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Empirical Investigation into the Ability-condition Interaction Effect of Cooperative Learning*

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Many studies have shown that cooperative learning results in a notable improvement in the learning performance of team members. In the present study the relative performance of the high-, medium- and low-ability students within cooperative learning teams is compared with that of students with an equivalent ability working using an individualistic learning method. A series of experiments are performed in which forty-two mechanical engineering sophomore students are randomly assigned to one of the two learning modes and are put into mixed-ability three-member groups. The experimental results show that the relative benefit of cooperative learning depends on the academic ability of the individual members within a cooperative team. Furthermore, the presence of dysfunctional teams may well account for the ambiguity in the results presented in the literature regarding the potential benefits of cooperative learning for students with differing levels of academic ability.

Keywords: ability-condition interaction; cooperative learning; heterogeneous teams; individualistic learning

1. Introduction

Many researchers have shown that, when implemented correctly, cooperative learning fosters a spirit of teamwork, encouragement, and support, and yields a significant improvement in the academic performance of the team members [1–9]. However, previous studies are inconsistent in their conclusions as to whether high-, medium-, and low-ability students all benefit equally from their participation in heterogeneous cooperative learning teams. For example, Yager, Johnson, and Johnson [10] reported that high-, medium-, and low-ability students all benefit from cooperative learning, whereas Johnson, Johnson, Roy, and Zaidman [11] argued that the benefits of cooperative learning are restricted to medium- and low-ability students only.

Moreover, in real-world classrooms, difficulties invariably arise when students of different genders, with different abilities, personalities, learning styles, and work ethics are forced to work together in a team. As a result, some students with an initially favorable attitude toward cooperative learning may begin to doubt its benefits, while others with an initial resistance to cooperative learning may become even more resistant [12]. Cooperative teams that have such members almost inevitably become dysfunctional over time, and therefore the benefits of cooperative learning are lost.

Thus, the objective of this study is to investigate the relative benefits of cooperative learning for students with different academic abilities and to examine whether the existence of dysfunctional teams is a reason for the apparent inconsistency in the related findings presented in the literature.

2. Method

2.1 Subjects

The experimental stage of this study was conducted in the spring semester of 2006 and included 42 mechanical engineering sophomore students (41 male and 1 female) from the National Pingtung University of Science and Technology in southern Taiwan. The students were randomly assigned either to cooperative learning or to individualistic methods of learning, stratified for academic ability (as measured by the students' average test scores in the previous semester) such that each group contained 21 students in accordance with a randomized block design [13, 14]. Within the cooperative learning group, the 21 individuals were assigned to three equally-sized 'high-ability', 'medium-ability' or 'low-ability' groups [10, 11] in accordance with their average test scores in the previous semester. Within each ability group, one member was chosen at random and assigned to a cooperative learning team. This process was repeated iteratively until each of the 21 students had been assigned to a learning team. Thus, on completion of the assignment process, the 21 individuals were organized into a total of seven learning teams, each team comprising one high-ability member, one medium-ability member and one low-ability member. Having been assigned to a group, the students were informed that they were to remain within the same group for the entire semester and were to work in a cooperative

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fashion in solving the learning tasks assigned to them. For the purpose of comparison, the 21 students using the individualistic learning method were also randomly assigned to seven 'teams' that were stratified according to the members' academic abilities, although they were instructed to always work alone. Table 1 presents the average test scores and statistics that the 42 students had attained in the previous semester. Overall, the data confirm that the students with differing levels of learning ability were uniformly distributed among the teams in the two learning methods. In other words, the efficacy of the random assignment process in creating heterogeneous teams [15] is confirmed. In addition, the results of a *t*-test revealed no significant difference in the mean test scores of the students in using two different methods, $t = 0.15$, $p = 0.88$. Thus, it was inferred that the two learning conditions were equivalent in terms of the students' academic abilities prior to the experimental stage of the study.

2.2 Course

The experimental investigation was conducted in the Planar Dynamics course, a core course for all 42 participants in the study. During the course, the students learned the basic principles of planar dynamics, developed the skills required to formulate planar dynamics problems, and mastered the mathematical tools and skills required to solve a broad range of planar dynamics problem. The course contents were divided into four sequential teaching units of varying durations, i.e., Unit 1—Planar Kinematics (six weeks), Unit 2—Energy Method (three weeks), Unit 3—Force and Acceleration Method (six weeks), and Unit 4—Impulse and Momentum Method (three weeks). In addition to the regular 3-hour/week daytime classes, the students also attended mandatory homework classes (7-hour/week) in which they studied in accordance with their assigned learning method under the supervision of two teaching assistants.

2.3 Independent variables

In this study, the independent variables are the learning method (i.e. cooperative or individualistic) and the ability level of the students (i.e. high, medium, or low). In the cooperative condition, the students were instructed to work together as a group, thereby ensuring that each team member worked diligently, mastered the assigned material, freely offered their ideas and suggestions, listened to others, shared ideas and materials, and praised and supported one another [8, 12]. The cooperative learning teams were carefully implemented in such a way as to develop positive interdependence, face-to-face interaction, individual accountability, team skills, and group processing [16–18]. Consequently, in both the regular classroom sessions and the additional homework sessions, the team members were instructed to sit together so as to permit face-to-face interactions. Each classroom session generally began with a short lecture outlining the class contents, explaining the basic concepts to be covered during the class, giving hints to the problems to be solved, demonstrating the necessary problem-solving skills, and so on. Thereafter, a discussion period took place in which the three members of each collaborative team took turns in playing particular roles designed to promote positive mutual interdependence and team skills [8, 12]. Specifically, the student seated in the center of the three team members was designated the 'team leader', and was tasked with leading the team in discussing or summarizing the class contents, or solving the assigned problems, while the two remaining team members were designated 'supporters', and were tasked with actively participating in the team discussions by questioning, correcting, encouraging, and praising one another [5, 19]. Importantly, the role assignments were rotated every two weeks such that each team member spent an equal amount of time in each role. After the discussion period, a short question-and-answer (Q&A) session took place in which the instructor posed short questions to randomly se-

Table 1. Average scores of team members within different ability groups in previous semester

Team	Cooperative learning					Individualistic learning				
	Ability group					Ability group				
	High	Medium	Low	Mean	Std deviation	High	Medium	Low	Mean	Std deviation
A	75.10	74.20	68.00	72.43	3.16	74.73	74.68	60.05	69.82	6.91
B	78.18	71.00	61.00	70.06	7.05	75.36	73.00	68.77	72.38	2.73
C	86.05	74.00	69.74	76.60	6.91	79.18	73.82	60.91	71.30	7.67
D	74.45	71.91	70.50	72.29	1.63	77.05	72.82	70.86	73.58	2.58
E	78.86	72.14	62.05	71.02	6.91	77.82	74.14	68.14	73.37	3.99
F	75.59	73.00	60.82	69.80	6.44	76.73	71.41	64.55	70.90	4.99
G	77.59	74.64	69.95	74.06	3.15	81.41	72.05	70.14	74.53	4.92

lected individuals within the class in order to assure individual effort accountability [4]. Each lecture / discussion / Q&A cycle lasted for around 15 to 25 minutes, with the time spent on each stage of the cycle allocated in the ratio of approximately 3 : 2 : 1.

Each homework session began with an announcement of the six engineering problems to be solved during the course of the session. Note that by announcing the problems in this way rather than assigning them in advance, it was ensured that each student spent an equal amount of learning time tackling the problems, irrespective of their learning method. Thereafter, one of the two teaching assistants provided a short explanation of the first homework problem in a lecture-type session, and the students were then asked to solve the problem in accordance with their assigned learning methods. As in the regular daytime classes, the members of the cooperative teams took turns in playing the roles of either leader or supporters and the role assignments were rotated on a two-weekly basis such that each member spent an equal amount of time in each role. Following the problem-solving session, the students in the cooperative teams undertook a practice-session in which each team member practiced the homework problem alone in order to make sure that they had fully mastered the material. In the event that they encountered difficulties, the students were actively encouraged to seek help from their team mates [3, 10]. Thereafter, a new lecture / problem-solving / practice cycle was launched with a new homework problem. The cycle was repeated twice in each one-hour period with a typical time allocation of approximately 1 : 3 : 2 for the lecture, problem-solving, and practice stages, respectively.

Throughout the duration of the study, the students were tested on the course contents on an individual basis to ensure individual effort accountability [4]. Moreover, to promote group processing, the students in the cooperative learning teams were reminded of their common goal, namely to maximize the success of all the members within the team, and they were encouraged to examine whether or not they had reached this goal whenever the answer sheets for the test were returned to them [6, 8].

The students using the individualistic learning method participated in the same daytime and evening sessions as the students in the cooperative learning groups and were taught by the same instructor and teaching assistants. However, during the discussion, problem-solving and practice stages of each cycle, the students using individualistic learning were explicitly instructed to work alone and were told to seek help from either the instructor or one of the teaching assistants rather than one of their peers in the event that they encountered problems [3, 10, 11, 20]. To enforce the two learning conditions, the two teaching assistants moved around the classroom encouraging the students in the cooperative learning groups to participate in the team discussions and reminding those individualistic learning students to study alone. The instructor and the two teaching assistants met for 10 minutes during each instructional day in order to review the conditions and procedures laid down for the study. The experimental conditions were then observed during each daytime and out-of-hours session, with the instructor or teaching assistants completing a checklist to ensure that each of the learning conditions was correctly implemented in every case.

2.4 Dependent variable

The dependent variable in the present study is the student's academic achievement and it was measured by means of four unit tests, one given at the end of each teaching unit. Each test lasted for three hours and consisted of six to eight engineering problems chosen from the exercise section of the course textbook [21]. While taking each test, the students in both learning conditions worked individually and were assigned a score in accordance with their own performance. A solution flowchart was prepared in advance by the instructor for each test item to indicate the key intermediate stages and results in the solution procedure. Using these flowcharts, the students were awarded partial credits even if their final solutions were incorrect. The test papers were graded independently by the two teaching assistants, and the two sets of results were then compared to ensure their reliability [22]. In analyzing the test results obtained over the course of the semester, the raw test scores were converted to z scores to ensure that each unit test received an equal weight, and the z scores achieved by each student for the four unit tests were then averaged to obtain a composite z score representing the overall academic achievement of that student.

3. Results and discussion

3.1 Identification of dysfunctional cooperative learning teams

Students within a successful cooperative learning team not only exhibit a greater intrinsic motivation to learn than those who study alone [4, 8], but they also attain a higher level of academic achievement [7, 8]. However, in dysfunctional cooperative teams, some team members stop cooperating with their peers and work alone, while others simply socialize with members of their own team (or others) and spend significantly less time on-task as a result. In the worst-case scenario, the behavioral problems of one team member may prompt conflicts among the other members, thereby reducing the learning per-

Table 2. SN ratios for the dependent variable of cooperative teams

Cooperative team	Academic achievement (n = 3)
A	–2.05
B	7.62
C	5.98
D	0.23
E	7.82
F	9.03
G	8.71

Table 3. SN ratios for the dependent variable of students using individualistic learning

Condition	Academic achievement (n = 21)
Individualistic learning	5.83

formance of the entire team. As a result, students within a dysfunctional cooperative team tend to achieve a lower academic performance than those who study in an individualistic learning mode. Consequently, in identifying dysfunctional teams, this study considers both cooperative and individualistic learning conditions and deems a team to be dysfunctional if its members exhibit a lower academic performance than that of students working alone.

Taguchi and other Quality Engineering researchers have advocated various theories and practices for combining quality characteristics in such a way as to obtain an improved quality measure [23–25]. The resulting quality indexes have been used throughout industry to improve the quality of a wide variety of products and processes [26–28]. In this study, Taguchi quality indexes are used as a means of identifying dysfunctional teams within an educational context.

Taguchi proposed various generic signal-to-noise (SN) ratios for evaluating the quality of engineering products or processes. In detecting the presence of dysfunctional cooperative learning teams, this study utilizes the Taguchi larger-the-better SN ratio [26–28]. For Taguchi larger-the-better type problems, the response values or quality characteristics have non-negative values and the aim is to increase the value of the response toward the largest number possible (preferably infinity). In the current study, this definition neatly fits the problem of evaluating the students' academic achievements. The larger-the-better SN ratio is formulated as $SN = -10 \log (\Sigma 1/y_i^2/n)$, where log (. . .) is the base 10 logarithm function, Σ is the summation operation, y_i is the i-th individual response value, and n is the number of data points [23–25]. Note that in Taguchi Method a higher SN ratio is always indicative of a better quality [23–28].

Table 2 presents the Taguchi SN ratio values for the academic achievement variable in this study. Note that the results are obtained by substituting the values of the academic achievement for each team into the formula given above. Note also that the value of n given at the head of the second column indicates the number of data points used to compute the value of the SN ratio for the academic achievement. Thus, the SN ratios for the academic achievement was computed using n = 3 since each team comprises three team members and each member contributes one data point to the SN calculation. Table 3 presents the SN values of the 21 students in the individualistic learning condition. The results presented in the second column in Table 3 (i.e. the SN ratio for academic achievement) suggest that cooperative learning teams A and D are dysfunctional since their SN values (–2.05 and 0.23, respectively) are lower than the mean SN ratio (5.83) of the students in the individualistic learning condition. Note that these findings are consistent with those presented by Hsiung [20] where the supporting evidence was provided by off-task behavior frequency observations and peer support surveys.

3.2 Dysfunctional teams and ability-condition interaction

Figure 1 plots the mean test scores of all the low-, medium- and high-ability students within the cooperative and individualistic learning conditions. It can be seen that the high- and low-ability students in the cooperative learning condition achieve a higher test score than those in the individualistic learning condition (i.e. 0.48 versus 0.15 and –0.25 versus –0.46, respectively). By contrast, the medium-ability students achieve an improved academic performance when working alone rather than within a cooperative team (i.e. –0.11 versus 0.13). As expected, the high-ability students achieve a higher score than the low-ability students in both learning conditions.

Previous studies disagree as to whether high-, medium-, and low-ability students all benefit equally from their participation in heterogeneous cooperative learning teams. For example, in a study to examine whether different-ability students benefit academically from collaborating with each other in a map-reading curriculum unit, Yager, Johnson, and Johnson [10] reported that high-, medium-, and low-ability students (a total of 75 second graders) all benefited from participation in heterogeneous co-

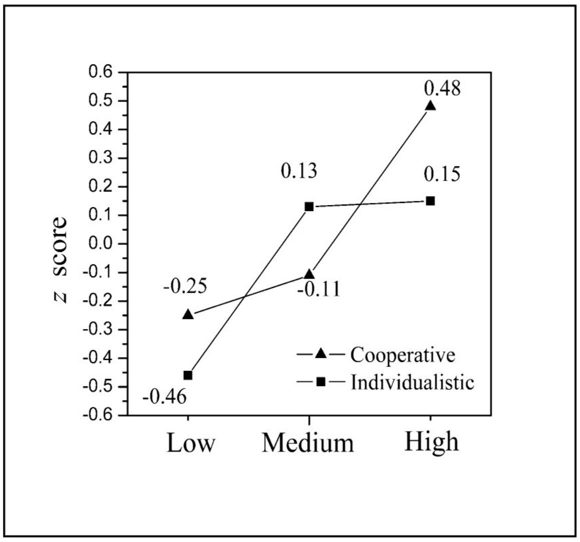

Fig. 1. Mean scores of different-ability students *before* scores of dysfunctional teams are removed.

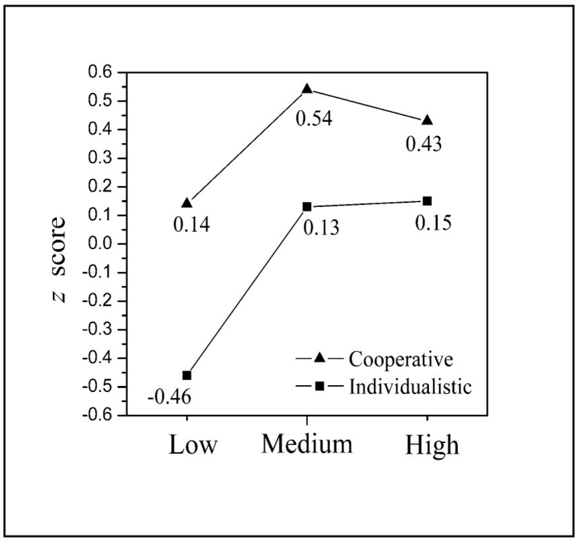

Fig. 2. Mean scores of different-ability students after scores of dysfunctional teams are removed.

operative learning groups. However, a different study examining the student achievement in a social studies curriculum unit (subjects were 48 fourth-grade students) Johnson, Johnson, Roy, and Zaidman [11] reported that the benefits of cooperative learning are felt more strongly by medium- and low-ability students. More recently, Hoon, Chong, and Binti Ngah [29] found that, in the learning of matrices, high-ability students achieved higher score gains than low-ability students in a comparison of three different cooperative learning strategies (the 262 subjects were from four different secondary schools). The results presented in Fig. 1 suggest another possibility, namely that cooperative learning benefits high- and low-ability students, but hinders the academic performance of medium-ability students. This interaction between the student's academic ability and the learning condition is clearly shown by the fact that the two lines in Fig. 1 cross at their mid-point positions. Previous studies offer no explanations regarding the origin of this ability-condition interaction effect. However, the results obtained in this study suggest that the interaction between a student's ability and the learning condition is a direct consequence of the presence of dysfunctional teams. Figure 2 illustrates the mean test scores for the students within the two learning conditions when the scores of the team members within the two dysfunctional teams (i.e. teams A and D) are excluded. In contrast to Fig. 1, the two lines in Fig. 2 are approximately parallel to one another, i.e. they do not cross at their mid-point positions. In other words, the ability-condition interaction effect is greatly reduced. The fact that the two lines are nearly parallel implies that in a non-dysfunctional group, students of all abilities benefit from a cooperative learning environment. As a result, the ability of the instructor to identify dysfunctional cooperative learning teams in a timely and reliable manner is of crucial importance in spreading the benefits of cooperative learning to students of all academic abilities within the class.

3.3 Identification of troubled team members

In this study, it is asserted that students within a dysfunctional team who have difficulty in adapting to a cooperative learning approach can be identified by comparing the academic achievement of each team member with the average academic achievement of all the students of an equivalent ability. The results obtained in this study indicated that the high-ability student within cooperative team A had an average test score of 0.48 compared with a mean test score of 0.48 for all the high-ability students. However, the medium- and low-ability students within cooperative team A had significantly lower average test scores than the mean test scores of all the medium- and low-ability students (i.e. –1.89 versus –0.11 and –0.94 versus –0.25, respectively). The high-ability student in team D achieved a slightly higher mean test score than the average score of all the high-ability students (i.e. 0.69 versus 0.48). However, the mean test scores of the medium- and low-ability members of team D were significantly lower than the average scores of all the students with an equivalent ability (i.e. –1.57 versus –0.11 and –1.46 versus –0.25, respectively). The results therefore suggest that the dysfunctional nature of teams A and D is a result of the presence of the four medium- and low-ability students within their ranks. The ability to identify troubled students within a dysfunctional cooperative learning team has a number of important implications. For example, Archer-Kath, Johnson, and Johnson [30] reported that individual feedback is more effective than group feedback in increasing students' achievement motivation, actual achievement, and uniformity of achievement. Therefore, identifying troubled students within a dysfunctional cooperative learning team and providing these individuals with direct feedback may well be beneficial in improving the dynamics within the team and improving its academic performance as a result.

3.4 Study limitations

Generalizing the results of this study is limited by the sample size, characteristics of the subjects, types of tasks, the skill of the instructor, and specific operationalizations of the independent and dependent variables. The sample size in this study is limited to the size of a typical engineering class available to the author. Generally, to implement cooperative learning, types of tasks and the skill of the instructor greatly affect the interactions among students, and consequently the success of cooperative learning. In other words, in a successfully implemented cooperative learning environment, dysfunctional teams may not exist at all and the ability-condition interaction effect may be explained by other reasons. This study uses the Taguchi larger-the-better quality index as a means of identifying dysfunctional teams, which is also subject to further study, though it has been widely and successfully used in industry. It would be more appropriate to classify the students into different academic abilities by using a standardized test [10, 11, 29]. However, no such standardized test was available for sophomore students, and an alternative was adopted. Given that some core courses, such as engineering mathematics, statics, fluid dynamics, and thermal dynamics had been taught in the previous semester, student performance in the previous semester was used to classify students into different levels of academic ability. Nonetheless, despite these limitations, the results obtained in this study are robust because of the stratified random assignment of students to the two conditions, the use of the same instructor to teach both conditions, the measurable nature of the dependent variable, and the confirmation of condition implementation. In a future study, further investigations will be performed to explore whether the present findings are equally applicable in a broader educational context.

4. Conclusions

The relative performance of the high-, medium- and low-ability students within the cooperative learning teams is compared with that of students with an equivalent ability within the individualistic learning condition. A series of experimental investigations was conducted using 42 sophomore students from the Mechanical Engineering department of the National Pingtung University of Science and Technology in southern Taiwan. The major conclusions of this study can be summarized as follows: The relative benefit of cooperative learning may well depend on the academic ability of the individual members within the cooperative team. Specifically, cooperative learning benefits high- and low-ability students in terms of improving their academic performance, but hinders that of medium-ability students. Moreover, the interaction effect observed between the students' ability and the students' learning condition may be a direct consequence of the presence of dysfunctional teams.

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