What about Creativity in Computer Science Education?

Anisija Žižić [1]; Andrina Granić [2]; Michael Paul Lukie [3]

[1] Elementary School Petar Kružić, Split, Croatia

[2] University of Split, Faculty of Science, Split, Croatia

[3] University of Winnipeg, Faculty of Education, Winnipeg, Canada

Abstract

Not all educational institutions encourage creativity and it is therefore vital that more attention be placed on the importance of understanding specific strategies that foster creativity at all levels in the classroom. Creativity conferences and workshops have become internationally common and have resulted in positive change-based initiatives in the field of creativity. These creativity research initiatives have attempted to provide a framework for educating "digital natives" and this framework provides the knowledge and skills necessary for students in the 21st century. We suggest that the development of creativity should be fostered with students through creative thinking and problem solving. This targeted development of student creativity may increase their personal fulfillment and increase their employability in our changing knowledge-based societies. In addition to creativity representing an important 21st century skill, it is a field that has experienced increased awareness, and it is fundamental to who we are as human beings. This paper presents definitions, theories, and achievements in the field of creativity from the educational domain of computer science.

Keywords: Creativity; evaluating creativity; computer science; computer science education; e-learning.

Introduction

Over the recent decades, there has been a substantial increase in the topics, perspectives, and methodologies related to creativity literature. Recently, the psychological understanding of creativity has become more sophisticated although the field of creativity has become increasingly fragmented. A concern within creativity scholarship is the issue that arises when researchers in one subfield of creativity are often entirely unaware of the advances in another subfield of creativity (Hennessy and Watson, 2016). Since creativity is considered to be an essential 21st century skill, the study of the creativity concept referred to as idea generation (ideation) has gained importance. Significantly, idea generation (ideation) is necessary when information and knowledge are available anywhere and anytime. Without establishing an educational and operative culture that understands the importance of creativity, we are unable to adequately "prepare young people for jobs that do not yet exist, using technologies that have not yet been invented, to solve problems of which we are not yet aware" (Jones, 2014, p. 2).

Computer science education (CSE) is an effective starting point for implementing changes in learning and teaching that support creativity. CSE supports the development of creative skills and problem solving in educational areas such as school subjects, university courses, and everyday life. As opposed to teaching to the test and memorization, educational goals should promote the application of knowledge and skills in novel and unfamiliar conditions (e.g., new situations, new surroundings, limited resources). In order for researchers to determine a way to support creativity in CSE, they posed questions regarding the connection between computer science (CS) and creativity. These questions included CS students' experiences reflecting creativity, creativity supporting teaching and learning in CSE (formal, informal, e-learning systems, mind mapping), criteria for creative CS lessons, frameworks for fostering creativity in higher education, and in developing Creativity Support Tools. The results of this research suggested a solid foundation for changing CSE that includes creativity supports. However, these changes may also be applied to other educational domains. Some of these changes that may be applied include the use of simple creativity techniques and include creativity supports applied to complete course changes.

E-learning is beneficial for supporting creativity in CSE but requires an innovative pedagogy that emphasizes the engagement and the motivation of students. Ubiquitous IT is useful for evaluating creativity and is especially useful in developing new instruments appropriate for CSE. However, the most frequently used instruments are intended to only measure creativity in a general context. Using technology to assist learning is complex and requires careful planning. In addition, using technology has the potential to enhance implicit, informal, and formal learning. Technology may be applied to strengthen the connections between perceiving, learning, knowing, and action while providing scaffolding for unsteady attempts at tackling new problems. Technology may also be designed to shape our behaviors in ways that we only subsequently come to understand, to endorse, or to reject (Goodyear and Retalis, 2010). The rich and growing possibilities for connecting technology, creativity, and CSE, to enhance human creativity should therefore be of great interest to education professionals.

Creativity: Definition and theories

Modern creativity research began in the 1950s and 1960s (Sawyer, 2012) and Guilford (1950) was credited with the earliest research defining creativity. Guilford (1950) identified two phases of the creative process, divergent thinking and convergent thinking. Divergent thinking was characterized as the ability to produce a broad range of associations to a given stimulus or to arrive at many solutions to a problem, while convergent thinking was characterized as the capacity to quickly focus on the one best solution to a problem (Guilford, 1950). Torrance (1966) recognized that cognitive variables such as ideational fluency, originality of ideas, and sensitivity to missing elements form the basis of the creativity phenomenon. In addition, Torrance Tests of Creative Thinking (TTCT) were developed to measure creative thinking in verbal and nonverbal ways (Hebert et al., 2002). Although there has been no consensus regarding the definition and the assessment of creativity (Walton, 2013), the most widely used working definition of creativity states that "creativity is the ability to generate ideas and artifacts that are new, surprising, and valuable" (FET Workshop, 2013, p. 1).

According to Ruth Noller[1], a symbolic equation for creativity may be represented as $C = ƒa(KIE)$. In this equation, creativity is generated by the interaction between Knowledge (K), Imagination (I), and Evaluation (E), where (a) represents the individual's attitude. The Creativity term (C) may be distinguished as everyday creativity, historical creativity (h-creativity), psychological creativity (p-creativity), group creativity, non-human creativity, technological creativity, artistic creativity, or spontaneous creativity. Creativity has a multiplicity of definitions and as a result, there are many questions that remain unanswered in the field of creativity research. Some of these unanswered questions include the following: What is the priority of person-centered or systemic methods in creativity research?, What methodological significance do quantitative or qualitative approaches to analyzing the phenomenon provide?, Is creativity a general or a context-specific phenomenon?, Can animals or machines be creative?, and Should the development of creativity be the primary research focus or should the conditions under which creativity originates be the focus?

Creativity and computer science

Saunders and Thagard (2004) examined the question, How is creativity related to CS? The study analyzed historical examples of creative problem solving in CS and analyzed 50 research interviews[2] conducted with working computer scientists in academia and industry. The research

[1] Ruth Noller (1922-2008), distinguished Service Professor Emeritus of Creative Studies, State University College at Buffalo [SUCB], leveraged her background as a former professor of mathematics to develop a formula that elegantly described the factors that produce creative behavior.

[2] Published in the on-line student magazine "Crossroads" (Association for Computing Machinery (2002).

determined that when a computer scientist (with the appropriate background and ideas) becomes frustrated with a repetitive, boring, and difficult task, their frustration could be ameliorated through the incorporation of new technologies and through the creative contributions of computer science. In addition to technological frustrations with CS, other areas of interest include the intrinsic pleasure of building computers, financial interests, and the writing of computer programs. An example of the application of creative problem solving within CS includes the use of local and distant analogies. Local analogies (LA) relate problems from the same domain or from very similar domains (e.g., Engineers from Apple Computers were influenced by the 1979 Xerox Palo Alto Research Center and their development of menus, windows, and user-friendly word processors.) while distant analogies (DA), relate problems from different domains (e.g., the application of biological genetic algorithms to CS neural networks). Both local and distant analogies may be combined to provide new pathways of thinking and invention within the field of CS. One such example of this combination is Alan Kay's invention of Smalltalk, an object-oriented, dynamically-typed, and reflective programming language. The principles of Smalltalk could be traced to Sketchpad and Simula (LA), and to the distant analogy (DA) Kay recognized between object-orientated programming and biological cells.

In addition to understanding the historical cases of human creativity in computer science, it is also important to understand how creativity in computer science relates to the creative processes of working computer scientists. To understand the creative processes of computer scientists, 50 interviews were conducted where computer scientists were asked the following questions: What do you do to get yourself thinking creatively? and What is your problem-solving strategy? The analysis of the interviews revealed that computer scientists exhibited two modes of creative work, an intense mode and a casual mode. The *intense mode* was described by the participants as the mode that most looked like work while the *casual mode* was described as the mode where creative thinking usually involved inspiration striking during a break from work.

Table 1: Intense and casual mode activities performed during creative work of interviewed computer scientists in academia and industry.

	INTENSE MODE	CASUAL MODE
A C T I V I T I E S	**writing** ("writing stuff down, often free-flow"; "blank paper lets you develop an idea in any form you can scribble"; the pencil and paper help to capture thoughts and preserve them beyond the span of short term memory) **experimentation** **examples** **pictures** **lists** (a list of the various issues; numbered list of the steps to take when solving a problem) **problem solving** (restatements of the problem; "anything that could help crack it open"; "first lay out all the options"; "ask myself questions"; "determine the components and parameters of the problem") **relatively rational and systematic work** **creative communication** (conversation; "bouncing ideas off"; "brainstorming with"; whiteboards)	**physical exercise** (running, hiking, bike riding, "Go to the beach and run and run and run! Then think and jot things down quickly, saving the refinements for later.") **martial arts** **driving** ("...gives me a lot of time to contemplate and just let my mind range from topic to topic... ") **subway ride** **shower** ("Once I have a problem, it becomes part of me, and ideas come up mostly in non-work situations. I came up with a major idea for my thesis while in the shower. ") **lying in bed** (getting great ideas in the middle of the night or on waking) **getting stimulated creatively by any kind of creative work** ("A good film or art exhibit or any creative work done with excellence can inspire me as much as computing. ", "Reading someone else's creative material starts the juices flowing again. ", "Reading articles in Science magazine about biology or something else completely outside of what I usually do is also stimulating.")

Although the intense mode appears to be less creative than the casual mode (when ideas come out of the blue), the intense mode appears to be a critical component of a computer scientist's creative work. The research determined that creative researchers will typically organize their days to provide time for both modes but the intense mode remains most responsible for many important discoveries. Herman Helmholtz would agree and suggests that "Creative ideas...come mostly of a sudden, frequently after great mental exertion, in a state of mental fatigue combined with physical relaxation."[3]

Romeike and Knobelsdorf (2008) examined the characteristics of creativity by exploring if creativity forms a possible pathway into the field of CS. For this study, the computing[4] experiences of students majoring in CS and Bioinformatics were examined. A biographical research approach was employed where 135 computer biographies, written by CS majors and Bioinformatics majors (all novices), were examined. The research defined the *Computer biography* as a personal narrative where the participant described his or her computing experiences. The student biographies revealed information about the students' knowledge and beliefs about computer science and their interactions with CS artifacts.

The term "creative" is referred to by Romeike and Knobelsdorf (2008) as an action that leads to original, adaptive, and useful ideas, solutions, or insights. The term also includes the typical characteristics of creativity and these include high interest, intrinsic motivation, enjoyment, and the challenges individuals encounter as the result of the work itself (Ruscio and Amabile, 1996). In contrast to historical creativity, which describes ideas that are novel and original, p-creativity (psychological creativity) refers to ideas that are fundamentally novel to the individual (Boden, 2004). From an educational perspective, p-creativity is based upon practical knowledge and the willingness of the individual to acquire and to use this knowledge. Romeike (2007a) proposed a model where three comparable dimensions of creativity in the field of CS and their impact on CS education were described and illustrated:

1. Person - A dimension that describes the influence of creative work on motivation and interest.
2. Subject/Activity - A dimension that identifies creative processes as being central to software development.
3. Environment - A dimension that describes the impact of computer software and its creativity supports.

The three dimensions Romeike (2007a) describes may affect the CS learning process. Therefore, the three dimensions of this model were combined with the structuring content analysis[5] developed by Mayring (2004) to help describe the role of creativity in pathways to CS found in Table 2. Table 2 presents a framework of the study and the research questions, the codes, and the results are further sub-divided into the three dimensions according to Romeike's model.

The results of the Romeike and Knobelsdorf (2008) study indicated that the characteristics of creativity were reflected in the biographies of the students who chose to major in CS. The biographies revealed that students perceived CS, from the context of programming, as fun, creative, and autonomous. Students identified that when they engaged in programming their main motivation was to produce effective and working software. In the majority of student programming processes, students identified some chosen tasks as meaningful and identified some products as irrelevant. Students identified the process of programming as most important to them, which is typical of creative artists. The computer science students were fascinated and interested in the possibilities that the computer offered them. The students represented highly-creative student factors and they expressed a strong desire in gaining further knowledge, exploration, and understanding about the computer. In addition, some of the students who enjoyed becoming involved in creative activities,

[3] A quote by Hermann Helmholtz (1821–1894), a German physician and physicist who made significant contributions to several widely varied areas of modern science: physiology, psychology, physics, philosophy.

[4] Term computing refers to all kinds of computer usage and interaction.

[5] Structuring content analysis is qualitative research method which 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.

often described their CS lessons as disappointing. Therefore, CS education must emphasize creativity in the classroom to ensure greater student intellectual engagement and to reduce student withdrawal from these CS classes. It is anticipated that more CS students may choose to pursue further study in CS when they discover the creative benefits to be gained in the CS classroom.

Table 2: A framework of the study whether creativity forms a possible pathway into the field of Computer Science (CS).

	PERSON	SUBJECT/ACTIVITY	ENVIRONMENT
Research question	*Is the motivation that encourages students to become involved with CS connected with creativity?*	*Do students perceive CS and the activities that characterize it as creative?*	*Do student biographies reflect ICT as a creative environment?*
	In addition, students' reflection on the role of the school and CS classes were considered.		
Codes	**Motivation:** challenge, fun, interesting, producing for usage, identification with a group or with an artifact, doing original work, reputation, relevance, altruism **Habits:** ability to think critically or evaluative, to sense problems, to see opportunities, to explore, to experiment, to behave actively in school and outside school	Creative subject, art, problem solving, product (artifact) – oriented, building blocks, incentive, knowledge, restrictions, experiments	Possibilities for creative work, atmosphere of diversity, creativity support
Results	In 1/3 of the biographies descriptions of students' motivation for computing and habits corresponding to characteristic factors of creativity were found. Interest for computers is the most frequently expressed motivational characteristic. Two groups were identified; one group is fascinated by the possibilities computers offer (originality, experimenting, autonomously exploring computers are important aspects) and the other one is interested in computers in more pragmatic way (efficient computer usage is central; knowledge gathering is necessary for using the computer and solving problems more efficiently). All the negative comments refer to CS classes -generally described with a negative shade (teacher's lack of knowledge and poor communication skills are mostly criticized).	Product (artifact) orientation is the most frequently mentioned creativity characteristic of CS. Problem solving was described implicitly in students' programming experiences. CS class meets students' expectations when the subject matter contains programming and working on projects; computer usage per se is evaluated very negatively.	Computer is seen as a creative tool – it supports user in gaining relevant knowledge; provides the basis for exploration and experimentation; offers immediate feedback; allows dissemination of results to others. Internet serves as a source of information, inspiration and stimulation. Only in few biographies a related person is mentioned as relevant: a parent from the CS field, a friend with the same interest or an inspiring teacher.

Applying creativity in computer science education

Jahnke, Haertel and Wildt (2015) determined that creativity is difficult to teach. However, the culture, the broader "environment", the teaching methods, the learning scripts, and the "structures" may be arranged in such a way that fosters learners to become more creative. An optimal creative learning culture includes the following six aspects and they have been developed from empirical findings:

1. Fostering student independent and self-reflective learning.
2. Enabling students with the ability to work autonomously.

3. Supporting research curiosity and increasing the motivation to learn.
4. Fostering constructive learning environments where users create a product.
5. Fostering a new culture of thinking through the pursuit of multi-perspectives.
6. Providing students with the opportunity to develop original and entirely new ideas.

According to Resnick (2007), the spiraling cycle of imagining, creating, playing, sharing, reflecting, and then finally returning to imagining is ideally suited to the needs of the 21st century. Resnick (2007) also contends that such a spiral cycle assists learners of all ages to develop their creative-thinking skills.

A number of EU funded projects began in 2012-13 with the goal of facilitating a positive impact on technology-enhanced learning. The projects were specifically designed to assist computational environments for educational purposes and their focus centered upon current understandings of creativity in education and creative thinking. This creativity research has led to the development of Creativity Support Tools (CSTs). These tools were developed as a means to enhance creativity beyond the classic psychological methods and the combination of learning models served to provide creative learning environments. Some of the Web-based CSTs available at no charge include the following: (1) HatParty[6] for brainstorming and to motivate students to produce new ideas; (2) Bright Sparks[7] to provide students with new problem solving points of view; and (3) C-book[8] to ignite student creative mathematical thinking (Zizic, Granic and Sitin, 2016).

Criteria for designing CS lessons

Romeike (2007b) concluded that school-based CS lessons provided fertile ground for creativity and he described specific criteria for designing creative CS lessons (Table 3). A sample lesson is presented for introductory programming in a German high school where a creativity framework based upon these criteria is applied. The criteria for creative CS lessons are based upon the findings from psychological and educational literature and may be implemented when designing and evaluating computer science lessons. In addition, the criteria reflect and combine general pedagogical principles that are essential and beneficial for creative practices in CSE.

Romeike (2007b) applied the Criteria for Creative CS Lessons to an eleventh grade German high school class by introducing them to computer programming. The visual programming language Scratch[9] was chosen as the programming language and it was additionally used as the creativity supporting tool. Student attention and motivation were fostered within students by explicitly indicating to them the relevance and intended use of their programming. Students were given the opportunity to choose meaningful programming topics and some of these topics included animating their names, animating the story of their everyday lives, animating topics from their imaginations, and in developing computer games they could play. Scratch was appropriately suited for the student-programming tasks because a building block metaphor could be used as a visual representation to introduce students to the CS content. The programming concepts were available to students in the form of blocks that could be snapped together thereby avoiding programming syntax errors. Importantly, before the students were formally taught some programming concepts, the research reported that many students regularly discovered these concepts by working on their projects.

Initially, students were provided with an example program to spark their creativity and the teacher encouraged them to brainstorm this program's possibilities. In so doing, the teacher demonstrated to the students what they could achieve with learned concepts. Students were

[6] http://hatparty.eu/

[7] http://brightsparks.city.ac.uk/

[8] http://www.mc2- project.eu/index.php/technology

[9] The visual programming (mini) language Scratch was originally designed for young students to develop 21st century skills. Mini languages are said to provide an insight into programming and teach algorithmic thinking for general computer science in an intuitive, simple, but powerful way.

challenged with open-ended tasks, with variable solution complexity, and with independent working time. Some of the student tasks were provided with specific directions. An example of such a task was described to students as: Design a program that displays your name and animates the letters to interact with the mouse or keyboard! This student task was designed to familiarize them with the concepts they had just learned, to explore the programming environment, to find solutions to their ideas, to implement their ideas, and to test their ideas. The teacher would circulate in the classroom, would encourage the students to explore possibilities, and would only intervene if they were asked. Such a work period usually concluded with the end of a lesson. However, for those students who wanted to elaborate on their work or extend and modify their programs, students were encouraged by the teacher to continue their work at home.

Table 3: Criteria for Creative CS Lessons according to Romeike (2007b).

Criteria for Creative CS Lessons			
Requirements for the SUBJECT	**Requirements for the TASKS**	**STUDENT-ORIENTED Requirements**	**Requirements for the TEACHING- ENVIRONMENT**
Relevance As creativity requires personal involvement, the subject of a lesson needs to be appealing to the students (or presented that way). **Problem management** Typical creative activities for CS which should be present in creative lessons are problem solving and the creation of a product, followed by the implementation of a model.	**Subjective novelty** Even if it is unlikely that a student will come up with a general new solution or product, subjectively new (p-creative) ones should be aimed for. **Openness in possible results, approaches and solution methods** Creative processes are characterized by problem finding, creative problem solving, exploring and discovering, hence tasks should allow several approaches to the problem, diverse solutions and different degrees of elaboration of the problem. **Application of concept knowledge** A solid foundation of knowledge is essential to creative practice. Concept knowledge needs to be emphasized in contrast to product knowledge or factual knowledge. **Inspiration** A creative achievement is always preceded by a stimulus (content, formulation or circumstances of a task, learning situation). In CS lessons this means revealing to the students which software will be used and which ‘broader’ problems it is supposed to solve.	**Identification** Identification of a person with the task is fundamental for creative practice which can get a person enthused, deeply involved with a task and trigger a flow-condition. For CS lessons this implies that the content needs to be (or can become) meaningful to the student (e.g. by taking over responsibility and/or later presentation). **Originality** Every student is a unique individual with his or her own ideas, visions and preferences. Obeying this criterion means allowing space for a student’s originality demands, i.e. letting the student bring in a personal touch.	**Experimenting** Being creative means to experiment with ideas, to explore the space of possibilities and to test solution possibilities. A tool used should provide meaningful feedback; for example, the compiler of a programming environment supports experimenting in CS lessons as it gives detailed feedback to the learner. **Freedom in time** Creativity is hard to realize under time pressure, as time is needed to gather, evaluate and realize ideas. Projects in CS lessons support this criterion. **Climate of diversity** Group pressure, early evaluation and expected perfection are known to oppress creativity. Instead the lesson should allow encouragement and inspiration among students. New ideas should be welcome and diverse solutions supported and presented. **Teacher as a coach** The teacher needs to diminish the leading role of transferring knowledge, correcting and assessing and assisting only when a problem cannot be solved by a student himself. Teacher motivates and encourages the students.

Finally, the students uploaded their programs to the Scratch webpage and some programs were presented to the class at the beginning of the next lesson. Such student presentations included a discussion of their ideas, their problems, and a description of their programming strategies. However, if students discovered and applied new concepts in their programs, they then explained these discoveries to the rest of the class. At the end of the course, every student developed a game with the condition that all of the learned concepts were to be applied within the game. The task resulted in a variety of computer games ranging from pong games, memory games, sport games, and shooting games.

The introductory computer programming teaching unit fulfilled all of its expectations. Importantly, the students enjoyed the lessons, the learning objectives were met, and the students' overall perception of CS improved. As a result of the lesson, students concentrated their efforts and were intrinsically motivated. As evidence of this intrinsic motivation, students remained in the classroom in order to continue working on their projects even when the class time had expired. In addition, the presentation and dissemination of the students' programs led to increased motivation in the next day's lesson.

As the result of this creative teaching experience, Romeike (2007b) suggests that creativity should be applied in programming courses and creative teaching lessons are worth implementing into those courses. The suggestion is also made that creativity may additionally serve as a principle in other fields of CS. Romeike (2007b) contends that students exhibited increased motivation and interest with the creative and low-risk programming lessons. Importantly, female students exhibited an improved performance within the creative teaching setting.

Fostering creativity in universities

Universities are also important in fostering student creativity because these institutions are expected to educate students to innovate and to help develop their creative ideas. In order to transmit specialized knowledge to students, institutions of higher education are challenged to develop or even to enhance their students' creative potential. Students must be encouraged to learn to think in multiple dimensions and to reach beyond the spectrum of available options. It is also important that students form new relationships between established elements and discover entirely new concepts or previously unconsidered connections.

To accommodate creativity in the university context, project teams from the DaVINCI project "Designing creativity-supported learning cultures in higher education" (2008-2011), collected interview data about the understanding of creativity at UAMR Germany, 2009. The interviews were conducted with 10 exceptional expert university teachers and 10 university teachers active in pedagogy. In addition to the interviews, each participant completed an online survey. In terms of higher education, the concept of creativity was understood in a multitude of ways. The understanding of creativity ranged from viewing it as a phenomenon which may be influenced by a change in attention, to viewing it as the development of one's own conception.

The understanding of creativity was also understood as a creative linking of previously unconnected ideas or thoughts, as the ability to see objects and relationships from different perspectives, as the ability to abandon habitual patterns of thinking, and as the ability to create and to implement entirely new ideas. As a result of the interviews[10], the project team developed a number of approaches for fostering creativity. These approaches form a conceptual framework and allows for individual strategies to be developed (Table 4).

[10] The interviews were analyzed by means of "open codings" and the empirical data was used to formulate a theoretical model entitled „Conceptual Framework for Fostering Creativity: 6 Ingredients "by following the Grounded Theory. This was done as part of DaVINCI sub-project Didactics".

Table 4: Fostering creativity in higher education - “Conceptual Framework for Fostering Creativity: 6 Ingredients”.

Richness of creativity in higher education	Description (Enabling students to do…)
6. Original, entirely new ideas	The production of many ideas can be encouraged through creativity techniques and an appropriate environment: “enable the possibility of arrival”; allowing and encouraging mistakes.
5. Fostering a new culture of thinking	Change of perspective; break through routines and patterns of habit; take a different attitude; reduce prejudice; integrate provocations; dealing with ambiguities; reflection on one's own creativity and thought-structure; knowledge about the inner-workings of the brain.
4. Fostering constructive learning	Where students create something (e.g. creation of interconnections in theses); research-mode learning projects, aid and outreach projects (e.g. planning a congress).
3. Fostering fascination, increasing motivation to learn	Fostering of “research curiosity”, learn to ask right questions; enabling situated learning, use experiences of students, developing interesting ways to pose questions or problems; variety; establish a link to practice; use of metaphors, humor; individualization in larger courses.
2. Fostering the ability to work autonomously	Enabling the individual student to set the acquisition of knowledge in motion; enabling students to learn that they are responsible for steering the processes of learning; enabling to make one's own decisions.
1. Fostering independent, self-reflective learning	Critical thinking, learner “constructs” knowledge oneself rather than adopting it; enabling students to hold an internal dialog, breaking out of a receptive posture, supporting lateral and critical thinking.

The teacher must ultimately decide which level of creativity richness to pursue in the classroom and the teacher should learn strategies to structure courses that promote creativity-supportive learning. The implications of designing such creativity-supportive courses may include changing elements of a session[11], changing elements of a complete session, changing elements of multiple sessions, changing elements of an entire course, or changing elements of the curriculum for the entire university.

Three essential elements should be considered when applying creativity supporting actions in education:

1. Technical Elements (e.g., learning management systems, social media, community platforms, and Web 2.0 tools).
2. Social/Organizational Elements (e.g., forms of communication and participation, roles of instructors, students, and student group size).
3. Educational Elements (e.g., formal and informal learning, problem-based learning, and creativity-supportive concepts) (Jahnke, 2011).

Table 5 presents examples of fostering creativity with respect to educational, social, and technical elements.

[11] Individual meeting of a course during the semester.

Table 5: Examples of fostering creativity: Educational, social, and technical elements.

Element	Examples of fostering creativity	
Educational elements	Mode of the course	Discussion walls, circular seating arrangements, several assessments instead of one exam, evaluation of progress throughout the course.
	Learning process	Student involved in: creative process, creative process and creative product, defining a problem and the way to solve it.
Social/organizational elements	Altering the classroom setting depending on the strategy for promoting creativity.	
Technical elements	Using cognitive techniques (synectic technique, headstand method, thinking hats), discussion, brainstorming, facilitating a shift in perspective, encouragement in establishing distance between oneself and the situation, breaking down barriers to creativity (lateral thinking).	

Jahnke (2011) describes creativity-fostered teaching and learning in higher education in the following three examples.

1) Experimental online learning in production engineering (PeTEX[12])

The educational design advanced by Jahnke (2011) included both reflective and constructive student learning. *Reflective learning* consisted of student activities where they created hypotheses, parameters, and reflected on their results by observing an online telemetric experiment in Mechanical Engineering. *Constructive learning* consisted of student activities where they planned a remote experiment, conducted a remote experiment, and wrote a diary about the learning process. The Platform for e-Learning and Telemetric Experimentation (PeTEX) was integrated into existing courses and was used as a standalone course. For the *integrated into existing courses* component, homework and questions were provided to guide students through modules. The grading of students consisted of online assessments (40%) and consisted of existing assignments. For the *used a standalone course* component, students wrote a report about their results and wrote a learning diary. There were differences in instructions given to students depending on the level of their knowledge when creativity was required in the learning process. The beginner level students received more support with instructions where the given task reflected a given experiment. The intermediate level students received less instructions and included tasks such as solving a problem that required creativity. Finally, the advanced level students found an appropriate question, developed the problem and solution, and reflected upon the process. For this activity, the social context consisted of individual learning (first phases) and collaborative learning where students discussed the results of the experiments online with community members.

2) Informal learning supported by online forums (InPUD[13])

An information and communication system from Germany called, Informatics Portal University of Dortmund (InPUD), was implemented to solve information deficiencies by supporting knowledge sharing among novice and expert computer science students, study advisors, and faculty members. InPUD includes an information space and communication opportunities for students. The information space was where students shared CS knowledge, discussed how to learn successfully, and discussed their study management skills. The communication opportunities included online discussion boards with more than 1500 participants. The online discussion boards provided students

[12] Platform for eLearning and Telemetric Experimentation. PeTEX project (2008-2010) aimed to develop online learning (interactive live experiments) within remote laboratories (the physical-real laboratories in Germany, Italy and Sweden).
[13] Informatics Portal University of Dortmund (Germany).

with opportunities to discuss course contents, study groups, examinations, and organizational issues. The fostering of creativity in InPUD was accomplished by providing students with the opportunities to share their knowledge and concerns. Some of the knowledge and concerns shared in InPUD included: (1) a forum about how to study successfully; (2) a forum that allowed students to open up about problems; (3) a general discussions forum; and (4) a forum to pose questions to the group and to receive an answer. A longitudinal study was undertaken to gauge student satisfaction with the InPUD community and the study revealed positive student satisfaction. Some of the positive student comments from the study include the following: (1) InPUD is a helpful and appropriate way of sharing knowledge; (2) InPUD helps in organizing information; (3) InPUD provides a flexible communication space for learners; and (4) InPUD fosters critical and reflective thinking.

3) Mind mapping scenario

The mind-mapping scenario supported multi-perspectives where students collaborated to create a mind map. After the activity, students were directed to persuade other students why their definition of the concept (or any given task) was superior by providing arguments and/or statements. The result was a complex mind map consisting of many different perspectives. The activity was significant because it reinforced to students the desirability of being both flexible and open.

These preceding three examples demonstrate the multi-layered dimensions of creativity for a specific context.

Evaluating creativity in computer science education

There are several aspects related to the measurement of creativity and these aspects may assist the researcher when choosing an adequate measurement instrument. Firstly, the component of creativity that is to be measured must be defined. Secondly, the specific context in which creativity will be measured must be defined. Recent scientific literature suggests that existing measures of creativity have come under criticism and this criticism has been identified as stemming from both a conceptual and practical basis (Lubart et al., 2009). Numerous studies indicate that creativity is primarily domain specific and scholarship suggests that creativity should therefore be measured from within each of these specific domains. Significantly, it has become clear that a simplified and a continuously up-to-date scoring system is required when measuring creativity. It is apparent that as the originality of some of these measurement ideas evolves over time, the results include outdated test norms based upon tables, and outdated test norms with a statistical rarity of ideas. In most cases, the norms used to measure creativity tests are outdated.

From an educational context, there is a great demand for instruments that detect creative potential and for instruments that monitor the development of this creative potential (Lubart et al., 2009). One of these recently developed instruments is the Evaluation of Potential Creativity (EPoC)[14]. The EPoC is an international battery of evaluation of creative potential and it allows creative giftedness to be measured. The EPoC includes verbal and graphic subtests that measure two key modes of creative cognition, divergent-exploratory thinking and convergent-integrative thinking. Therefore, to measure creativity in the context of CSE, we recommend that specialized instruments be developed or existing specialized instruments such as EPoC be modified. In addition, standardized tests should be produced for different cultures and countries. However, until these tests are accessible, the measurement of creativity in a general context should be considered.

Conclusion

The use of creativity techniques in CSE may range from implementing paper and pencil tasks (e.g., brainstorming and mind mapping) to adopting ICT-based techniques that reflect different cultures, teaching styles, and domains. An individual's creativity depends upon their deep conceptual

[14] EPoC is initially developed in France for elementary students. It is available in five languages: French, English, German, Turkish, and Arabic, but there are developmental trends across school-grade levels and it is being translated in other languages and normed for other countries.

understanding of a given field and their creativity develops with increased time and effort. Although creativity involves problem solving, an equally important aspect to creativity includes seeking out problems to solve. What can we do to democratize creativity so that it is available to everyone? We recommend that individuals must attend to transforming their current thinking position by building bridges within their thinking. These bridges may be built by examining how the brain processes and uses internal factors and external influences.

According to current models of brain research, the human brain processes and then makes use of a number of internal factors and may be inhibited by a number of external influences. The internal factors include patterns and routines but they may be suspended through the application of creative thinking. For CSE and education generally, the growth of creativity may be inhibited by a number of external influences. For a typical school environment, these external influences may include early evaluation, surveillance, reward, competition, and limited choice. Since students' activities in many CS classes are primarily understood as "solving the teacher's problems", the intentional consideration of creativity in these classrooms should include hands-on and discovery learning, assigning open tasks, and assigning product-orientated tasks in formal learning settings. The examination of software artifacts is important to the CS classroom and their usefulness should be examined from the perspective of the student. Although commercial CS products are more advanced than student-produced artifacts, students do not perceive this difference as essential. Importantly, students perceive the process of producing meaningful artifacts as creative and it is this p-creativity that should be fostered in the classroom.

Implementing creativity-supporting activities in the classroom, regardless of their extent or form, may be very educationally beneficial for students. Such creativity-supporting activities provides students with new perspectives and provides them with an openness to the problem solving process. In addition, creativity-supporting activities provide students with exposure to different attitudes, assists students when overcoming barriers, and prepares students for complex and multifaceted employment environments. The positive outcomes of creativity-supporting teaching and learning activities are encouraging. Further investigations into fostering creativity and enhancing learning in computer science education is therefore important.

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About the Authors

Anisija Žižić is a mathematics and computer science teacher at the Primary school Petra Kruzica Klisin Split, Croatia. She is a PhD student in the Faculty of Science at the University of Split and works at the Center for Excellence for the Split-Dalmatia County. Her research interests include creativity, education, and working with children in order to help them reach their full potential and lead productive, fulfilling lives.

Andrina Granić is a Full Professor in the Department of Computer Science, Faculty of Science at the University of Split. She received Ph.D. and M.Sc. degrees in Computer Science and a Dipl.-Ing. degree in Electrical Engineering, from the University of Zagreb, Croatia. Her areas of expertise include Human-Computer Interaction (HCI), Interaction Design (IxD), and Technology Enhanced Learning (TEL). Dr. Granić has published more than 100 peer-reviewed papers as book chapters or in journals and conference proceedings. She is on the Editorial Board of five journals and has been on the Program/Organization Committee for more than 50 academic conferences. She has been involved or is currently participating, as a coordinator or as a partner, in national and international projects. For the past ten years she has reviewed research project proposals for the European Commission and national research foundations. In addition, Dr. Granić is the Croatian representative for the International Federation for Information Processing (IFIP) Technical Committee on Human-Computer Interaction and is a member of the IEEE Computer Society.

Michael Paul Lukie is an Assistant Professor in the Faculty of Education at the University of Winnipeg where he teaches secondary education courses in physics, science, and mathematics. He is a doctoral candidate in the Department of Secondary Education at the University of Alberta and his doctoral research uses a phenomenographic research methodology to investigate students', teachers', and professors' conceptions about what it means to understand physics.

Addresses

Anisija Žižić;
Primary school Petra Kruzica Klis; Put svetog Ante 30;
21231 Klis; Croatia.
e-Mail: anisijas@yahoo.com

Dr. Andrina Granić;
University of Split; Faculty of Science; Department of Computer Science;
Ruđera Boškovića 33, 21000 Split; Croatia.
e-Mail: andrina.granic@pmfst.hr

Dr. Michael Lukie;
Faculty of Education; The University of Winnipeg;
515 Portage Avenue; Winnipeg, Manitoba;
R3B 2E9; Canada
e-Mail: m.lukie@uwinnipeg.ca