Designing Learning Environments for Creativity in Engineering Education

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Abstract: - This paper proposes a framework for designing and improving learning environment for creativity in engineering. The framework consists of the following three components: (1) instructional design based on knowledge from psychology, (2) development of systems for supporting creative activities, and (3) objective evaluation of learning results related to creativity. Based on that framework, we design and practice a program of robot based course for freshmen at Chubu University. As a result, we confirm the following two advantages of our framework: (1) learners' idea generation skills were improved and (2) their meta-cognitive activities were also activated.

Key-Words: - creativity, engineering education, education to programming languages, instructional design, evaluation of instruction, reflection, LEGO Mindstorms

1 Introduction

In recent years, engineering education in universities has extensively incorporated project-based classroom practices aimed at fostering a creative attitude in learners through experience in production activities such as fabricating a robot or building a bridge of straws, [1, 2]. As an example of this approach, we have attempted to incorporate such creative education practices into education targeting university students [3]. Specifically, we divided students into groups, and put to them the challenge of creating a robot using LEGO Mindstorms. As a result, we confirmed that the students were able to learn through experience the importance of "Thinking" and "Using one's hands" in the context of creative production activities.

In this way, creative education in engineering education involves the accumulation of know-how through practice. Many of these activities, however, are attempts at investigation based on the educational experiences of teachers. It is important to examine class design and evaluation methodologies; for example, from the following perspectives: "How classes should be configured to ensure the most effective learning?" or "How should practical results be evaluated, and how should these evaluations be used to further improve the classes?" In the current study, we propose a framework for achieving more effective design, execution, and evaluation of creative education in engineering education.

The framework consists of the following three components.

(1) Instructional design based on knowledge from psychology

Up to now, many attempts at creative education have involved classes designed based on the experiences of the teachers. By contrast, the framework proposed here actively incorporates knowledge from psychology in relation to education and learning in addition to the experiences of the learners, in order to achieve more effective classes. Based on this approach, we then designed classes that can be expected to demonstrate better results in terms of learning.

(2) Development of systems for supporting creative activities

In the field of software engineering, many systems – most notably "idea generation support systems" – have been developed to support "Thinking activities" in the context of creative activities. In real situation, people learn a great deal from trial and error, in the repeated process of creating and evaluating prototypes. In the framework proposed here, we have developed a creative activity support system that focuses on "Production Activities" and "Evaluation Activities," and have introduced this system into a class environment.

(3) Objective evaluation of learning results related to creativity

A large number of the creative education practices mentioned above involve subjective evaluations of class results based on questionnaires. Furthermore, these questionnaires are limited to qualitative evaluations of the changes in the learners with regard to creativity. In order to gain a detailed understanding of what the learner specifically learned with regard to creativity, however, it is necessary to conduct evaluations based on objective data; for example, changes in knowledge and skills related to creativity. In the framework proposed here, we will objectively evaluate learning results by establishing items that will enable evaluations of increases in skills related to creativity.

The purpose of this research is to design classes based on the above framework, and through its practice, to clarify its effectiveness as well as areas requiring improvements. Based on this framework, we designed creative education classes for engineering education. We put these classes into practice for one half of an academic year targeting first-year engineering students, and conducted evaluations and observations of the learning results.

2 Instructional Design

2.1 Setting learning objectives

When designing classes, it is necessary to set learning objectives. In the practice of creative education up to now, there have been objective goals with regard to contents, but the learning objectives with regard to creativity have been abstract.

In this research, we set as the learning objectives "improving idea generation skills in creative activities." Specific perspectives for evaluations were "Number of ideas (volume of idea generation)"; "Scope of ideas (variation in the ideas generated)"; and "Depth of ideas (depth of study regarding a single idea)." Based on these perspectives, we then objectively evaluated the degree to which the students' idea generation skills changed.

These evaluation perspectives correspond to the "Creativity Factors" proposed by Guilford – "Fluent thinking (volume of ideas produced)"; "Flexible thinking (the ability to produce a wide range of different ideas)"; and "Elaborative thinking (the ability to specifically elaborate on and complete the idea)" – and are considered appropriate indexes for measuring creativity in learners [4].

2.2 Applying knowledge from psychology

In these classes, we actively incorporated knowledge of psychology in relation to education and learning in order to achieve more effective classes. In the classes, we focused on knowledge from psychology related to meta-cognitive activities in creative activities.

The field of learning sciences, which studies human learning processes in educational situations points out the importance of "meta-cognition" in which the learner's own activities in an educational or learning situation are seen from a "meta" perspective [5-9]. Especially, in the field of design education, the importance of meta-cognitive activities such as self-reflection has also been suggested [10], and some practical studies that intended to foster reflective activities in design have been conducted [11,12].

Among the various types of meta-cognitive activities, the authors' prior research into the practice of creative education suggested the effectiveness of "reflection" in particular – the activity of looking back at one's own activity processes [3]. In the classes in the current study, rather than simply having the learners experience creative activities, we incorporated this meta-cognitive activity of "reflection" into the classes as well.

2.3 Setting learning phases

The educational program consisted of three main phases.

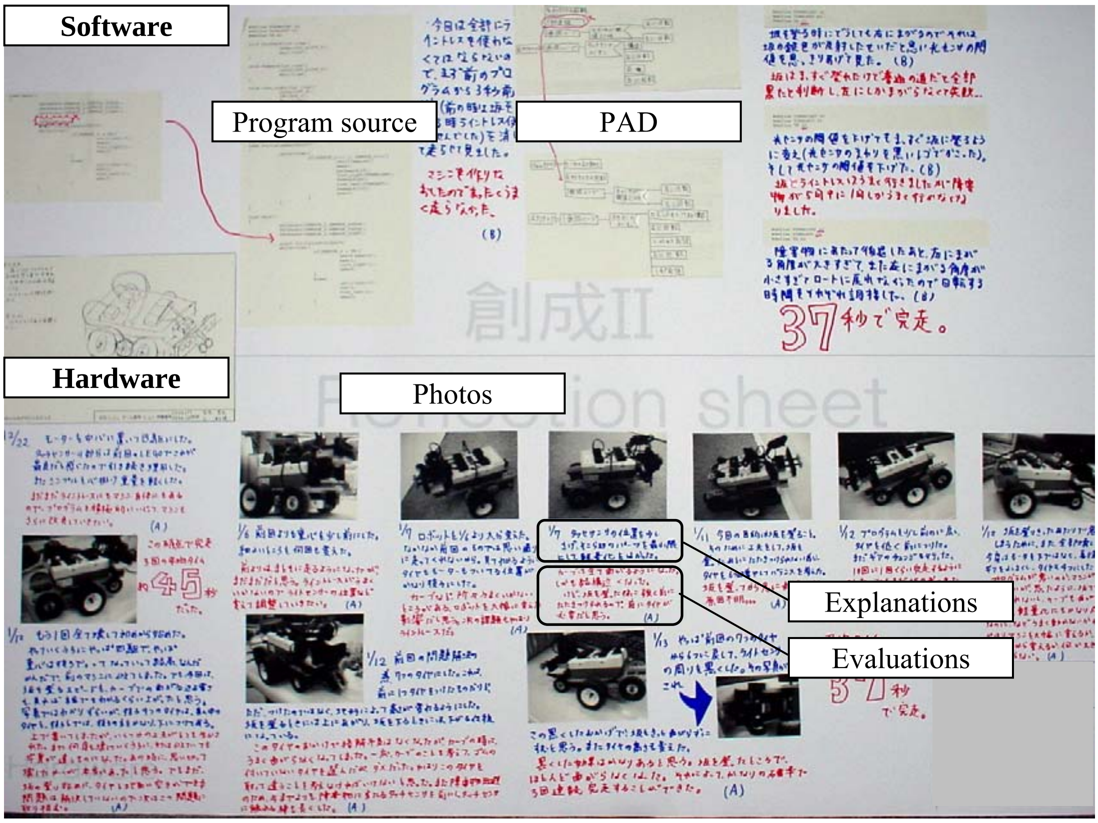

Fig. 1 The example of entry of the Reflection Sheet.

Phase 1: Introduction

As an environment for creative learning activities by learners, put in place a programming environment comprised of a laptop PC for each student, and have the learners acquire basic knowledge of LEGO Mindstorms and relevant programming language.

Phase 2: Experiencing creative activities

Learners form pairs, working together to produce a robot (the creative activity set as the theme for the class); they then participate in a "time trial" competition. The competition is a race comprising one lap of a course. The learners are required to produce a robot that not only moves, but also avoids obstacles and has a function that traces a line where it has moved.

During these activities, the learners regularly record the status of their own pair's progress (robot's shape (photograph), robot's movement (movie), race results (time), control program, and comments). These status reports are recorded using the creative activity support system described in the following section.

Phase3: Reflection

After the creative activities, learners undergo "Reflection" to deepen their understanding and awareness of their own creative activities. Learners summarize their groups' creative processes in a chart using a piece of paper measuring about 2m x 1m (hereinafter referred to as the "Reflection Sheet").

The Reflection Sheet is divided in half, from top to bottom. On the top half of the sheet, the learners position the PAD (Problem Analysis Diagram) and the program source on a timeline (a software element), and on the bottom half of the sheet, they place a photo of the robot (a hardware element). As a supplementary explanation for these materials, at each stage of the creative activities, the learners write on the sheets (1) what they are planning and (2) what results they achieved (Fig. 1). The materials used for placement on the Reflection Sheet are the items recorded in the creative activity support system.

2.4 Creative activity support system

In the classes in the current study, we incorporated the meta-awareness activity of "reflection." During Reflection, by looking back at the process of trial and error in their own learning activities, the students learn many things. At this time, in order to ensure that the learners gain a detailed understanding of their own creative activities, it is necessary to regularly record

Fig. 2 The creative activity support system (http://edu.cs.chubu.ac.jp/LEGO/).

the details of the activities conducted as part of creative activities. Furthermore, when creating the robot, it is necessary to undertake “version management” of both the software and hardware elements over a long period of time.

In this study, we therefore developed a creative activity support system that would enable recording, management, and viewing of the groups’ creative activities, to provide support for the learners’ “Reflection” activities. This web-based system, which is comprised of a PHP linked with a database (MySQL), enables the learners to upload any items related to the group’s creative activities using a browser (Fig. 2). The information recorded by the learners is updated in real time, so the learners can check the ranking status of their own or other learners’ teams at any time.

Using this system, the learners regularly record the status of their groups’ activities. They then create the Reflection Sheet while viewing their own creation processes, which they have recorded in the system, and downloading the appropriate data as required.

3 Actual Classes

Based on the Learning Phase described in section 2.3, we conducted an actual class in creative education; a course held in the Autumn Term in the 2004 academic year at the Chubu University College of Engineering. The learners included 131 first-year students in the College of Engineering Department of Computer Science. The curriculum for this course lasts for 13 weeks, with each (weekly) class lasting 135 min. The activities in each of the Phases outlined above were allocated as follows:

Classes 1-6: Introduction (Phase 1)
    Learning computer settings and C language
Classes 7-8: Creative activities (Phase 2)
    Producing robots
Class 9: Reflection (Phase3)
    Creating Reflection Sheets; discussions
Classes 10-11: Creative activities (Phase 2)
    Producing robots
Class 12: Reflection (Phase 3)
    Creating Reflection Sheets; discussions
Class 13: Presentations

In these classes, because of the number of classes available, we conducted the cycle of activities in Phase 2 and Phase 3 twice. In the second cycle of creative activities, we had the learners completely dismantle the robots produced in the first cycle, to encourage them to take on the challenge of creating new ideas. In the 13th class, each group of learners gave presentations on their own creative processes and the characteristics of the robots they had produced. Of the 131 students (65 groups) that participated in the classes, 50 groups succeeded in producing robots that completed the obstacle course.

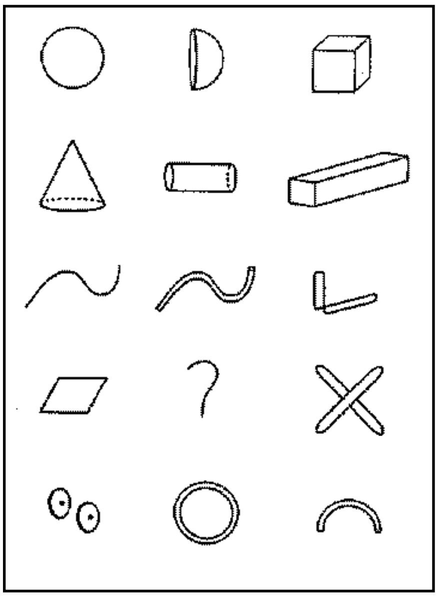

Fig. 3 The sheet for design task.

4 Evaluation of Learning Results

In these classes, in order to evaluate the learning results for skills related to the learners' creativity, we presented design tasks before and after the classes, based on an arrangement of Finke's "invention tasks [13]." A total of 91 students participated in the design tasks. The students were given sheets that presented with 15 specific types of parts (Fig. 3), and were asked to come up with new ideas for arranging these parts in any way that they pleased, sketching their ideas on a piece of paper one at a time. Each of the students was randomly assigned one of three themes for these ideas: "Playground equipment," "Furniture," and "Stationery." They were also given a 20-minute time limit.

First, we categorized the ideas generated by the students according to the functions of each idea. Specifically, Author 1 categorized the responses according to the respective themes (Table. 1).

Table. 1 The categories of ideas.

Playground equipment	Furniture	Stationery
Ride	Store	Store
Spin	Hang	Write
Hang	Carry	Erase
Slide	Organize	Cut
Go in	Place	Stick
Go across	Sit	Draw
Swing	Clean	Measure
Run	Sleep	Hold
Climb	Light up	Clean
Throw	Cook	Record

4.1 Changes in Learners' idea generation skills

First, we evaluated the changes in idea generation skills during creative activities, which were set as the learning objective in these classes. In this paper, we calculated these changes based on the variations in the functions of the ideas; that is, the "Scope of ideas." Similarly, we expressed the "Depth of ideas" as the maximum value for the depth of study regarding an idea with a single function.

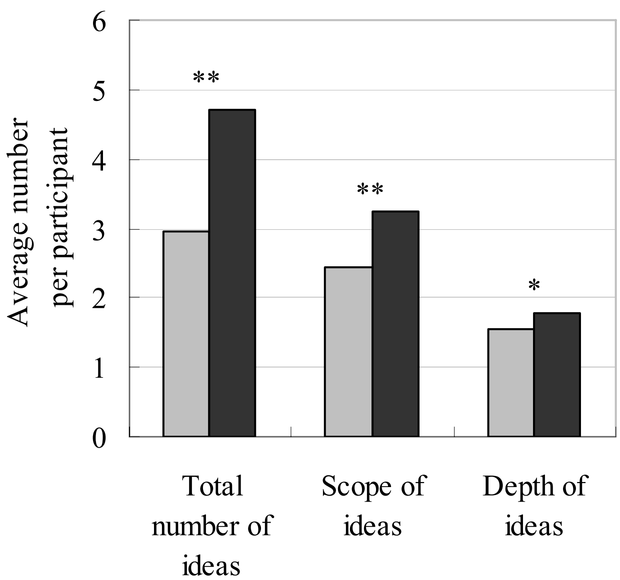

Fig. 4 Changes in Students' idea generation skills (**: p<.01, *: p<.05).

From the results of these evaluations, we confirmed that the number of ideas generated increased after the classes as compared to before ($t(90)=4.481$, $p<.01$) (Fig. 4). We also confirmed that both the scope ($t(90)=3.727$, $p<.01$) and depth ($t(90)=2.629$, $p<.05$) of the ideas generated increased after the classes were completed. The above results suggest that the students learned idea generation skills through these creative activities.

4.2 Changes in behavior related to learners' Reflections

Next, we analyzed the extent to which the learners underwent autonomous reflection through the Reflective Activities introduced into the classes.

We tabulated the number of learners who underwent Reflective Activities in terms of "Reexamining ideas with functions that were thought of before" in the context of design tasks, and confirmed that when thinking of ideas, the ratio of learners who reexamined the functions they thought of before increased from about 19% to about 38% ($\chi^2(1)=8.723$, $p <.01$). Although this is only a small ratio of the entire group of learners, these results indicate that the number of learners who undertook autonomous reflection in creative activities increased as a result of having experienced Reflection in the classes.

5 Conclusions

In this study, we propose a framework for designing and improving learning environment for creativity in engineering. The framework consists of the following three components:

(1) instructional design based on knowledge from psychology, (2) development of systems for supporting creative activities, and (3) objective evaluation of learning results related to creativity.

Based on that framework, we conducted an actual class in creative education; a course held in the Autumn Term in the 2004 academic year at the Chubu University College of Engineering. As a result, we confirm the following two educational effectiveness of our framework:

(1) learners' idea generation skill were improved through experiencing creative activities.

(2) their meta-cognitive activities were also activated as a result of having experienced Reflection in the classes.

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