Creative and Collaborative Problem Solving in Technology Education: A Case Study in Primary School Teacher Education

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Many public and private institutions believe that there is a growing need for employees who are able to think creatively and solve a wide range of problems (Grabinger, 1996). On the other hand, several researchers have maintained that many of the skills and competencies needed in working life are seldom obtained at school (e.g., Resnick, 1986). Therefore, competencybased or performance-based approaches to teacher education have been recommended in order to give students a broader perspective and to equip them to teach technology (Custer, 1994; Sinn, 1996; Whitty & Willmott, 1991). In particular, it has been argued that creative problem solving is an integral part of technology education, in contrast to an instruction-following method of technology education, reproducing artifacts, and teacher-dominated work (De Luca, 1993; Sellwood, 1991; Williams & Williams, 1997). Wu, Custer, and Dyrenfurth (1996) suggested even more forcefully that (creative) problem solving should be a core content area and method of teaching technology. These approaches particularly seem to fit technology-oriented modules in teacher education.

In this article, the Creative Technology Education Project (CTEP) is presented, and phases of problem-solving processes in which the participating primary school student teachers generate alternatives and evaluate ideas are analyzed. The aims of this project were to introduce technology education goals and contents to these students, as well as to offer tools for learning and teaching technology, and to facilitate personal growth. One purpose of the project was to encourage the students to become familiar with technology and problem-solving processes and to develop especially creative skills and abilities (e.g., ideation and the evaluation of ideas). For those purposes, a model was introduced, named the Overall Mapping of a Problem Situation (OMPS). This model helps students in ideation (the generation of alternative solutions) and evaluation of ideas when working on project teams. This model was practiced with concrete technology education projects. Thus, the project focus was on collaborative problem solving, with special emphasis on ideation and the positive evaluation of ideas.

Creative and Collaborative Problem Solving

Different ways to emphasize creative problem solving in small groups have been suggested (e.g., Dooley, 1997; Grabinger, 1996; Hill, 1999). A common feature of these approaches is to place students in the midst of a realistic, ill-defined, complex, and meaningful problem with no obvious or correct solution. Students work in teams, collaborate, and act as professionals, confronting problems as they occur – with no absolute boundaries. Although they get insufficient information, the students must settle on the best possible solution by a given date. This type of multistaged process is characteristic of effective and creative problem solving. These stages may include (a) formulating the problem, (b) recognition of facts related to the problem, (c) goal setting, (d) ideation or generating alternatives, (e) the evaluation of ideas, (f) choosing the solution and, (g) testing and evaluating (De Luca, 1993; Fisher, 1990; Welch & Lim, 2000). The process is nonlinear and follows no particular rules because rational approaches miss the entire point of creative problem solving.

In accordance with Hennessy and Murphy (1999), the term collaboration is used in this article to describe social interaction within a group or a team, when students actively talk and share their cognitive resources, working together to produce a single outcome. They are also supposed to establish joint goals and referents, making joint decisions, solving emerging problems, constructing and modifying solutions, and evaluating the outcomes through dialogue and action. Collaboration requires students to actively communicate (e.g., negotiate or debate) and work together (e.g., set goals, plan, generate alternatives) with the aim of producing a single outcome (e.g., an object, a computer program, or a technological process/system). The students must then evaluate their outcome through dialogue and action (Hennessy & Murphy, 1999).

When problem solving is creative, the ideas or products produced during the problem-solving process are both original and appropriate (Fisher, 1990). For these purposes, various idea-generation techniques or ideation models are valuable (Smith, 1998). The number of alternative solutions is important because the best way to come up with good ideas is to have plenty of choice (Parker, 1991). Consequently, the outcome of creative problem-solving activities depends largely on the creative processes and ideation techniques that have been learned and applied. Furthermore, there are factors of attitude (interest, motivation, and confidence), cognitive ability (knowledge, memory, and thinking-skill), and experience (familiarity with content, context, and strategies) that influence problem-solving processes (Fisher, 1990). For example, nonjudgmental positive feedback and the acceptance of all ideas, even absurd or impractical ones, are important in all creative group processes for generating significant alternatives (Higgins, 1994). There should be room for free ideation sessions. Evaluative critiques should only take place afterwards.

Numerous models for curriculum changes in technology education, as well as for introducing creative problem-solving processes, are available nowadays in both technology education literature and school textbooks (Johnsey, 1995). Nevertheless, there still appears to be an overemphasis on passive learning and the old traditions of craft learning (Kimbell, 1997). Moreover, some renewed curriculum models lead easily to a situation in which the construction phase immediately follows the planning phase, without enough time for conceptualization, ideation, and the evaluation of ideas (Alamäki, 2000; Elmer & Davies, 2000). An especially important aspect of technology education and teacher education is providing the opportunity to get away from routine activities and low-level thinking so that students can find fresh new ideas and approaches, for example, by utilizing group dynamics or special creative methods (Smith, 1998).

There is an obvious need for young technology teachers to act as agents for change. Moreover, it is obvious as well that more research and development effort should be directed towards introducing creative problem-solving approaches in technology education (Gilbert & Boulter, 2000; Lee, 1996). Instruction and teaching models experienced during primary school teacher education often serve as learning models for students. The plan of the CTEP, described in more detail below, was based on the assumption that collaborative and creative problem solving would be valuable for developing a premium technology education study module for primary school teacher education. The purpose of the study presented in this article was to discover how students perceive the creative process and to what extent they learn creative skills, especially those that involve generating alternative ideas and the self-evaluation of these alternatives.

The following questions guided this study:

1. What are the key factors in creative problem-solving processes from the point of view of primary school student teachers?
2. Have students learned creative skills during their enrollment in the CTEP?

The CTEP

The practical goal of the CTEP was to introduce student teachers to the OMPS method and to help them to become familiar with problem-solving processes, ideation techniques, and evaluation of ideas.

Of the 118 participating students, 80% were female and were on average 24 years old. According to the collected background information, 77% of the students had little or no previous knowledge or experience regarding the contents and methods of technology education. Less than 10% of them, however, disagreed with statements indicating high motivation and responsibility in their work, as well as success in planning and collaboration during the CTEP. Only about 15% of the participating students thought that the CTEP was of little significance to the primary school teaching profession or that the CTEP offers little that is applicable to their profession. It can be concluded, therefore, that the students' attitudes to the project were largely positive and that they agreed with the project goals.

At the beginning of the CTEP, the students attended four hours of lectures and demonstrations about creative problem solving. The sessions covered different idea generation techniques, such as brainstorming and analogous thinking. In addition, the students became familiar with the theme through WWW pages (Lavonen & Meisalo, 2001) that presented problem-solving models and a couple of idea-generating techniques, such as the OMPS (Sellwood, 1991). Different (e.g., creative, social, and personal) abilities and skills needed in creative problem solving, as well as ways to establish a creative and open atmosphere, were discussed. After the above-mentioned sessions, a four-hour workshop was organized in which the students worked in small groups. In these workshops,

Figure 1. An example of a planning process expressed by a map constructed during the creative phase. In this phase, the primary school student teachers utilized the OMPS-method.

The Problem: How to design a coaster for a coffee-pot in a creatively different way.			
Facts: - should insulate - be used on a table - 20 hrs to plan and make it - …	**Opinions:** - beautiful coaster - always on display - wooden - not big - recycling materials	**Goals:** It should be - useful - easy to move - modern - …	**Visions:** - Ideal for Y2K - Artistic
Approach A: interesting shape **Idea A1:** oval + traditional + easy to turn on the lathe + beautiful ? how to avoid familiarity ? how to inspire makers **Idea A2:** triangle + cups can be placed in the corners + innovative + interesting + easy to make from wood ? how to stock **Idea A3:** star.. + …	**Approach B:** coaster with layers **Idea B1:** two layers + kettle holder underneath + innovative + interesting ? how to prevent keeling over **Idea B2:** three feet and hooks for cups + innovative + interesting + can be moved with one hand ? how to prevent keeling over **Idea B3:** a candle can warm the coffee-pot from below + …	**Approach C:** Integrated tray and coaster **Idea C1:** big wooden construction + practical as tableware + innovative + can be given as a present + embellishment for the table ? how to manage in time **Idea C2:** double heart + … + … + … ? … **Idea C3:** … + …	**Approach D:** box… **Idea D1:** tea bags in the coaster + easy to find + gift + innovative ? … **Idea D2:** spice-rack integrated with the coaster + ideal for a party + easy to clean the table + … ? how to manage in time **Idea D3:** … + …

students became familiar with the OMPS method by using it to plan a bridge or tower to be constructed out of newspapers.

During the planning phase of the project (four to eight hours), the groups of 3 to 4 students worked in 24 collaborative teams according to the basic principles of the OMPS method and generated a map of the creative process (see Figure 1). First, the students had to find, formulate, and specify the problem *(How could something be done differently?)* and recognize the facts (agreed by the team) and opinions related to the problem. Next, the teams set the problem or team assignments in a cogent phrase, such as: *How can an interesting electric toy be constructed differently? or How can a game be designed differently?* In addition, the students had to set the goals and visions (ideal performance). Then, the students had to create suitable approaches for solving the problem and to generate problem-solving alternatives. Every alternative idea was subsequently backed up by presenting at least three reasons for its adoption. Nonjudgmental positive feedback and the acceptance of all ideas, even absurd or impractical ones, were held as important rules during all group processes that generated creative alternatives (Higgins, 1994). During the planning phase, the teams identified, on average, 3.8 (SD = 1.30) facts and expressed 2.1 (SD = 1.6) opinions related to the problem. The teams set, on average, 2.7 (SD = 1.0) goals and created 1.9 (SD = 1.2) visions. They generated, on average, 3.4 (SD = 0.59) problem-solving approaches and 7.3 (SD = 2.4) ideas as to how to solve the problem. In the subsequent maps, there were 13.6 (SD = 7.7) positive evaluations of the presented ideas and 3.9 (SD = 3.4) constructive "how" questions. Some teams presented their ideas in figures.

During the creative process, it was also possible to ask constructive questions about the idea or to combine, redefine, and piggyback ideas. After generating dozens of ideas, students chose the most appropriate solution by comparing the positive feedback and constructive questions that related to each idea. Typically, the final solution was a combination of several original ideas. During the ideation phase, the students were encouraged to follow the creative rules and to utilize idea generation techniques while working in collaborative groups. After selecting the final ideas, students then planned out how they would construct the structure or perform the process.

After generating alternatives, evaluating them, and designing and planning the project, the students created something new in their design solution process utilizing paperboard, wood, metal, and/or plastic and the appropriate tools. The teams spent approximately 12 hours in the workshop and worked according to their previously agreed plans. It was intended that the students should be creative in their teams and that they would modify their preliminary plans during the practical work period. Finally, each team presented their innovations to the other groups and evaluated both the innovations and the entire process, first by themselves and then with the others. The construction and evaluating phases are not included in this article.

Implementation of the Study

This research can be described, in accordance with Stenhouse (1985), as exploratory evaluation research, in which data were gathered to evaluate the CTEP described above. It is a typical case study in which different approaches to data gathering is used, including gathering data in numerical form. Moreover, the study also has features of developmental research, which Richey and Nelson (1996) defined as a systematic study of designing, developing, and evaluating instructional programs, processes, and products that must meet the criteria of internal consistency and effectiveness.

For evaluating the creative problem-solving processes, a questionnaire consisting of 23 items was utilized, thereby yielding self-evaluative data concerning the students' success as regards the conceptualization and evaluation of ideas, as well as on their success with creative problem solving. The items were formulated on the basis of theoretical ideas about features of creative problem-solving processes presented in the theoretical framework of this article. For each Likert-type item, there were five alternatives, varying from *strongly disagree* (1) to *strongly agree* (5). The questionnaire included some items about the students' background as well as items about their motivation and general success during the teaching experiment.

The items were located randomly in the questionnaire, which was accessible over the Internet, and the students were asked to fill in the forms after the last meeting. Eighty-five students out of the 118 students who participated in the project answered the questionnaire. A preliminary item analysis based on item-to-item correlations and item-to-total score correlations led to the elimination of four of the questionnaire items. For example, the item *I learned to support the self-respect of other students* only had a 0.15 correlation to the total score and was, therefore, rejected from the final analysis. It is obvious that the students must have misunderstood the rejected items or that the items were ambiguous. On the other hand, it is also possible that the students did not agree with the rejected items. The internal reliability of the remaining 19 items was high (Cronbach alpha = .89).

An exploratory factor analysis was used to reduce the large number of original variables to a smaller number of factors and to examine how the problem-solving process was experienced by the students. The Kaiser-Meyer-Olkin measure was within a very reasonable range; KMO = .80 (Norusis, 1988). Barlett's test of sphericity also supported the use of a factor analytic approach (Bartlett's test = 845.9, $p < .00001$).

Results

The questionnaire data were analyzed with the SPSS program, utilizing principal axis factoring as the extraction method and varimax with Kaiser normalization as the rotation method. This method was used to determine how students experienced the key factors in their creative problem-solving processes. The exact number of factors was determined by means of Cattell's scree-test. The comprehensibility criteria were also used, and the number of factors was limited to four, since the meaning of the factors was then readily comprehensible (Dunteman, 1989). To determine the internal consistency of each factor, a Cronbach alpha coefficient, based on the average interitem correlation, was determined for each factor. The Cronbach alpha coefficients of the factors varied between 0.83 and 0.88. Each factor, therefore, measured one quality and, thus, a meaningful interpretation of the factors was possible. On the other hand, no far-reaching generalizations were allowed regarding the structure or properties of the problem-solving processes. The factor analysis simply made it easier for us to describe how these 85 students experienced creative problem-solving processes during the CTEP.

On an aggregate level, these four factors explained 57.2% of the common variance, with eigenvalues of 6.19, 2.14, 1.42, and 1.13, and percentages of total variance of 32.57%, 11.26%, 7.46%, and 5.96%, respectively. The communality, 57.2%, indicated that four factors could be used satisfactorily as predictors for all 19 variables. Moreover, the extent to which each item played a role in the interpretation of the factors was high. The eigenvalues indicated that Factor 1 covered most of the variance, and the other factors each contributed about the same amount to the explanation of the variances.

Each of the four factors indicating the students' perspectives regarding problem-solving processes and variables (items) that described the highest loading on each factor are presented in Table 1. Three items also had loadings over 0.30 on other than their main factors, and these are commented upon below. The factors were labeled on the basis of researcher discussion on variables (items) loading on a factor. The means and standard deviations of each item are also presented in Table 1.

Factor 1, *success in problem-solving processes*, explained 32.5% of the total variance and included seven items. The first two items (F1-I1 and F1-I2) loading on this factor are connected to the problem-solving processes. Recognizing problems in one's surroundings (F1-I6) and restricting a problem (F1-I7) belong to the first phase of the process and are, therefore, a natural starting point for the problem-solving process. The creative atmosphere that is indicated in items F1-I5 and F1-I3 is necessary to establish a creative problem-solving process, but it is not sufficient to ensure that one can be launched. Another prerequisite for success would be knowledge about ideation techniques and ideation skills. These perspectives to problem-solving processes are indicated in items F1-I3 and F1-I4, which describe perspectives for ideation, but they do not tell how students succeeded in generating alternatives or about the quality of their ideation. On the other hand, these items also had high loadings (0.47 and 0.43) to the second factor dealing with the students' success in ideation.

Factor 2, *productive ideation*, consisting of six items, explained 11.3% of the variance indicating students' opinion about their ideation skills. Two items (F2-I1 and F2-I4) indicate the quality of the ideas. It is important that ideas generated during a creative process are originalØotherwise one should label the process as routine. It is also important that the students learn to combine and develop others' ideas further. The key issue for success in creative processes is how the creative power of the group can be utilized in finding fresh ideas. The number of ideas (F2-I2, F2-I5) is also connected to their quality. It is known that in the beginning of an ideation session common, familiar ideas typically come to mind. Therefore, if there are many ideas in the group, at least some of them will be of high quality. It is important to use creativity (F2-I6) and to be both intuitive and systematic in turn (F2-I3) during the process of ideation. Item F2-I6 also had a high loading (0.40) on the fourth factor, which in this case dealt with positive attitude.

Factor 3, *collaborative support and evaluation*, consisting of four items, explained 7.5% of the variance. Items F3-I1 and F3-I4 indicate that students learned to express their feedback positively and constructively. The two remaining items (F3-I2, F3-I3) deal with positive attitudes when evaluating ideas.

The remaining two statements loaded on Factor 4, *positive attitude*, explained 6.0% of the variance. Item F4-I1 indicates that students behaved positively, and the other item (F4-I2) deals with a positive attitude as regards the creative process.

Means of the first two items loading on Factor F1 were 3.6 and 3.7. Thus, most students thought that they had learned about the nature of creative processes and how to work according to the principles of creative processes as well. This is what was expected, since these topics were emphasized during both the lecture and the

Table 1. Means and Standard Deviations and Varimax, with Kaiser Normalization Rotated Factor Loadings for Principal Axis Factoring, Calculated for the Items Measuring Primary School Student Teachers' Opinions About the Creative Process in the Project

	Mean	SD	Factor Loading
F1: Success in problem-solving processes			
Cronbach's alpha for the factor = 0.85			
F1-I1. I learned [illegible] cycling of the principal phases of creative processes	3.37	.91	.805
F1-I2. I learned about the nature of creative processes	3.72	.91	.851
F1-I3. I believe in the saying "It is possible to generate ideas [illegible]"	3.55	.90	.595
F1-I4. I learned ideation modes	3.57	.90	.520
F1-I5. I learned to generate a creative atmosphere	3.11	.92	.263
F1-I6. I learned to recognize problems around me	3.30	.90	.190
F1-I7. I learned to identify (?) and restrict a problem	3.65	.75	.115
F2: Productive ideation			
Cronbach's alpha for the factor = 0.84			
F2-I1. I learned to generate original ideas	3.18	.78	.709
F2-I2. I learned to generate many alternatives	3.36	.85	.707
F2-I3. I learned to combine intuitive and systematic ideation	3.37	.91	.655
F2-I4. I learned to develop further ideas presented by other students	3.72	.92	.578
F2-I5. I learned to trust the principle "If we have many ideas, at least some of them will be high quality ideas"	3.91	.85	.558
F2-I6. I used my creativity	3.48	.96	.187
F3: Collaborative support and evaluation			
Cronbach's alpha for the factor = 0.87			
F3-I1. I learned to give positive feedback to other students' ideas	4.02	.77	.882
F3-I2. I learned to appreciate others' ideas	4.19	.76	.815
F3-I3. I learned to recognize advantages in the ideas of others	4.14	.81	.677
F3-I4. I learned positive and constructive feedback on the ideas other students presented	3.90	.78	.646
F4: Positive attitude,			
Cronbach's alpha for the factor = 0.95			
F4-I1. I am positive about creative processes	3.59	.84	.930
F4-I2. I have a positive attitude to creative processes	3.63	.91	.726
n = 85			

workshops. Much time was also spent on understanding the meanings of ideation and the evaluation of ideas. Means of the items loading on the second factor indicate that, according to the self-evaluative data, the students had learned (at least reasonably well) to generate alternatives. Means of all items loading on the third factor indicate that the students had, in their own opinion, learned how to give positive and constructive feedback regarding other students' ideas. One may also note that much was discussed as regards how to give constructive feedback, which was also practiced during the project. Even the meaning and the value of such behavior during creative processes were discussed. The students were familiar, for example, with how positive feedback defines what is valuable in an idea presented by another student. Positive feedback also indicates where or from which direction possible solutions can be found. Moreover, positive peer feedback is important for the self-respect and confidence of other students.

Discussion

Based on the identified factors, the means and standard deviations of the self-evaluative data on creative process skills, and the primary school student teachers' maps, it could be effectively argued that the OMPS method helps students understand the nature of creative processes and, particularly, that there are different phases involved in each of these processes. The mean (3.7) of item F1-I7 indicates that the students believed that they had learned to identify and restrict a problem. This is one of the most important phases in problem solving (Sapp, 1997). Factors 2 and 3 indicate that the students believed that they had succeeded in generating alternatives and, in particular, to evaluate and appreciate others' ideas. This means that the students felt that they had learned to give positive feedback regarding other students' ideas, to recognize the advantages of those ideas, and even to develop them further. It is obvious that a formal method in which each idea has to be backed up by the presentation of at least three reasons for its adoption is necessary for success. Such evaluation creates a nonjudgmental positive atmosphere for creativity, and it helps to behave positively as indicated in Factor 4.

On the other hand, the number of approaches (M = 3.4) and ideas (M = 3.3) generated during the ideation phase was comparatively low. This was reflected by the students' opinion on the item I learned to generate original and new ideas. The mean of this item (3.4) was one of the lowest. Furthermore, the students felt that they did not learn enough about the generation of many original and new alternatives. Those skills are important when extremely new alternatives are wanted (Amabile, 1996). From the point of view of similar projects, it is important to observe that more efficient guidance in generating alternatives is needed. Students should be carefully introduced to techniques that can be used for generating numerous alternatives because the best way to get good ideas is to have plenty to choose from. It can be concluded that the outcomes of creative problem-solving activities depend on the creative processes as well as ideation techniques learned and applied (Smith, 1998).

The items measuring the students' success in the ideation and evaluation of ideas loaded on different factors. This result means that the students succeeded in separating those aspects when evaluating their problem solving. Both abilities (ideation and the evaluation of ideas) are essential for creative problem solving as well as the ability to segregate them. The ways in which the human mind works when creating new ideas can be argued. As de Bono (1970) emphasized, critical thinking is needed when one is evaluating ideas and in the open creative thinking that is required to generate alternatives.

In summary, this case study indicates that creative problem-solving approaches may be efficiently used to improve teacher education. On the other hand, students must be encouraged to create many possible solutions to problems and then to select the best ones. Furthermore, students should receive a thorough introduction to creative problem solving in general (Williams & Williams, 1997). Such training could be beneficial because many students in our study became anxious when no formula existed or no direct guidance was given to their work. In addition, the recognition of facts connected to the background of the problem proved to be important in this study. Thus, it is essential for the creative process that students have relevant information available.

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