Qualitative Research in Computer Science Education

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ABSTRACT

This paper discusses the suitability of the qualitative research approach to computer science education research. It is based on the following two observations: First, only a small proportion of works presented in the computer science education literature contain some experimental component (Fincher and Petre, 2004; Valentine, 2004). Second, those research works conducted in computer science education that do, usually employ a quantitative research approach. This paper focuses on the qualitative research approach presenting its nature, discussing its relationships to the quantitative research approach and addressing its application in general and in the context of computer science education in particular.

Categories and Subject Descriptors

K.3.0 [Computers and Education]: K.3.0 General

General Terms

Human Factors.

Keywords

Computer science education research, Research methods, Qualitative research, Qualitative research in computer science education.

1. INTRODUCTION

Consider the following two research works conducted in order to reveal students' problem-solving strategies in the context of sort algorithms.

The results of the first research are based on a validated test on sort algorithms and an adequate quantitative data analysis method that compared the performance of students who implemented the algorithms in some programming language with that of students who did not implement the algorithms and were exposed only to the relevant theoretical aspects. This research indicates several significant differences in problem-solving performance between students of the two groups. The research is based on a representative sample and claims for conclusions.

The second research presents data obtained from interviews with a small number of students from the two above-mentioned groups, together with its analysis. The results suggest mental processes that may explain how students of the two groups use different sort algorithms. Without any claim for the generalization of its results, the research proposes that its findings can be useful for instructors who teach sort algorithms.

It is clear that these two researches employ different research methods. We propose that the differences depend largely on the objective of the research works in general and on the way in which the research results are intended to be used in particular. On the one hand, if a researcher wishes to know whether algorithm implementation in some programming language influences students' performance of specific tasks that deal with sort algorithms, the qualitative-oriented conclusion about significant difference in students' performance may be of interest to the researcher; On the other hand, if the researcher's objective is to learn about mental processes that presumably guide students of the two groups in a variety of problem-solving situations, the researcher might find the descriptive, interview-based qualitative approach more useful.

This paper focuses on the qualitative research approach which was represented by the second research mentioned above. In a more general perspective, the paper aims at addressing the theme of research in computer science education (CSE), which has recently be receiving a lot of attention from the CSE community (Dale, 2002; Almstrum, Hazzan and Ginat, 2004; Valentine, 2004; Fincher and Petre, 2004; Almstrum, Guzdial, Hazzan and Petre, 2005). Two examples of recently conducted activities that indicate this growing interest are the new SIGCSE committee (under the SIGCSE Committee Initiative) on Teaching Computer Science Research Methods (facilitated by Hilary Holz and Anne Applin) and the Scaffolding Research in Computer Science Education hands-on workshop[1], which aims at introducing higher-education faculty to research in CSE. Participation in Scaffolding involves attending workshops as well as carrying out a research. Our own interest in the application of qualitative research in CSE stems also from our observation that most of the research conducted in CSE employs quantitative research approach. This observation is based on the review of the research articles published in the CSE literature during the past five years.

Joining the growing interest in CSE research and in light of the relative lack of qualitative research in CSE, we aim, in this article, to illustrate how the qualitative research approach, which has been

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[1] The Scaffolding Research in Computer Science Education workshop: http://depts.washington.edu/srcse/.

used for many years in other educational research fields, such as mathematics education, may be used in CSE research.

In order to convey our messages, the paper is organized as a dialog with a Fictional (somehow Skeptical) Reader (FSR) in which we attempt to answer questions that address the nature of qualitative research and its application in general, and in the context of CSE research in particular. In the course of the dialog, illustrative examples of research works in CSE that employ the qualitative research approach are presented.

2. QUALITATIVE RESEARCH: ESSENCE, CONNECTIONS TO OTHER RESEARCH APPROACHES AND APPLICATION

This section addresses questions that might be posed by a CSE researcher who, in general, is considering which research approach to use for his or her planned research and, in particular, is wondering about the suitability of the qualitative research approach for that research.

2.1 What is qualitative research?

FSR (Fictional, somehow Skeptical, Reader): I noticed that the CSE community has recently been expressing growing interest in research. I am aware of the fact that in other educational research areas a qualitative research approach is applied. However, as far as I know, this approach is not usually applied by the community of CSE researchers. Maybe this community is simply not familiar with this approach. As someone who already uses this approach, may I ask several questions about it?

Sure. In fact, I think that this discussion is timely and that there is room for such an examination within the community of CSE practitioners.

FSR: Let we start by discussing a practical issue: In what situations should I consider applying the qualitative approach?

That is a good starting point. The qualitative research approach is usually used for the investigation of social phenomena, or in other words, situations in which people are involved and different kinds of processes, such as educational ones, take place. Within this arena, qualitative research is usually conducted in cases in which what we want to learn about environments, situations and processes can not be retrieved by quantitative data analysis methods. Indeed, quantitative data analysis can shed light on many aspects of such situations and may enable us to argue for a certain degree of generalization. The nature of quantitative research does not, however, enable the researcher to explore all aspects of complex situations. Let me also add that, by the same token, I am not claiming that the qualitative research approach enables us to present a full picture of complex situations either. I am claiming, however, that the qualitative research approach enables us to highlight many angles of people-centered situations.

For example, consider the graduate research conducted by Mariana Teif, the fifth author of this paper. Her research investigates junior high school students' comprehension of basic object-oriented concepts (Teif and Hazzan, 2004). Quantitative data analysis could indeed confirm or reject specific hypotheses that are formulated at the onset of the research, but could it describe and analyze mental processes that take place?

Furthermore, since this research is one of the first research works about object-oriented understanding conducted on junior high school students, had you wanted to formulate hypotheses, what available knowledge would you use to base their formulation on? In addition, how would you obtain the representative sample needed for common quantitative data analysis? The qualitative research setting designed for this research included interviews with pupils from one class that studied basic concepts of the object-oriented approach and observations made in that class. This data enabled the researcher to address, analyze and describe students' learning processes and conceptions of the relevant object-oriented objects.

FSR: I think that in general I understand in what situations qualitative research may be useful. At this point, can you please elaborate on its basic characteristics so that I may grasp its essence?

As I see it, the main characteristic of qualitative research is that instead of aiming at accepting or rejecting an a-priori defined hypothesis, research works that use the qualitative approach aim at constructing a theoretical framework that emerges from the analysis of the data gathered during the research and enables to explain the research results in a coherent manner. Such a framework is called a grounded theory (Glaser and Strauss, 1967). Glaser and Strauss explain: "Generating a theory from data means that most hypotheses and concepts not only come from the data, but are systematically worked out in relation to the data during the course of the research." (p. 6).

This approach naturally inspires a special research setting and process. Specifically, in order to construct a grounded theory, qualitative research is characterized by a spiral structure, in which each phase is based on the previous stages and elaborates on the framework that has been constructed so far. Metaphorically, the qualitative research approach can be described as an on-going dialog between the researcher and the research field, through which the former improves his or her understanding of the later. This approach, which intertwines the development of a theory together with the research process itself, is therefore especially suitable for the investigation of topics that have not been previously researched.

For example, consider the doctoral research, conducted by Victoria Sakhnini, the fourth author of this paper. Her research focuses on senior high school students' learning of abstract data types. Specifically, the research aims at describing students' thinking processes involved in the definition, implementation and use of abstract data types. In the literature survey conducted at the beginning of her research, Sakhnini found no studies that deal with high school students' understanding of this topic. Studies that did examine the learning of abstract data types were conducted on other populations and focused on different aspects than those mentioned above. Therefore, in order to construct a grounded theory, the qualitative research approach was found to be suitable. The iterative research setting designed for this research, allowed a spiral progression of data collection and analysis, and, in parallel, the gradual formulation of a theoretical framework describing the research findings.

FSR: As I understand it, the construction of a grounded theory is one of the more important characteristics of

qualitative research. But is that all that characterizes qualitative research?

Not at all. In fact, as I perceive it, this characteristic is a meta-character of the qualitative research approach from which stem all its other characteristics. At this stage, I would like to mention three additional important characteristics of the qualitative research approach.

First, the data and products of qualitative research are verbal. With respect to the data collection tools, this characteristic of the qualitative research is expressed by the fact that the main data gathering tools are interviews and observations.

Second, the data analysis methods employed in qualitative research aim at directing the researchers to interpret the data from the perspective of the participants in the investigated situation, i.e., to understand the meaning that the participants in the research associate to the researched phenomenon.

Third, …

FSR: Excuse me if I seem to be loosing my patience, but I think that you are overlooking the main argument raised against the qualitative research approach – that is, the question of generalization. What about that?

That is exactly the third idea I wanted to address. In short, generalization has a different meaning in the case of qualitative research. Please let me elaborate on this matter. As I mentioned before, the main target of qualitative research is to construct a grounded theory. In order to do so, the course of a typical qualitative research work is iterative, and is based largely on data collection by means of interviews and observations. As a result of such a research setting, a qualitative research work usually focuses on a relatively small number of participants who are part of the research field. In order to enable the potential reader of a qualitative research to evaluate the relevance of the research findings to the case he or she is dealing with (in other words, to assess the level of generalization of the results of a qualitative research), the research participants are selected very carefully and the description of the research field and its results is very detailed (this writing style is called "thick description").

For example, consider the doctoral research conducted by Yael Dubinsky, the second author of this paper. The research examines the teaching of software development methods (Dubinsky and Hazzan, in press, 2005). One of its aspects focuses on the coaches' perspectives. For this purpose, four coaches were interviewed. The analysis of this gathered data was aimed at eliciting the meaning attributed by the coaches to a new situation whereby they were required to guide their students in software development processes. If you read the paper describing this research, you will see how the detailed description of the research field enables its readers to judge the degree of generalization of the research results with respect to the situation with which they are specifically dealing.

By the way, I might add that there is also a perspective that argues that generalization, in general, is irrelevant for educational situations, and that accordingly, the application of a research approach that aims at generalization, is simply not pertinent in such situations.

2.2 Relationships between the qualitative and quantitative research approaches

FSR: From what you have said so far, I understand that one should consider using a qualitative research approach when aiming at investigating a complex situation that is mostly unknown. I wonder whether it were not possible to study such a phenomenon by formulating a set of hypotheses and examining each of them using the quantitative hypothesis rejection/acceptance approach?

Of course it can be done, and it may be useful in many cases, such as in situations in which one wishes to examine a correlation between two numerical data sets. But I am not sure that our research interest is limited to such situations. For example, how would we employ this approach when examining students' beliefs about CS or the nature of the interaction between different parties in the research field? Indeed, you may formulate a list of hypotheses to be accepted or rejected based on a quantitative examination. I do not, however, see how such an approach will enable you to hear the voice of the field, delving, for example, into the reasons that lead to specific situations.

FSR: Ok. So what about combining the two research approaches – the quantitative and the qualitative? For example, why not start with a qualitative research work, trying to identify the important observations as they are revealed by the participants in the research field. Then, based on the findings of the first stage, test several hypotheses and then, based on the findings of the second phase, start a second qualitative research phase that aims at explaining those quantitative findings.

Good idea. Indeed, it is possible to do that, and here is an illustrative example – the graduate research conducted by Larisa Eidelman, the third author of this paper. This research investigates the high-level CS studies in Israeli high schools (Eidelman and Hazzan, 2005). Specifically, the research focuses on gender and sector-cultural aspects of choosing and persisting in high-level CS studies in Israeli high schools. As you have just suggested, the research was conducted in three stages.

Since no similar previous research has ever been conducted on this specific population, it was irrelevant to formulate hypotheses at the beginning of the research. Furthermore, it was also clear from the start, that the situation is complex and that the research should concentrate on the *social world* of those who are involved in the process of choosing and persisting in high-level CS studies in Israeli high schools. Accordingly, the research began by using a qualitative tool – an open-ended questionnaire – that was analyzed using content analysis techniques[2], and which enabled to identify relevant variables, to determine the research population and to formulate focused research questions.

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[2] Content analysis is a data analysis method used to determine the presence of certain words or concepts within texts or sets of texts. Researchers quantify and analyze the presence, meanings and relationships of such words and concepts, and then make inferences about the messages within the texts, the writer(s), the audience, and even the culture and time of which these are a part. Source: http://writing.colostate.edu/references/research/content/pop2a.cfm

At the second stage of this research the variables that were identified at the previous step were tested quantitatively. Specifically, in order to check connections between gender, sector and the selection and persistence of studying high-level CS, students' answers to a comprehensive questionnaire were analyzed by quantitative analysis techniques.

At the third stage, in order to gain new perspectives on the results obtained from the quantitative analysis of the questionnaire, in-depth interviews were held with female high school students and their teachers, as well as a series of observations in high-level CS classes. The data analysis at this stage was inductive: The analysis began with the identification of the themes that emerged from the raw data and continued with their grouping into logical and meaningful categories, which, at a latter stage, were organized within a comprehensive theoretical framework.

The different research approaches employed in the different stages of this research implied practical considerations, as illustrated by the two following actions. First, the number of participants at each stage was different; while the second quantitative stage involved a large number of participants, the third qualitative stage consisted of a (relatively) small number of participants. Second, while the questionnaire used in the second stage was closed and could not be changed after it was formulated and distributed, interviews conducted at the third stage were semi structured, a fact that enabled flexibility as they were being conducted.

2.3 Application of qualitative research

FSR: Let us see where we stand now. I do see the usefulness of the qualitative research approach and what it can achieve. I also see some relationships between qualitative research and quantitative research. You also mentioned briefly the research tools and I feel that it would be appropriate now to elaborate on them and to focus on the actual implementation of a typical qualitative research. Specifically, how is data gathered and how is the gathered data analyzed?

Let us start with the data gathering tools. The most common data gathering tools used in qualitative research are interviews and observations (which sometimes are recorded on videotape to enable repeated viewing). For example, the main research tool in the research I described about high school students' understanding of abstract data types, was observations in CS classes that studied this subject. The observations provided an opportunity to document the actions, behavior, reactions and additional environmental characteristics in students' natural environment. In addition, in order to learn about students' thinking processes and about difficulties they face in related problem-solving situations, open interviews with the students were conducted in which the students were asked to solve relevant problems in a think-aloud fashion.

In addition to observations and interviews, additional qualitative research tools exist for data gathering, such as researcher diaries, reflections, artifacts and documents. For example, in the research work on teaching software development methods, videotapes and forum messages were among the main means of data gathering; In the research on junior high school students' understanding of object-oriented concepts, the researcher diary enabled to document the goings on in class, in a very systematical way. In

general, each data-gathering tool can complete, deepen and broaden findings obtained using other data-gathering tools.

Different data analysis methods also exist and the main one used for the construction of a grounded theory is the inductive analysis. I mentioned this data analysis method before when I described the research on gender- and sector-related issues in choosing and persisting in high-level CS studies in Israel. The inductive analysis is supported by the constant comparison technique, which guides us to keep examining our findings using information we obtain from different sources (interviews, observations, etc) and different informants.

I would like to add that the application of these data-gathering and data-analysis tools requires experience that can be gained mainly simply by practicing them.

FSR: Indeed, that is a very impressive list of tools. But, what about achieving the research goals? Can you please elaborate on how the actual data gathering and its analysis ensure that the researcher answers the research questions?

Sure. Let me please highlight several aspects of this *not* short and simple process.

First, as you can see from our conversation so far and from the examples of research works I presented, it is suitable to employ a qualitative research approach mainly in the study of personal experiences and processes (such as learning, understanding, teaching, choosing), which are descriptive in nature. Accordingly, and naturally, it would be appropriate to study such topics based on the analysis of verbal-descriptive data – the kind of data with which the data-gathering tools used in qualitative research provide us. Patton's metaphor (2002), in which he metaphorizes (quantitative) questionnaire with a photograph and qualitative interview with a film, is appropriate here. He notes that although both are images, the first (questionnaire) "captures and freezes a moment in time", while the second (interview) "offers a fluid sense of development, movement and change". The above-mentioned research on senior high school students' understanding of abstract data types, which investigates (learning) processes, is one illustrative example of the appropriateness of employing a qualitative research setting for this reason.

Second, the qualitative research approach enables to present the research participants' voice in depth and in detail. The above-mentioned research on students choosing and persisting in studying high-level CS is an illustrative example of the appropriateness of employing a qualitative research setting for this reason. The themes emerged during the research are presented from the participants' perspective and are illustrated by quotes of learners, teachers and other participants in the research field.

Third, interviews enable to search for the origins of phenomena observed during the analysis of data gathered using other tools. For example, in the research on junior high school students' understanding of object-oriented concepts, the interviews enabled to investigate, in greater depth, the origins of misconceptions observed, based on the analysis of questionnaires.

Finally, the spiral nature of qualitative research enables the researchers to gradually improve their understanding of the researched topic. For example, in the research on teaching software development methods, the iterative nature of the (action)

research[3] enables gradual refinement of the emerged teaching framework.

2.4 Embracing qualitative research in CSE

FSR: I must tell you that you are very convincing. But, the more I am convinced about the usefulness of qualitative research in different CSE situations, the more I wonder why it has not yet been embraced by the CSE research community.

Good question, but before I delve into the explanation I would like to mention that the qualitative research approach has been used in CSE ever since the early days of the discipline. For example, Spohrer and Soloway (1986), who analyzed novices' misconceptions in programming[4], stated: "In contrast to the construct-based surface structure approach to program analysis, we have been developing a descriptive theory of buggy novice programs that is based on the cognitive plausible, deep structure knowledge that programmers have: goals and plans" (p. 625). Another example is the phenomenographic research methodology, which is also applied in the context of CSE, and is also based on a qualitative research approach (Booth, 1997).I believe, however, that the potential contribution of the qualitative research approach to CSE research has not yet been fully exhausted.

I am going to address your concern about why the CSE community does not use the qualitative research approach more intensively, and I would appreciate your response. I believe that the root of this phenomenon relates to the communities within which CSE research is conducted. Specifically, in many cases, CSE research is conducted in CS departments, which do not commonly apply the qualitative research approach. In other cases, when CSE research is conducted in psychology or cognitive science departments it is influenced by psychological research methods, which are mostly quantitative.

Let me just add that all the research works that I described in our conversation were conducted in a science & technology education department under the supervision of the first author. Indeed, in science education research, the qualitative research approach is much more accepted, and naturally, in such a research climate qualitative research works are accepted more openly.

FSR: Yes, that makes sense. I will think about it and let you know if I have any comments.

3. CONCLUSION

FSR: Since I must leave now, I would appreciate it if you could just summarize what, in your opinion, are the main benefits one might gain by using the qualitative research approach in CSE?

I would suggest two main benefits: Expansion and deepening of your research findings. Let me please explain.

First, qualitative description may enable us to *expand* our findings. The open nature of the qualitative research may lead us to new, and sometimes even unpredicted, research directions that were not considered at the beginning of the research.

Second, the qualitative approach may enable us to *deepen* our findings. As I said previously, in many cases, CSE research deals with topics related to learners' mental, cultural and social processes. Such processes, by nature, are rich, consisting of many details and perspectives. Accordingly, it is reasonable to assume that if we approach these processes with a qualitative approach, which concentrates on the details that constitute them, we may deepen our understanding of such processes.

In summary, as I have mentioned before, I am not arguing that one approach (quantitative or qualitative) is preferable over the other. What I am claiming is that some phenomena are more suitable for investigation using a qualitative research approach.

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[3] Action research is a research methodology that pursues action (or change) and research (or understanding) at the same time. It is based on a cyclic process that alternates between action and critical reflection, while continuously refining the research methods and deepening the understanding of the investigated action. Source: http://www.scu.edu.au/schools/gcm/ar/whatisar.html

[4] Thanks to Mark Guzdial for these informative data.