Creativity as a Pathway to Computer Science

Maria Knobelsdorf
Freie Universität Berlin
Takustr. 9
14195 Berlin, Germany
+49-30-838-75187
knobelsd@mi.fu-berlin.de

Ralf Romeike
Universität Potsdam
August-Bebel-Str. 89
14480 Potsdam, Germany
+49-331-977-3108
romeike@cs.uni-potsdam.de

ABSTRACT
The study presented in this paper explores characteristics of creativity and the question whether creativity forms a possible pathway into the field of Computer Science (CS). For this purpose, we analyze computing experiences of students majoring in CS and Bioinformatics. The study is part of two research projects exploring creativity in CS Education and students' pathways to CS.

Categories and Subject Descriptors
K.3.2 [**Computers and Education**]: Computer and Information Science Education – *Computer science education*, *Literacy, Self-assessment.*

General Terms
Experimentation, Human Factors.

Keywords
Creativity, CS, Pathway, Wider Access, Computers and Society, CS Education Research, Pedagogy, Computer Biographies.

1. INTRODUCTION
Even though creativity was not the subject of the two of our previous studies, that explored how students learn and understand Computer Science (CS) in light of their computing experiences, they revealed elements of creativity. The characteristics found were quite promising and we decided to reinvestigate the empirical data on creativity. The study presented in this paper explores characteristics of *creativity* that may form possible pathways into the field of CS. For this purpose, we chose *structuring content analysis* procedure.

The paper is organized in the following way: in the next section we describe the empirical data from our recent studies and we explain the reason for reinvestigation. In section 3, we examine related work, discuss the characteristics of creativity in CS Education, and present the research questions of our study. In section 4, we describe the *structuring content analysis* procedure and the corresponding category system. Finally, in section 5, we present the results of our study. The paper concludes with section 6, where we interpret the results.

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2. COMPUTER BIOGRAPHIES
In our research project at the *Institute of Computer Science, Freie Universität Berlin*, we investigate how students learn and understand CS in light of their computing experiences because we want to develop didactical interventions for CS teaching. We assume that students enter the CS classroom not as tabula rasa, but with some existing knowledge and idea of CS. We assume that these preconditions for learning are developed through a learning process which, among other factors, is composed of the interaction with CS artifacts. Our purpose is to elaborate on students' interaction with CS artifacts and the focus of our research is on computing[1] in both formal and informal settings. So far, we have developed a biographical research approach, which allows us to analyze students' individual computing stories in retrospect. Our data gathering method provides autobiographical computing narrations in written form, which we call *computer biographies* [20].

A computer biography is a story a person tells about his or her computing experiences. Typically, a story is told from an individual, subjective point of view and contains only those aspects that the author considers to be valuable and important for the story. When asked to write down their own computer biography, CS majors are eager to explain why and how they became CS graduates. Such texts usually follow a typical narrative pattern and are constructed in a very coherent way. In between we find important experiences that fostered or constrained the students' development. Since computing and CS are closely related (especially for novices), computer biographies reveal information about students understanding and beliefs of CS [6].

In this study, we examine 135 computer biographies that had already been analyzed in two previous studies [6, 20]. The biographies are written by CS majors (72 men, 16 women) and Bioinformatics majors (25 men, 22 women) who have just started higher education. These students describe a great fascination for computing and a great interest in exploring and learning more about computers in connection with the creation of software artifacts. Characteristics that appear here are typical for creative processes. Considering the frequency and the central role these aspects play in computer biographies, it is interesting to examine the role of creativity in pathways to CS.

[1] The term computing refers to all kinds of computer usage and interaction.

3. CREATIVITY

In our research project at the University of Potsdam, we investigate the impact of creativity in CS Education. The intermediate results show a positive correlation between the use of creative tasks and student motivation and student outcomes in secondary education CS classes.

3.1 Definition

The term "creativity" has been used with different meanings and has been discussed controversially in the field of psychology. Correspondingly, research in creativity focuses on a variety of aspects, such as identifying, assessing, and fostering creativity. Moreover, various dimensions such as a creative person, creative process, influence of environmental factors, and creative products are explored in creativity research (see e.g. [16] for further consideration).

In contrast to historical creativity, which describes ideas that are novel and original in the sense that nobody has ever come up with them before, p-creative designates something that is fundamentally novel to the particular person [1]. In educational context, p-creativity is based on knowledge in practical form as well as on the willingness to acquire and use this knowledge. We consider learning processes from an individual's perspective as described by Boden [1].

With this in mind, we call a phenomenon "creative" in this paper when it leads to original, adaptive, and useful ideas, solutions, or insights (cp. [5, 17]). Typical characteristics of creativity include high interest, intrinsic motivation, enjoyment, and individual's challenge by the work itself (cp. [18]).

3.2 Creativity and CS

Computer science, as computer scientists see it themselves, is a creative field to work in, where creativity is demanded and encouraged (for example [3, 8, 19]). Astonishingly, creativity is rarely reflected in CS education research. A current key word "creativity" search in the ACM Digital Library provides us with only few publications related to education. These publications can generally be assigned to few groups in the contexts of student motivation, how CS or activities in CS are perceived, and ICT (Information and Communication Technology) for supporting creative practice:

1. In programming courses, allowing and encouraging students to be creative increased motivation and interest [9, 10, 15]
2. Students of CS perceived software development as creative, and these phases were preferred [4, 13]
3. Computers and software tools can support creativity [2, 21, 22]

In [14], we proposed a model where three comparable dimensions of creativity in the field of CS and their impact on CS education were illustrated and described. To sum the dimensions up: in the PERSON-dimension, the influence of creative work on motivation and interest is described; the SUBJECT–dimension identifies creative processes as being central to software development; and in the ENVIRONMENT-dimension, the impact of computer software and its support of creativity is pointed out. These three dimensions can affect learning processes in CS.

From the professional perspective, factors related to the PERSON-dimension were found in studies about programmers' motivation in open source projects. In these studies, creativity-related factors – namely how creative a person feels when programming – were revealed to be the most pervasive drivers for engaging in the projects [7]. The following creativity-related factors were identified: usage, intellectual stimulation, reputation, identification with the group, learning, and altruism. We will refer to these and other factors as indications of creativity when analyzing computing biographies.

3.3 Research Questions

Research in CS Education reveals the occurrence of creativity in learning situations in schools and at universities. When considering the computer biographies of CS students, learning processes and their motivations are also described. Being interested in the question whether creativity forms a pathway to CS, we state the following research questions:

1. (PERSON) Is the motivation that encourages students to become involved with CS connected with creativity? Intrinsic motivation is the most important component in creative performance. This can provide teachers with two implications: First, if the students are already intrinsically motivated due to creative experiences in CS when starting CS studies, this should be used and fostered in the course. Second, finding the factors that trigger intrinsic motivation helps to determine scenarios, activities, and aspects of CS that may motivate other students to engage creatively in CS as well.
2. (SUBJECT/ACTIVITY) Do students perceive CS (and therefore the activities that characterize the subject) as creative? CS can be a creative field to work in. However, this is not necessarily obvious for someone who has just begun to be active in the field. CS activities that students who decided to major in CS had attributed and perceived as creative may encourage other students to do so as well.
3. (ENVIRONMENT) Do student biographies reflect ICT as a creative environment? ICT provides tools that support creativity. However, computers offer many possibilities for keeping oneself busy in a non-creative way as well. Identifying software that can be used creatively could help teachers to choose the right tools and tasks for fostering creative work in a well directed way.

In addition, we are interested in finding out how students reflect the role of school and CS class. CS is taught as a non-obligatory subject in all German high schools. This offers every student a chance to learn about CS in school and should motivate students to choose CS as their subject for their studies. Students who have already learned about CS within their free time should get the chance to extend their knowledge, obtain inspiration, and be reinforced in their creative involvement with CS. Answers to these questions help to evaluate whether and how much CS lessons succeed, how well such important tasks are fulfilled by CS high school education, and, if necessary, which interventions can influence the teaching process in a positive way.

4. ANALYSIS PROCEDURE

Our purpose is to reinvestigate the computer biographies of CS majors under the characteristics of *creativity* that have already been determined. For this purpose, we chose the *structuring content analysis* developed by Mayring [12]. "*Structuring content analysis* seeks to filter out particular aspects of the material and to make a cross-section of the material under ordering criteria that are strictly determined in advance, or to assess the material according to particular criteria" ([11], p. 269).

4.1 Structuring content analysis

In this subsection, we very briefly outline *structuring content analysis* by Mayring in order to explain our data analysis to the reader.

Structuring content analysis is divided into several consecutive steps. First, the structuring dimensions must be determined in accordance to the research questions and the theoretical background. These structuring dimensions are subdivided into categories. The categories, together with coding rules and related textual passages, form a category system. After the first coding process with approximately 10-50% of the data the category system is revised. Then the final data coding is performed. After structuring the data in a very precise way, the coding results are processed. The last step can be taken with different purposes. We chose *type structuring* because it provides typical aspects of the structuring dimension; in our study, the typical aspects describe the role of creativity in pathways to CS.

Our structuring dimensions are called *Person*, *Environment*, and *Subject,* and we developed them based on the theoretical background and the research questions from the previous section. In order to guarantee the inter-coder reliability, the authors developed the category system together and coded the material in a peer-coding process. The corresponding category system is presented in the next subsection.

4.2 Category System

Based upon [14] and our research questions, we got three main categories: *Person*, *Subject*, and *Environment* The following paragraphs present subcategories and codes developed for each of the main categories. .

The main category ***Person*** has two subcategories: ***Motivation*** and ***Habits***. ***Motivation*** contains the following codes (italicized and bold) that refer to students' motivational aspects: doing something because it is a ***challenge, fun,*** and/or ***interesting***; ***producing for usage*** (doing something in order to use it); and to be motivated due to the ***identification with a group*** *or* ***with an artifact***; doing work that is ***original,*** provides ***reputation*** and ***relevance,*** and benefits others (***altruism***).

The subcategory ***Habits*** contains the following codes (italicized and bold) that refer to students' behavioral aspects in creative working and studying: creative or adaptive responses may begin with the ***ability*** to think ***critically*** or ***evaluative***, to ***sense problems*** or the need to act, to see the gap between knowledge and understanding, and to ***see opportunities*** to create new products or ways of behavior; learning strategies contain the ability ***to explore***, ***to experiment***, and ***to behave actively*** both ***in*** and ***outside school***.

The main category ***Subject*** focuses on the creativity characteristics of CS. This category contains the following codes (italicized and bold) that depict these characteristics from students' perspective: CS is a ***creative subject***; things done in CS are comparable with producing ***art***; ***problem solving*** requires creativity, for example searching for ideas; the purpose of a creative activity is ***product (artifact)-oriented***; the principle of ***building blocks*** is typical for CS and supports creative working as well; the working process is triggered by an ***incentive***, it requires ***knowledge***, has ***restrictions***, and can be solved ***through experiments***.

The main category ***Environment*** refers to the question how computers and the usage environment are perceived. This category contains the following codes (italicized and bold written): software and IDEs (integrated development environments) provide ***possibilities*** for creative working; an ***atmosphere of diversity*** can be inspiring, for example a computer club gives the opportunity for ideas exchange, provides mutual encouragement and excitement; and ***creativity support*** supports activities that results in individually new and usable solutions, artifacts and understanding.

We applied this category system to the biographies using the coding-software MAXQDA [MAX]. The results of the data analysis are presented in the next section.

5. RESULTS

In this section, the results are presented in a way that roughly reflects the analysis. First, we describe which aspects of the category system we found in the biographies. Next, we analyze the outcome using the research questions from section 3.3.

5.1 Is the motivation that encourages students to become involved with CS connected with creativity?

Concerning the main category *Person,* we were interested in the motivational aspects and habits. From all codes referring to these fields, in approximately 1/3 of the biographies, we found descriptions of students' motivation for computing and habits corresponding to characteristic factors of creativity.

Interest for computers, the most frequently expressed motivational characteristic, appears in various connections: fascination and curiosity for the computer and its functionality in the broadest sense; fun and enthusiasm for working with the computer, for example:

"Even though my first PC wasn't particularly fast or stable, I was yet fascinated by the machine's endless possibilities and I tried to explore it and experiment with it as far as I could […]." [058CS1987mU7] [2]

Not being necessarily an indication of creativity by itself, 'interest' relates more visibly to creativity when it is considered in context of the statement: interest, fascination, and fun appear in activities that comprise creative work such as web-page design, tinkering around with hardware, and programming. In addition, programming offers possibilities to create and design artifacts, to explore different ideas,

[2] This code identifies a biography. The first number is the biography number; the upper-case letters refer to the student's major subject (where B stands for Bioinformatics and CS for Computer Science); the second number is the student's year of birth; the lower-case letter refers to gender (f stands for female and m for male); U7 refers to the study. All quotes from the biographies were originally written in German and have been translated by the authors.

and to work independently. See the next text example for illustration:

"[CS class] was also something different. You didn't need to sit there, listen to the teacher, take notes etc. You could work independently and write programs." [127B1987fU7]

All statements that refer to 'interest' refer also to learning and working habits: working autonomously, creating something on one's own, active and autonomous exploring and learning are the most frequently mentioned aspects of the category habits.

Even though we found biographies where students mentioned just to be interested in computers, some of them wanted to understand computer functionality for a particular, practical reason - they wanted to know something in order to solve a particular problem. Therefore, we could identify two groups: one group is interested in computers and is also fascinated by the possibilities it offers. For them, originality, identification with original work or produced artifacts were an important aspect. This group likes to experiment with and explore the computer autonomously. The other group is interested in computers as well, but more with the purpose of one's own scope of use in mind. For some students reputation that they gained through the acknowledgement of their work and expertise by their friends and family is an important aspect. This also reveals some form of pride as a factor.

Hardly anyone mentions *critical thinking*, *evaluation ability*, and *problem spotting* – all very important characteristics of creativity. However, our data gathering instrument did not ask the students to write about these aspects, which might be the reason of their absence.

All the negative comments or voices of disappointment refer to CS classes, which are generally described with a negative shade. Students that belong to the second group criticize mostly the teacher's lack of knowledge and poor communication skills. In contrast, students that belong to the first group judge their CS classes positively when the teacher was motivated him- or herself and created a learning environment that supported autonomy.

5.2 Do students perceive CS (and therefore the activities that characterize the subject) as creative?

Students' computing activities develop through the biography, as examined in our recent study [6]. The activities mostly start with gaming, followed by exploring applications and their possibilities, experimenting with the computer, knowledge gathering, and the Internet usage. Along the way, they discover programming mostly for creating web pages. By the time, some students have CS as a subject in school and continue to learn how to use the computer or write programs. Hence, many computer biographies contain a considerable part as a programming biography:

"The big turnaround happened when I started to learn Java programming in the 11th grade because now I was able to create programs according to my own wishes [...]." [026CS1986mU7]

While the first mentioned above activities do not really relate to CS, programming itself does. Programming influences students' image of CS. Therefore, we found product (artifact) orientation as the most frequently mentioned creativity characteristic of CS. However, we could not find any of the other characteristics.

Problem Solving is a central ability in CS and it is emphasized in CS classes in schools and at universities. Furthermore, problem solving is also an important ingredient in creativity. However, in the biographies this aspect did not appear explicitly at all. Problem solving was described implicitly when the students described their programming experiences. The perception of understanding problems as a challenge to achieve a goal is very motivating for the students as opposed to solving problems in order to satisfy the teacher or to receive a good grade.

CS class meets students' expectations when the subject matter contains programming and working on projects. Subject matter that focuses on *the computer usage per se* is evaluated very negatively.

5.3 Do student biographies reflect ICT as a creative environment?

In creative computing pathways, with the first access to a computer, students gained the opportunity to do things that they had not been able to do before:

"A PC offers really amazing possibilities." [092B1988mU7]

Thus, the start of a "career" in CS is initiated with the first computer contact. Soon its possibilities are explored and finally it is used to create software artifacts. At this point the computer is seen as a creative tool, as described by [21]: it supports the user in gaining relevant knowledge; provides the basis for exploration and experimentation; offers immediate feedback (this concerns mainly programming languages and/or web design); and allows disseminating the results to others, for example by publishing a personal web page online. Apparently, the Internet serves as a catalyst: it serves as a source of information, inspiration, and stimulation as well:

"With my first Internet access [...], I was able to expand my knowledge continuously and even prove it through creating web pages." [002CS1985mU7]

Only in few biographies a related person is mentioned as relevant: a parent from the CS field; a friend who shares the interest; or an inspiring teacher.

6. CONCLUSIONS

The results of the study show that characteristics of creativity are reflected in computer biographies of students who chose to major in CS. These students particularly perceive CS as fun, creative, and autonomous; which is typically described in the context of programming. We identified striving for well working software as the main motivator for engaging in programming. In the majority of programming processes, tasks chosen by students themselves are meaningful to them, but often surprisingly irrelevant as a product. In these processes the activity (mostly programming) is most important, which is typical for creative processes and known from artists. This group of students is fascinated and interested in the possibilities that a computer offers them. They express a strong desire for gaining further knowledge, exploration, and understanding. We consider the activities of this group as highly creative.

Another group of students shows fascination and interest for the computer as well, but in a more pragmatic way. For these students the efficient computer usage is central. Knowledge gathering is understood as necessary for using the computer and solving problems more efficiently. While the approach of the second group fits CS lessons offered in schools, the students who enjoy becoming involved in creative activities often describe their lessons as disappointing. Apparently, a bigger emphasis on creativity in CS classes is needed in order not to bore and loose more creative students. Possibly, even more students can be won, if they discover the creative side of CS.

Are the produced software artifacts useful, as it is required by our definition of creativity? The usefulness needs to be looked at from a personal point of view as well. However, while a certain use of games and web pages exists, commercial products are obviously more advanced. However, this aspect does not seem to be essential to students. The process of producing meaningful artifacts is perceived as creative. It seems to be as equally important as the use of an artifact, if not superior to it.

We are impressed by the motivation, fascination, and stamina when gathering relevant knowledge, and enthusiasm that are expressed by the students in respect to their creative activities. In school settings this attractive perception of CS seems to be less likely to occur. A typical school environment includes factors known for suppressing creativity: early evaluation, surveillance, reward, competition, and limited choice. Furthermore, in many CS classes students' activities are primarily understood as "solving the teacher's problems". Here we see that a change towards an intentional consideration of creativity in CS classes is needed. This would include hands-on and discovery learning, assigning open tasks, as well as product-orientated tasks in formal learning settings. Accordingly, the fascinating efforts students show towards CS out of personal interest could be encouraged and fostered for a successful understanding of CS. Therefore, we want to encourage educators to inspire the students to work creatively in CS classes.

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