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Effectiveness of Problem-solving and Teamwork Skills for Cultivating Technological Creativity within a Team-based Design Course

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Abstract

Recently many studies in the United States that have presented functional groups, decision-making, and teaming skills as important pedagogical tools for engineering faculty to integrate into their curriculum. However, the examination-oriented education in Taiwan has tended to turn assessment into a tool that increases competition instead of cooperation. In this situation, schools and teachers pay closer attention to learning and memorizing knowledge instead of training students' skills, attitudes and other non-cognitive attributes. Over the past six years, the department of Mechanical Engineering at National Central University in Taiwan has implemented a comprehensive transformation of its undergraduate programs. The strategies pursued to accomplish this transformation included comprehensive curricular reform, and the integration of industrial environment in the undergraduate education process. This major reform led to two questions: (1) Did participants exchange information about their implementation by email or in other ways? (2) What teamwork skills did they learn? This paper provides quantitative and qualitative evidence that examines the group learning process of an open-ended creative mechanical design course for technological creativity cultivation. Surveys and semi-structured interviews were collected and analyzed to evaluate the curriculum, and to understand students' learning difficulties to determine directions of improvement. Overall, the top three abilities students gained were: (1) Efficient use of time to reach consensus; (2) Growth of problem-solving ability; and (3) Development of teamwork strategies. Finally, lessons learned from this study are presented to help develop a cooperative classroom atmosphere and to improve the effectiveness of this course in following years.

I. Introduction

In this study, we follow the principles of Seat and Poppen [1] that students must learn to deal with ambiguity and vagueness. This lack of a single right answer required our students to develop new methods for dealing with problems because most of their previous experience involved textbook-type problems with a single right answer. Furthermore, engineering students in Taiwan tend to be especially anxious about making mistakes.

Project design, however, is concerned with whether students are approaching problem-solving in a logical way, and whether they can formulate rules for the patterns they observe, more than with whether students find the right answer.

During the last six years, the department of Mechanical Engineering at National Central University in Taiwan has undergone a comprehensive transformation of its undergraduate programs. The strategies pursued to accomplish this transformation have included comprehensive curricular reform, and integration of the industrial environment in the undergraduate education process. As this course evolved over six years, we found that active and cooperative learning was critical for effective project design. In this paper, we will describe our course design, the use of cooperative learning techniques, and the series of instructional activities to facilitate students' teamwork skills. Also, we will present evaluation data and students' reflections that they have drawn from their teamwork experiences.

II. Literature Review

1. Cognitive Style and Cultural Values of Engineering Students

Engineers typically have a cognitive style known as field independence. Engineers prefer problems that are structured and predictable, whereas activities with unpredictable responses (e.g. group discussion) are neither structured nor predictable. Thus, the students preferred to read about the techniques, read about examples, and then pass a written test [2].

Furthermore, cultural values can play a pronounced role in the group dynamics of cooperative learning activities. The majority of engineering students have been rewarded for being competitive, getting the right answer, and getting higher grades than most of their classmates. However, in courses where team performance becomes part of the evaluation process, the student must master an entirely different set of abilities that demonstrate knowledge by [3]:

(1) Help team members and cooperating in a group;
(2) Helping to plan;
(3) Pacing and scheduling projects;
(4) Getting peer and teacher feedback on work; and
(5) Teaching classmates.

Therefore, learning teamwork skills may be difficult for engineering students. The shift from the traditional system of education to one based on groups and student participation also redefines what a good student does, which can threaten and raise the anxiety of the traditionally good student. Furthermore, the highly competitive nature of most problem solvers also hinders teamwork ability.

2. Issues in Implementing Cooperative Learning

According to constructivist theories of learning, knowledge must be actively constructed by the learner for learning to occur. Thus, it is crucial to arrange the cooperative process so that each student's success is dependent on not only the group's overall success but also each individual group member's personal success [3]. By making the group's success dependent on the

individual achievement of each group member, this arrangement would provide a motivational climate that would provide even more impetus for group members to assist one another in educationally appropriate ways. Horn et, al. [4] further concluded that factors which might influence the variability of cooperative leaning outcomes are:

(1) Prior skills in group learning (metacognitive awareness)
(2) Nature of social interaction
(3) Presence of rewards and benefits
(4) Type of learning task
(5) Individual characteristics (personality, attitude)

There is a consistent body of research on the academic benefits of classroom goals that stress learning over performance. When students do not have to worry about normative evaluation and are encouraged to work for the sake of mastery and intrinsic enjoyment, they are much more likely to ask for assistance when they face difficult tasks [5].

Jordan and Le Matais [3] further described four general theoretical perspectives that explain the beneficial effects of cooperative learning on performance. One perspective involves *motivation*, and the second is the *social cohesion* perspective, while the third and fourth perspectives are while are the *cognitive-developmental* perspectives. Further, he found that providing group rewards and holding students individually accountable for learning are key influences on cooperative learning performance successes.

III. Instructional Design of the Course

According to social theories of learning, when a group of students are working towards a common goal or perceive that they are positively interdependent, they are more encouraged to help each other. The three following three activities are based on the theories of cooperating learning to cultivate a supportive classroom environment, which allows students to take risks in their learning in an atmosphere which invites cooperation and shared ownership. This can be achieved when students are given the opportunity to develop strategies for working together.

1. Settings for Student Cooperation

In order to stimulate creative and effective learning from teaching others, we first divided the students into groups of three to five students, with each group taking the roles of both presenters and observers. Generally the presenting group has the same members of the corresponding project design team. The presenting groups summarized the results of their work, highlighting key progress related to the design project, after which the observing group then made suggestions as to how the project might have functioned more effectively. The student work groups not only create opportunities for students to learn from one another, but also enable students to participate and interact. Students must provide instruction, evaluation and reinforcement to one another, thereby encouraging mutual assistance and social support.

2. World-wide-web (WWW) interactions

In order to provide follow-up and to encourage networking through frequent contacts

among participants during the year, we required students to develop the ability to ask questions and make comments about the projects done by other groups via interaction. For this, we employed a web-based learning environment called the *creativity activity bulletin board* as the basis to deal with students' difficulties that emerge during problem solving. The key concept of the bulletin board was to be responsive to students' comments and help them on-line with their problems. The purposes of the creativity activity board were:

(1) To encourage students to seek help from teachers as well as from peers, and thereby examine their problems from various perspectives.
(2) To monitor and encourage participation, and
(3) To foster informal interactions and immediate feedback between teachers and students.

The bulletin board was an area for students to discuss a particular topic, to post messages, and to share information or experiences with others. In addition, it allowed the participants to contribute ideas at different points in time. The ideas generated by these participants were stored in the board and can be accessed by other participants at their convenience. Thus, the participants could post their difficulties on the board so that other students could be involved and see how problems could be solved. Also, if the students had not contributed anything for a significant period of time, we tried to restate the importance of collaborative learning and encourage them to take an active part in course participation. Furthermore, web-based learning environment is an ideal environment for team teaching, since different courses can be linked, with various subject experts serving as guest lecturers.

3. Student-initiated Team Project

After the topic of their project was determined, the next step was for them to collect all the relevant information and look for the tools to meet their needs. Before going into this process, they had to administer a market survey to understand the needs of customers, and how practical their product would be. For this survey, they must identify the age group of potential customers, the price of product, and the characteristics of the buyers. Then the students will move to the next stage—information gathering. First they need to list what was needed (including the finished and unfinished articles), and then go out to look for those items. For example, their goal might be to develop a chart of the hardware stores, with their phone numbers, addresses, and the price of materials in it. They could make comparisons among them, and buy the most suitable things they want, which were not necessarily the cheapest. Finally they made a list of disbursement after shopping, and started to implement their mockups.

IV. Methodology

1. Data Collection and Analysis

Both quantitative and qualitative data from a questionnaire survey, and semi-structured interviews were collected and analyzed to evaluate the effects of teamwork and to understand the students' learning difficulties so that we could determine directions for improvement. First of all, a post-course questionnaire and an interview protocol were developed to assess student responses toward course content and classroom activities. The survey questionnaire was

conducted to discover the impact of the course and those aspects of learning activity that most contribute to the cultivation of creativity for engineering students. The Personal Evaluation Questionnaire consists of 10 items to evaluate experience as a team member [6]. The Likert items were based on a five-point scale of 0 indicating "not at all" to 5 indicating "a lot". Four areas of group work were included in the instrument:

- A general liking of groups;
- Self-efficacy in groups
- Group dynamics
- Help-seeking and help-giving in groups

Next, at the time of the end of the final presentations, students were asked to respond to a questionnaire, addressing the projects and the courses' formats. Some of the questions can be generally categorized as follows:

- Did participants exchange information about their implementation by email or in other ways?
- What have they learned in terms of the teamwork skills?

Finally, five of these participants volunteered to be interviewed two weeks later. The interview questions were in an open-ended, semi-structured format that focused upon finding evidence to provide explanations or reasons behind the teamwork project design.

2. Findings

Quantitative Results

(1). Did participants exchange information (e.g., seeking assistance from teachers and peers or giving assistance to peers) about their implementation by email or in other ways?

Table 1 lists the frequencies in first semester (posting, online, and website scores) and the second semester (number of visits, number of postings and website scores) of mean, median, standard deviation, minimum and maximum. Detailed tables were following by individual histograms. Table 1 also shows the increase in the numbers of postings (mean from 25.89 to 37.88) and visits (mean from 45.58 to 62.90) increase.

Descriptive Statistics

	Mean	Std. Deviation	N
Posting	25.8958	9.79631	48
Online	45.5833	25.92529	48
Website Score	18.6979	2.65125	48
Number of Visit	62.90	36.301	49
Numbe of Posting	37.88	15.084	49
Number of Team Visit	259.47	73.133	49
Number of Team Postin	158.59	32.208	49

Table 1 Frequencies of posting, online, and website scores

In summary, some students might express their opinions only on the webpage because it is with grades. It seems that many of the students prefer browsing or visiting instead of responding to

the posted questions.

(2) Correlation between personal evaluation and team evaluation:

The results show the correlation between the 10-question Personal Evaluation Questionnaire and the 4-questions Team Evaluation Questionnaire. It was found that some students participate more actively in their teams when they feel comfortable working with the team and feeling comfortable with their role. Another deduction may be that students seems become more open-minded as well as enjoy/appreciate teamwork

Qualitative results: Abilities learned from the course
Overall, the top three abilities students gained were:
(1) Effective use of time to reach consensus
(2) Growth of problem-solving ability
(3) Development of teamwork strategies

Students' Reflections on Team's effectiveness

Next, we interviewed five volunteers that were representatives of the groups. The qualitative data analysis was to suggest possible interpretations of the results of the survey in light of the information gained through the interviews. First of all, the five interview transcripts were coded, compared and summarized in terms of their attitudes and perceptions toward the instructional activities. This way, the reflections generated by the interview data could add to our understanding of rewards inherent in students' learning and could provide information suggesting how the instructional activities might be made more enjoyable, meaningful and productive.

1. Effective use of time to reach consensus

How to hold an efficient meeting was an important part of the plan, and the following group was very time-efficient in terms of their workload sharing:

> First, I think everyone must know what the project is about, and the goal has to be clear. And then, it's better that there is someone to be the recorder to write down what have we done and what we will do after the meeting. If there is a recorder, it would save us lots of time. If everyone reads the log before they come to group meetings, it would help a lot.
>
> Our team is composed of seniors, so everyone was under time pressure from further studies and graduation. In order to shorten the meeting time, as well as accelerate the progresses of every activity, we set a common team rule that: every defender had to provide more complete explanations and clarifications of his proposition. They also had to analyze others' suggestions. In the end, the team members would be the committees to make the final decision. By doing so, we could produce many ideas in the meeting, and could always find the most practical project.

The interplay of competing ideas and their resolution through social consensus implies both a

preparedness to engage in task-centered group discussion, and the capacity to effectively marshal and regulate the strategies necessary for more complex, higher-order learning on the part of all group members. It seems that initially students were unfamiliar with group cooperation, although they would find ways to encourage everyone to contribute after finding out the most effective way to do so. As long as the goal is clear, the efficiency of students' time management would improve, as the instructor said:

> I think we learn something from cooperative learning, because we didn't have opportunities to work as a group before. In fact, we have learned how to negotiate, how to communicate and how to distribute workloads.

Efficient group work is one of the important points of this research. Students need to have the creativity that an enterprise needs and the ability for group work. In this course, students would develop more efficient ways of group work, and they would support their final group decision when choosing a subject. In addition, they would communicate and negotiate, combining all the group members' achievements:

> The due day for our term project was just around the corner, and everyone had different ideas until one of our teammates proposed a brand-new idea. We liked it so much so we started to gear towards this direction. Yet when we used chopsticks and rubber bands to make mockup bike, we found there were some problems in our script since it was neither originative nor safe. Hence I insisted on keeping one part of the bike, with which all the group members agreed. From this experience, we learned the wonderful experiences of brainstorming and the importance of reaching consensus so that our tentative plan could be done efficiently.

2. Growth of problem-solving ability

Because it was the first time that students designed a product, they confronted many difficulties, for example, they tended to try out an idea without concerning how to make it, the required cost, and its practicability. It was due to their lack of information gathering skills and hands-on experience:

> The massage backpack we designed is a vibrator which controls the back from the breast. After testing its feasibility, we found that the slide did not move well, and it even stuck sometimes. We thought this might be because it was not smooth enough between metals, so we came up with some ways to solve this problem. We tried lubricating oil first, and see if it can improve the sliding. There was some improvement, but not much. Then we tried it again with its weights, although even after we added some books, it was not improved.

However, students could overcome their feeling of frustration and develop problem-solving strategies to cope with it:

> There were some difficulties when we talked with the hardware store owners, and they tell you the solution and how to make it. Some of them would ignore you, then you just have to find another factory or store, and then modify the mockup based on their suggestions.

The best way to solve this problem that they finally figured out, was to gather more relevant information, search for patent websites, and keep an eye on newly released products on the market. This kept them from re-inventing a product that already existed on the market, as well as helped them to be inspired by new ideas.

When confronted with difficulties, the students learned to try many different ways to complete their goal. For this reason, self-regulating students would be more conscious of their knowledge, faith, motives, and recognizes behavior – so these elements would join and renew their attitude toward practice subject [7]. The research of Butler and Winne [5] also verified that self- regulation contains the following three techniques: to set targets promoting knowledge, to think over relevant tactics, and to progressively form accumulative effects by monitoring. Therefore, students with more self-regulating skills would make more efforts, using knowledge and faith to establish their targets. By setting a new target or regulating existing work, learners may check tactics again and choose more efficient methods, change techniques could be developed, even new practices could be used [8]. From the interview data, we could see when students are thinking over more solutions of substitution, which also enhance their ability to overcome difficulties.

3. Development of teamwork strategies of teamwork

By analyzing the self-evaluation questionnaire, we found that students in group discussion mostly perform well in options about "Meeting attendance", "Listen with group members' opinions", "Provide opinions voluntarily." Thus it appears that the attitude toward participation of group meeting is positive. Furthermore, they describe how they find out each teammate's specialty and take advantage of it during the design process:

> We assigned two teammates deal with the portion that could be done individually. Both of them were quick, so they are good at adjusting the original plan according to the situation on the spot, and it turned out to be quite satisfactory. Even though one of our other teammate was competent, he was kind of slow. Nevertheless, he could be the group leader's partner to take care of last-minute polishing work.

When this group distributed the work, they considered each member's personality, habits, and ability, in order for each team member to express his expertise as well as distribute the workloads properly. For example, they have two teammates who are good presenters who were therefore responsible to present the report; they also had a web-page designer who was in charge of the construction and maintenance of our website. The problems tend to be solved more efficiently this way. In addition, attraction for and preference for cooperation with the partner also influenced their devoting effort to the task:

> We had weekly meetings to make sure each one had done his job. But from the middle or later period of the semester, the examinations continued, and our plan was usually delayed, until the members got after one another. This is the part to where people should pay attention in teamwork. The best thing about our group was that everyone was willing to communicate and to express his feelings. If there was someone who kept delaying his job, the others would point it out, and thus shorten the delay time.

Furthermore, the participants below reported relatively frequent use of self-evaluating, goal-setting and planning, keeping records and monitoring, and reviewing texts:

> We had a leader and members in our team. The leader was also the chairman of our meeting, and was in charge of distributing the work and supervision. The members had to carry out the tasks assigned to them, and provided new thoughts. For instance, A was both the leader and a member; B had to update and maintain the construction of our website; C was our recorder who wrote down everything we discussed; and D organized and documented our journals. To make progress, we held a team meeting and shared the responsibility.

The above results are encouraging but the analysis of the following data also show two areas for further potential revision in the course.

Factors that influenced students' capacities to learn

(1) Students' misconceptions toward the evaluation methods of this course

In the first semester of this course, students seemed apathetic toward the peer interaction via internet, which is required in this course. One student mentioned in interview:

> There's a time difference between receiving responses from classmates and the urgency of fixing the problem at hand. Sometimes we received replies to our question after we had solved it already. However it is impossible for us to go back to change, and if we do that, it would cause a detour in our next step.

One key point is that students may not understand the nature of online interaction at the beginning of this course. When students are concerned with evaluation, either to demonstrate ability relative to others or to gain rewards, but they do not believe in their own competence, then they are more likely to avoid any behavior that calls attention to their perceived lack of competence. Students who are unsure of themselves, both cognitively and socially, were more likely to feel threatened when asking their peers for help and more likely to avoid seeking help [8].

Secondly, they may think classmates' responses are not convincing, or did not receive feedback from others when they encountered problems, which influences their willingness to try further. Other students believed it was not enough to receive paraphrases from classmates. Or it might be possible that they enjoy interacting with other students on off-task behavior, such as casual conversation, rather than devoting effort to providing solutions to other students' questions. In this case, the interaction ends up becoming a chatting and problems are still not solved.

(2) Engineering students are unfamiliar with the concepts of teamwork

Since students had not previously done projects in groups, they had no experience of project-based learning from previous courses, so it took weeks for them to develop proper ways of cooperation. One student commented:

> I think the most difficult part is communication. It took a lot of efforts to persuade others and clarify your own points. What was good about this course is that you can think about a lot of things. But there was no one right answer for the questions, and no boundaries.

Because there was no limit to students' discussion, they have to decide themselves if they have to write a log for every step, and distribute the workload among team members.

On the other hand, one leader mentioned that sometimes he cared about the group efficiency too much:

> I would hold a conservative attitude toward things and I might sometimes think others' suggestions were not good enough. I would be concerned about the time efficiency problems and would like to stick with the agenda instead of chatting. Sometimes I will jump to a conclusion, which was not very good to the team.

V. Conclusions and Implications

This course is aimed at encouraging students to integrate all the basic theories they have learned, to develop their imagination and creativity, and apply it to the design and manufacture of industrial products. These students reported frequent use of the following three self-regulated strategies: organizing and transforming, reviewing notes, and seeking assistance from others. The participants in this study also reported relatively frequent use of self-evaluating, goal-setting and planning, keeping records and monitoring, and reviewing texts. They have also learned to trace back to the origin when they confront difficulties. In addition, they learned how to see things from multiple perspectives. Similar to the findings of Seat and Popper, [1], they had opportunities to share their opinions with others, both within and between groups. Although sometimes they had different ideas, they always managed to reach consensus efficiently.

According to the interviews with students and course assessment questionnaires, we make some suggestions that might be considered to improve future courses. Two important directions of improvement for future instruction:

1. Encourage Students' help seeking and help-giving behavior

It seems that students were not aware of the relationships between online interaction and its impact on problem-finding as well as problem-solving of project design. To improve this, conditions would have to be met. First, help-seeking would be adaptive in a more stringent way than was operationalized in Newman's study. That is, students would (a) engage in accurate comprehension monitoring and self-assessment of what they do and do not know, (b) formulate questions that address specific gaps in their knowledge, and (c) develop sufficient interpersonal skills for choosing, approaching, and communicating with someone who could potentially provide help [8].

Knowing the benefits and what to expect from the cooperative interaction would alleviate their anxiety and avoidance. Perhaps the novel cooperative methods failed to provide the communication skills necessary for these students to build rapport and help his teammates learn [9][10]. Therefore, we can provide specific instruction to individuals who are effective learners

to help them to better understand when and how to become effective learning facilitators.

2. Emphasize the importance of teams and team concepts [11]

The results of this study reveal that attraction for and preference for cooperation with partners also influenced their devoting effort to the task. Thus, teachers with an understanding of students' motivational dynamics of teamwork would be better able to construct effective working groups, interpret the results of student teamwork, and manage student conflict.

When adopting an innovative instructional method such as team projects or peer assessment, students tend to be resistive because of the sense of unfamiliarity. In many cases, engineering teachers themselves are not fully trained in team concepts. Therefore, if we as instructors point out the significance of group creativity to students when they face real industrial settings, students will be more capable and more motivated to meet the expectations of the course.

VI. References

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