for data collection in practical investigations include, survey data, interviews and transcripts of electronic communication, time/activity logging and non-intrusive (third party) observation of processes/activities.

Subsequent **data analysis** may involve techniques such as:

- statistical analysis:- which can be applied to coded transcripts, time and activity log data, coded survey data, coded interviews.
- qualitative analysis:- based in theories such as phenomenography[7], activity theory[5], and supported by software qualitative analysis software such as Nud*ist or NVivo[2]. These techniques are usually best suited to presenting variation in experiences and analysing interviews and conversational transcripts.

APPLYING THE MODEL

To see how the model is applied in practice consider a study of an introductory course on computer pro-

gramimng. The lecturer teaching the course has noticed over the years that students tend to confuse the concepts of alternation (choice) and looping. Consequently he wonders how students arrive at their understanding of how alternation and looping works and what sorts of internal models they have for these concepts.

Tools used to teach the course are desktop computers connected to a UNIX server running the gnu GCC compiler, and students are encouraged to install RedHat linux on home computers and use the same compiler there (if they have access to a computer at home).

The stakeholder group for the course is large, since this is the foundation programming course for all degree programmes and the Department as a whole has been involved in defining the content and method of teaching. The teaching approach has been decided by Departmental Commmittee and is not subject to alteration by the lecturer. The student cohort is drawn from a wide range of ethnic and cultural backgrounds, and their only previous educational experience has been at schools where class attendance was compulsory.

The teaching approach (educational theory) is based on a traditional model where lectures are used to introduce concepts followed by tutorials (in which conceptual solutions to practical programming problems are presented and discussed) and laboratories (where students are expected to write programs based on ideas discussed in tutorials). All the lecture material has been pre-prepared as PowerPoint presentations and is presented in a lecture theatre that seats 500 students.

The focus of interest in the study is "What models do students construct as they attempt to understand the operation of alternation and loop constructs in an imperative programming language?" If we can characterise this, then perhaps we can work out why many students appear to believe that an alternation construct implements looping.

Our lecturer has decided to choose a study approach called **phenomenography**. Phenomenography tries to describe the range of ways that concepts are experienced by learners drawing on qualitative data collected through interviewing a sample of the student cohort. This choice of approach determines the data that we collect (interviews) and also defines to a large extent the method used to structure that data and extract insights into how students have understood the course material on loops and alternation.

Future studies can use the initial study to provide a reference point, and investigate the impact of introducing new features to the learning context on the models of understanding that students develop.

For example the lecturer might introduce more practical programming exercises to the labs, requiring students to write programs using loops and alternation. Alternatively introducing Java applets into the lectures and providing the same applets as online revision resources thus providing interactive visualisations of the difference between looping and alternation.

CONCLUSIONS

The outline of the framework that we have presented is the first step in a vital discourse on the nature of structured investigations in CS education. Here we are attempting to elucidate the role of educational investigation, data collection and interpretation techniques. The aim is to enhance understanding of the role and nature of domain specific educational research, and to enhance the generality of specific investigations allowing their results to be deployed in other courses and domains.

The benefits of our approach include the enhancement of techniques for educational research and the emergence of practical insights into teaching practice that have impact on teaching, teacher education. Additional benefits include the development of innovative approaches to curricula and teaching methods for computer science and information technology courses of the future.

Not only do the envisioned outcomes have a practical impact on teaching practice and education of teachers, but also on the formal foundations of educational research within the computer science community. Strengthening the research profile and rigour attached to computer science education and helping to develop this fledgling area into a fully developed discipline with the concomitant research culture resources and cross-disciplinary knowledge necessary to promote scholarship of the highest standard.

Future Work

By proposing a researcher-centric framework of applied education research we hope to stimulate the following areas of activity.

- Work towards developing a foundation for the pedagogic development of the next generation of computer science practitioners at all levels (teachers, pedagogic experts, academics). Devise, test and disseminate guidelines and models for the the conduct of information technology education research.

- Generate practical experiences and results that are well tested and have both general and specific impact on teaching practice and teachers.

- Develop a sense of research community[4] developing both national and international contacts to raise standards and increase meaningful participation in computer science education research .

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[4]One group working towards this is the network based around Computer Science Education Research Groups International (CSERGI). For more information on this initiative see the following URL: **http://www.docs.uu.se/cergi**