

The Effects of Inquiry-Based Computer Simulation with Cooperative Learning on Scientific Thinking and Conceptual Understanding of Gas Laws

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The purpose of the study was to investigate the effects of inquiry-based computer simulation with heterogeneous-ability cooperative learning (HACL) and inquiry-based computer simulation with friendship cooperative learning (FCL) on (a) scientific reasoning (SR) and (b) conceptual understanding (CU) among Form Four students in Malaysian Smart Schools. The study further investigated the effects of the HACL and FCL methods on performance in scientific reasoning and conceptual understanding among students of two reasoning ability levels, namely empirical-inductive (EI) and hypothetical-deductive (HD). A quasi-experimental method that employed the 3 x 2 Factorial Design was applied in the study. The sample consisted of 301 Form Four students from 12 pure science classes in four Smart Schools which were all randomly selected and assigned to treatment (HACL & FCL) and control (TG) groups. The results showed that students in the HACL group significantly outperformed their counterparts in the FCL group who, in turn, significantly outperformed their counterparts in the TG group in scientific thinking and conceptual understanding. The findings of this study suggest that the inquiry-based computer simulation with heterogeneous-ability cooperative learning method is effective in enhancing scientific reasoning and conceptual understanding for students of all reasoning abilities, and for maximum effectiveness, cooperative learning groups should be composed of students of heterogeneous abilities.

Keywords: Science Education, Biotechnology, Attitudes, University Students.

INTRODUCTION

The development of thinking ability in individuals has always been recognized to be of great importance to enable them to make decisions wisely and to solve a problem efficiently. Acclaiming the importance of the

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development of thinking ability in students, Malaysian Curriculum Development Centre introduced thinking skills as one of the major skills to be inculcated in the Secondary School Revised Science Curriculum that was implemented in 2003 (KPM, 2002, p.20). Thinking skills refer to a set of mental capabilities or patterns of thought which are rational or logical in nature. For the purpose of this study, thinking skills also include scientific thinking or higher reasoning abilities that involve what Piaget has termed formal operational thought (Piaget, 1964), or renamed by Lawson (1995) as

hypothetical-deductive (HD) thinking patterns which include identifying and controlling of variables, proportional thinking, probabilistic thinking, combinatorial thinking and correlational thinking. Mastery of scientific thinking skills is one of the aspects given emphasis in the Smart Schools science curriculum (Poh, 2003). The Smart Schools were introduced in 1999 by the Government with the objectives of promoting a knowledge-based culture as well as producing caring students with critical and creative thinking skills (Multimedia Development Corporation, 2000).

Physics is a field that involves the study of physical phenomena, and students are continuously required to identify the hidden concepts, define adequate quantities and explain underlying laws and theories using high level reasoning skills (Nivalainen, Asikainen, & Hirvonen, 2003). In other words, students are involved in the process of constructing qualitative models that help them understand the relationships and differences among the concepts. A number of studies have found that students who lack reasoning skills do more poorly on measures of conceptual understanding than their more skilled peers (Cavallo, 1996; Lawson et al., 2000; Shayer & Adey, 1993). For example, the concrete operational students or empirical-inductive (EI) reasoners, whose thinking are largely limited to direct observation were found unable to understand the formal concepts (Lawson, 1975). The difficulties that students have with formal concepts relate to their inability to apply scientific reasoning skills that are necessary for explaining the concepts. Gas Law, for example, is a topic that was found to be difficult for both high school and college students to understand because it requires the understanding of the behaviors of particles at the microscopic level (Nurrenbern & Pickering, 1987; Nakhleh, 1993; Chiu, 2001) and involves the use of direct and inverse ratios which require proportional reasoning, the ability to identify and control variables, and probabilistic thinking. These reasoning skills are essential for understanding the concepts involved because gas laws can only be defined in terms of other concepts (temperature, pressure, and volume), abstract properties, and mathematical relationships. Recent study, however, found that Malaysian students in Form Two performed very poorly in science items that relate to physics which involve scientific reasoning skills (Kementerian Pelajaran Malaysia, 2000; Martin et. al., 2000). For example, on a question for the top 10% benchmark that requires an ability to interpret data given in a table, compute the appropriate ratio, and explain their results, Malaysian students performed lower than their peers in 29 nations, and score much lower than international average of 38 nations (Martin et. al., 2000). Thus, methods of instruction in physics must emphasize the development

of scientific reasoning skills as these skills are required for conceptual understanding.

Research studies have indicated that visualization of phenomena through computer simulations can contribute to student's understanding of physics concepts at the molecular level by attaching mental images to these concepts (Cadmus, 1990). According to Escalada & Zollman (1997), computer simulations provide opportunities for students not only to develop their understanding and reinforcement of physics concepts, but also to develop their skills in scientific investigation and inquiry. Inquiry-based science experiences conducted in relevant, meaningful contexts have been shown to develop higher order thinking skills in students (Roth & Roychoudhury, 1993). This is further supported by Cakir and Tirez's (2006) study that found inquiry-based science teaching and learning, with the support of computer simulation and collaborative contexts help learners to develop critical thinking and inquiry skills. Lawson (1995) cites literature indicating that the Learning Cycle approach that consists of Exploration, Concept Introduction, and Concept Application phases is an inquiry-based teaching model which has proven effective at helping students construct concepts as well as develop more effective reasoning patterns. Several studies involving adolescents in learning cycle science courses claim that the use of this instructional method in science classroom increased student understanding of science concepts and improved student reasoning abilities (Purser & Renner, 1983; Saunders & Shepardson, 1987; Schneider & Renner, 1980).

According to Vygotsky, a less skillful individual is better able to develop a more complex level of understanding and skill than he/she could independently through collaboration, direction, or help of an expert or a more capable peer. Scaffolding has been found to be an excellent method of developing students' higher level thinking skills (Rosenshine & Meister, 1992). Vygotsky's theories of scaffolding knowledge through peer discussion and interaction has been applied systematically under the rubric of "cooperative learning". Cooperative learning is an instructional technique in which students work together in structured small groups in order to accomplish shared goals (Johnson & Johnson, 1989). Research studies have clearly indicated the effectiveness of cooperative learning methods over either competitive or individual learning methods in the development of higher-order thinking skills as well as the achievement of greater learning outcomes (Johnson & Johnson, 1986). This suggests that with the help of sufficient scaffolding, or dynamic group support in cooperative environments, provided by inquiry-based computer simulations, an instructor, a more skilled partner, or a more capable

peer, will enable concrete operational students to enhance their reasoning skills toward formal thought.

The meta-analysis study done by Lou et al. (1996) indicates that low-ability students gain most from being placed in heterogeneous ability groups because they receive individual guidance and assistance from their more able peers. Hooper and Hannafin's (1988) study also give evidence that low ability students improved their performance more than 50% when grouped heterogeneously. However, the low ability students have a higher risk of being excluded from group activities because they are seen by high ability students as being less competent (Whicker, Bol, & Nunnery, 1997). Alternately, low ability students may be motivated to learn by the effects of social cohesion inherent in friendship groups (Lou et al., 1996). Advocates of social cohesion perspective (Johnson & Johnson, 1994; Cohen, 1986; Sharan & Sharan, 1976) argue that the extent to which cooperative learning has an effect on student achievement will be mediated strongly by the cohesiveness of the group. This study, therefore, tested

the 'diversity of intellectual abilities' hypothesis against 'group cohesiveness' hypothesis by placing students in heterogeneous ability grouping and friendship grouping, to investigate how much, if any, these groupings facilitated student's scientific thinking and conceptual understanding of gas laws within inquiry-based computer simulation and cooperative learning environment. In addition, the study explored the extent to which heterogeneous ability and friendship grouping affected learning for EI and HD students compared to their counterparts in traditional group work groups. Thus, three instructional methods were employed in this study: inquiry-based computer simulation with heterogeneous-ability cooperative learning (HACL), inquiry-based computer simulation with friendship cooperative learning (FCL) and inquiry-based computer simulation with traditional group work (TG).

PURPOSE OF THE STUDY

The purpose of this study was threefold. Firstly, it

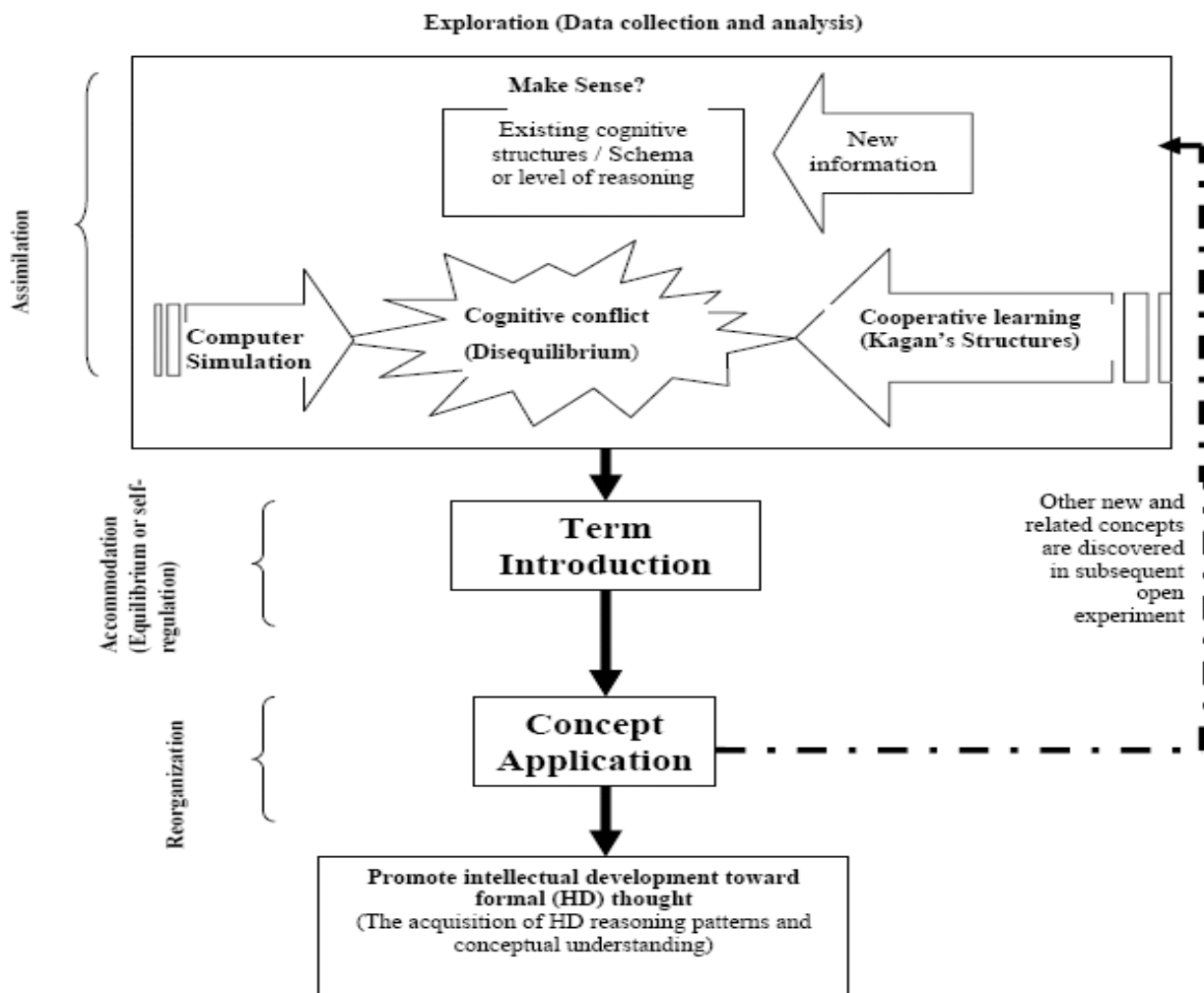


Figure 1: Theoretical Model of the study

was to investigate if there were any significant differences in student's scientific reasoning (SR) and conceptual understanding (CU) between learners who were taught in three different instructional methods. Secondly, it was to investigate the effects of these instructional methods on EI students and HD students in SR and CU. Thirdly, it was to investigate the interactions between the instructional methods and student's reasoning level on performance in SR and CU.

THEORETICAL FRAMEWORK

The theoretical framework of this study is based on Piagetian cognitive theory and Vygotsky's theory. Piaget (1952) believed that the cognitive development of students toward formal thought could be facilitated through three cognitive processes: assimilation, accommodation and reorganization. Vygotsky (1978), on the other hand believed that students are capable of performing at higher intellectual levels when asked to work in collaborative situations than when asked to work individually. He hypothesized that the social interaction extended the student's zone of proximal development, the difference between a student's understanding and potential to understand more difficult concepts. Based on these two theories, a theoretical model of the study was presented in Figure 1.

For this model, students might be exposed to inconsistencies and conflicts in their attempt to understand new information. Specifically, when the new information raises questions or complexities that an individual could not resolve with their accustomed patterns of reasoning. The desire to resolve incongruities between prior understanding and new information is accompanied by a feeling of imbalance or disequilibrium or cognitive conflict. As a result, students are required to resolve their cognitive conflict through visualization of physical phenomena via dynamic computer simulation and peer support in cooperative learning group. This will make them to recognize in what ways their current thinking fall short and reorganize their personal beliefs, as well as to go beyond their current thinking capability.

Students' active participation in collecting and analyzing data via computer simulation in cooperative learning group is designated as Exploration phase. This involves the interpretation of events in terms of existing cognitive structure or referred as assimilation. The Term Introduction phase promotes a new state of understanding or equilibrium or self-regulation when new concepts and principles are derived from the exploration experiences. Through the process of self-regulation, existing knowledge, or schema will be altered to allow accommodation to occur. The Concept Application phase provides additional experience that

may aid students to discover further application of newly developed concept and principles, providing opportunities for re-organization to occur. Other new and related principles are discovered by the students through extension activity in the subsequent open-inquiry experiment. This provides additional time and experiences to further encourage self-regulation and for stabilization of new principles. Via this process knowledge is constructed by individuals and accordingly, peers interaction may present different perspectives that may lead students to reconceptualise their own thinking.

Through the three phases of Lawson's (1995) learning cycle, students' thinking is expected to progress from concrete thinking about physics concepts to being able to deal with those concepts on a formal, abstract level. Consequently, the present study was set up to investigate the extent to which the integration of the Learning Cycle approach to computer-based simulations and cooperative learning would result in improved performance of concrete operational students in scientific reasoning and conceptual understanding of gas laws.

HYPOTHESES

On the basis of theory and evidence of related research and theoretical framework of the study, the following hypotheses were postulated and computed at the 0.05 level of significance.

Hypothesis 1: Students taught via inquiry-based computer simulation with heterogeneous-ability cooperative learning (HACL) method will perform significantly higher than students taught via inquiry-based computer simulation with friendship cooperative learning (FCL) method who in turn will perform significantly higher than students taught via inquiry-based computer simulation with traditional group work (TG) method in (a) scientific reasoning, and (b) conceptual understanding of gas laws.

Hypothesis 2: The HD students taught via HACL method will perform significantly higher than HD students taught via FCL method who in turn will perform significantly higher than HD students taught via TG method in (a) scientific reasoning, and (b) conceptual understanding of gas laws.

Hypothesis 3: The EI students taught via HACL approach will perform significantly higher than EI students taught via FCL method who in turn will perform significantly higher than EI students taught via TG method in (a) scientific reasoning, and (b) conceptual understanding of gas laws.

Hypothesis 4: There are significant interactions between the instructional methods and student's reasoning ability level in performance in (a) scientific reasoning, and (b) conceptual understanding of gas laws.

RESEARCH METHODOLOGY

Research Design

The study employed a quasi-experimental pre-test-post test / control group design. The 3x2 factorial design was employed to examine the effect of three different instructional methods on EI student and HD student's performance in scientific thinking and conceptual understanding. The independent variable was the three instructional methods: HACL method and FCL method (experimental group), and TG method (control group). The dependent variables were the learner's scientific reasoning ability and conceptual understanding. The second dependent variable, i.e., conceptual understanding was the degree to which a student's understanding of the concept at the particulate level of Gas laws corresponds to the scientifically accepted explanation of the concept. The moderator variable was the learners' scientific reasoning ability which was designated EI and HD levels.

Research instruments

The effects of the experimental treatments were assessed using four instruments. All the instruments used in this study were translated from English version into Malay language using "Back Translation Method" so that the respondents do not have problems in understanding due to language.

The Lawson's revised Classroom Test of Scientific Reasoning Skills, CTSR (Lawson, 2000) and Roadranga's Group Assessment of Logical Thinking, GALT (Roadranga, Yeany, & Padila, 1983) were used to measure the learners' level of reasoning ability. Each instrument consisted of 12 items measuring conservation of weight, volume displacement, proportional thinking, identification and control of variables, probabilistic thinking, combinatorial thinking, and correlational thinking posed in multiple choice formats.

The Gas Laws Performance Test (GLPT) was developed to assess learners' conceptual understanding. The test consisted of 10 items requiring students to give a brief answer to the question, and a reason for why that answer was given, while others required students to provide explanation to the phenomenon presented in the questions.

The Cooperative Learning Survey Questionnaire (CLSQ) was constructed to survey the perceptions of participants toward their performance measures on four elements of Kagan's cooperative learning structures. It consisted of 16 items grouped into four categories: Positive interdependence, Individual Accountability, Equal Participation, and Simultaneous Interaction. Each item was constructed on a 5-point, Likert-type scale

ranging from 1 (Strongly Disagree) to 5 (Strongly Agree).

All instruments were tested for reliability in a pilot study by determining the Cronbach coefficient alpha. The Cronbach alpha reliability coefficients of GALT (Pre-test) and CTSR (Post-test) were 0.6095 and of 0.6785 respectively. The Pearson's correlation coefficient among CTSR and GALT was 0.536. The GLPT test was administered as pre-test and post test to each HACL, FCL and TG group. The Cronbach alpha reliability coefficient of GLPT Test was 0.8445. The overall alpha reliability coefficient for the CLSQ was 0.8256 and the internal consistency estimate of each component in the questionnaire ranged from 0.4869 to 0.6814.

The EI and HD levels of learners' reasoning level was measured using GALT. Students with scores of 0 to 6 were considered to be concrete operational (EI students). Students who accumulated scores from 7 to 12 points were classified as formal operational (HD students). In order to account for possible pre-existing differences in overall ability between the treatment groups, the pre-test scores of GALT and GLPT were used as covariate measures.

Research Sample

The samples consisted of 301 Form Four pure science students (mean age 16.4 years old) from four different Smart Schools in Kedah and Penang. The study employed three classes or approximately 90 students from each of four randomly selected Smart Schools. They studied "Gas Laws", one of the topics in the syllabus of Form Four Physics. The participating students in each school were randomly assigned to one of the three conditions – HACL method, FCL method, or TG method as intact groups.

The HACL group was assigned by the teacher so that it comprised of two HD students and two EI students based on their individual test scores in GALT. The students in FCL group were assigned to four-member cooperative groups by having them choose randomly four members of their class with whom they most preferred or desired to work together. The FCL groups were found homogeneous in terms of reasoning ability as evidenced by the student's pre-test scores in scientific reasoning. To determine whether FCL groups whose members chose to work together were perceived as cohesive, all students completed a nine-item Group Cohesiveness Questionnaire (Hinkle, Taylor & Fox-Cardamone, 1989) at post test. Overall, the FCL groups were found fairly high cohesive ($M= 4.3038$, $SD= 0.5707$) on a five-point Likert scale. The traditional group work group (TG) served as a control group. The students in this group were given the choices to select

their own group members and to determine their group size.

Instruction with instructional materials

In this study, all groups received identical instructional packages: Gas Laws Simulation package (Figure 2). The Gas Laws Simulation Package consisted of a) Gas laws simulation; b) Molecular Laboratory Experiments (MoLE) Gas Laws Worksheet; and c) Learning Guide on creating a graph using MS Excel Spreadsheet, all of which were presented in a CD provided. The adopted gas laws simulation, categorized as iterative simulation, was a dynamic computer-generated graphic representation of molecular processes produced with Java Applet by Gelder, Haines and Abraham (2002). The simulation was embedded into the Gas Laws Simulation Package which was accessed as an Authorware package running on the CD.

The student was given step by step instructions on how to use the gas laws simulation and asked to explore the different parts of the simulation. A set of controls on Control Bar Region provided the student with the ability to vary the input parameters for the simulation. Students had to decide which variables to vary and which to keep constant before running the simulation and to make necessary observations. Each group of students then performed a set of experiments using prescribed instructions provided on Gas Laws Worksheet. The students were expected to discover mathematical relationships of gas laws from the graph created using Microsoft Excel Spreadsheets.

The implementation of learning group

The four key elements of Kagan's cooperative learning, i.e. Positive Interdependence, Individual Accountability, Equal Participation and Simultaneous Interaction were embedded into the structure of Gas Laws activities for HACL and FCL groups. To promote positive interdependence in gas laws activity, the task was structured using Roundtable, Think-Pair-Square, and Read-Think-Discuss-Write, so that every student must contribute for the assigned task and team members were obliged to rely positively on one another to make the task successful. For structuring a task to include individual accountability, each student was made accountable to the group for her/his portion of a task, such as graphing group's data and presenting group's result to other groups. Additionally, students were structured to take personal responsibility to understand the group solution to a problem and how that solution was obtained. Consequently, Numbered Heads Together was adopted with which individual student was randomly called on to present their group's answer during subsequent class discussions.

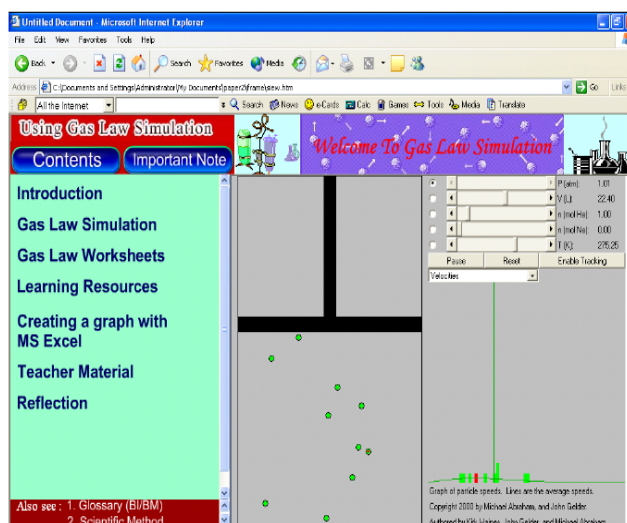


Figure 2. Part of the Gas Laws Simulation Package interface window

To ensure that the students participated equally, each student a) was assigned a different and important role in the group, such as reporter, recorder, checker, and team leader; and b) was expected to contribute to the discussion when his/her turn came by engaging in the tasks structured using Round Robin and Rally Robin. The tasks were also structured so that interaction occurred simultaneously both within and among teams. For example, using 'One stay, the rest stray' and 'Rally-Robin' structures for sharing information among teams and within pairs, active participation and feedback could occur for all students at a time. In order to ensure that each student committed to the assigned role, a learning contract was developed to be filled out by each group member.

The TG group experienced the same reactive effects of an inquiry-based computer simulation and group work as the HACL and FCL groups, but without the four key elements of Kagan's (1994) cooperative learning.

Administering the Study Sessions

The gas laws simulation activities sessions were administered in four separate sessions in different week, with 70-80 minutes for each session. The teachers of all instructional groups were provided a detailed lesson plan to conduct the learning activities. Prior to the start of first section, the teacher was requested to explain the specific requirement and procedure for the learning task. The first exploration phase of MoLE gas laws activity required approximately 40-60 minutes for students to complete. Prior to the investigations conducted in the study, the students had reviewed the concepts of gas pressure, and the basic principles of the Kinetic Molecular Theory of gases. A printed Gas Laws Worksheet was provided to guide the learners through

the exploration phase which was primary intended to get the learners to experience the concept of Gas Laws to be developed and search for pattern of regularity from the graph created using Microsoft Excel Spreadsheets.

The students, in their group then carried on their second exploration phase and follow-up investigation in the following class lesson. The students in HACL, FCL and TG condition were expected to discover mathematical relationships of gas laws and explain phenomena in the gas laws simulation in their own group, with little help of the teacher. The teachers acted as a facilitator, monitored groups and intervened to provide task assistance if needed. Only after the students had thoroughly investigated, discussed, and attempted to logically explain the phenomenon, the teacher offered the students a more in-depth or scientifically accepted explanation and new terms. The students then engaged in a hands-on activity on 'Balloon in a bottle'. These experiences aided students in finding answers to questions that they had generated during demonstration prior to the beginning of gas laws activities. The teacher then posed a new situation or problem which can be solved on the basis of the previous exploration experiences and term introduction.

At the end of the teaching session four in each school, the entire class in all groups' condition was asked to complete the Gas Laws Performance test. The cooperative learning survey questionnaire and Classroom Test of Scientific Reasoning Skills were administered immediately after the students completed the Gas Laws Performance test. The students in the FCL groups were also asked to fill out a Group Cohesiveness Questionnaire.

RESEARCH FINDINGS

The data was compiled and analyzed using SPSS for Windows (version 11.5). Alpha was set at 0.05 level of significance.

The pre-Experimental Study Results

Initial screening tests indicated adequate conformity to all univariate and multivariate assumptions of MANOVA/MANCOVA for multivariate normal distribution in each group, homogeneity of DV variance/covariance matrices across groups in the population, the linear relationship between the covariates and the dependent variables, and linear relationship among dependent variables. A Chi-Square analysis revealed that the difference in group sizes were not statistically significant ($\chi = 4.76$, $p = 0.093$), thus the Pillai's trace was used to evaluate the multivariate differences. The groups were tested for equality and the results of MANOVA (Table 1) indicated that the HD

and EI participants across the three groups were equivalent in scientific reasoning and conceptual understanding of gas laws.

The Experimental Study Results

Performed Post hoc pairwise comparison using the /lmatrix command (Table 2) showed that students in the HACL group significantly outperformed their counterparts in the FCL group ($p = .001$ and $p = .000$ respectively) who, in turn, significantly outperformed other students in the TG group ($p = .000$ and $p = .000$ respectively) in scientific thinking and conceptual understanding. Therefore Hypothesis 1 was supported. Also, HD students in the HACL group significantly outperformed their counterparts in the FCL and the TG groups in conceptual understanding ($p = .008$ and $p = .000$ respectively). Further, HD students in the HACL group significantly outperformed their counterparts in the TG group in scientific reasoning ($p = .004$), but did not significantly outperform their counterparts in the FCL group ($p = .107$). However, there were no significant differences between the performance of HD students in the FCL group and the TG group in scientific reasoning and conceptual understanding ($p = .224$ and $p = .219$ respectively). Therefore Hypothesis 2 was partially supported.

The results also showed that EI students in the HACL group significantly outperformed their counterparts in the FCL group ($p = .004$ and $p = .002$ respectively) and in the TG group ($p = .000$ and $p = .000$ respectively) in scientific reasoning and conceptual understanding. The EI students in the FCL group in turn significantly outperformed their counterparts in the TG group in scientific reasoning and conceptual understanding ($p = .018$ and $p = .005$ respectively). Therefore Hypothesis 3 was supported. An effect size in the eighties for comparing HACL and TG group indicates that the HACL method is an effective instructional method for promoting scientific reasoning and conceptual understanding. Overall, the HACL group outperformed FCL group with a relatively moderate difference on performance in scientific reasoning and conceptual understanding.

Finally, the results of MANCOVA showed that there was no significant interaction effect between instructional method and student reasoning ability level, as they related to scientific thinking and conceptual understanding of gas laws ($F(4, 586) = 0.74$, $p = .990$). This suggests that the effect of instructional groups did not depend significantly on the level of student's reasoning ability in both scientific thinking and conceptual understanding. Hence, hypothesis 4 was rejected.

Table 1. Summary of multivariate analysis of variance (MANOVA) results and follow-up analysis of variance (ANOVA) results on pre-SR and pre-CU.

Level	MANOVA Effect and Dependent Variables	Multivariate F	Univariate F
HD	Group Effect	Pillai's Trace 1.104 ($p = .375$), $df = 4, 150$	$df = 2, 75$
	Pre-Scientific Reasoning (pre-SR)		2.105 ($p = .129$)
	Pre-conceptual understanding of gas laws (Pre-CU)		.140 ($p = .870$)
EI	Group Effect	Pillai's Trace 1.772 ($p = .133$), $df = 4, 440$	$df = 2, 220$
	Pre-Scientific Reasoning (pre-SR)		1.210 ($p = .300$)
	Pre-conceptual understanding of gas laws (Pre-CU)		2.505 ($p = .084$)

Table 2. Summary of post hoc pairwise comparison

Comparison Group	Dependent Variable					
	Scientific Reasoning (SR)			Conceptual Understanding of Gas Laws (CU)		
	Mean Difference	Sig	Effect size	Mean Difference	Sig	Effect size
<i>Between Instructional Groups</i>						
HACL vs. FCL	6.099	.001	0.399	7.011	.000	0.514
HACL vs. TG	10.961	.000	0.766	12.436	.000	0.965
FCL vs. TG	4.861	.009	0.361	5.425	.002	0.417
<i>Between HD students across the three groups</i>						
HACL vs. FCL	6.479	.107	0.464	8.458	.008	0.662
HACL vs. TG	11.745	.004	0.808	12.730	.000	1.040
FCL vs. TG	5.266	.224	0.398	4.271	.219	0.393
<i>Between EI students across the three groups</i>						
HACL vs. FCL	6.120	.004	0.424	6.510	.002	0.643
HACL vs. TG	10.961	.000	0.853	12.247	.000	0.939
FCL vs. TG	4.841	.018	0.387	5.737	.005	0.446

Note. The mean difference shown in this table is the subtraction of the second condition (on the lower line) from the first condition (on the upper line); for example, 6.120 (Mean Difference for SR) = HACL – FCL.

DISCUSSION

The results of this study found that students who worked in HACL method outperformed those who worked in FCL and TG methods in conceptual understanding of Gas Laws. The results are consistent with cognitive elaboration theory which holds that explaining the material to someone else is the most effective means of learning (Slavin, 1987). The HD students in HACL group who held accountable to provide explanation to group members could examine their comprehension in detail, and this has been shown to lead to an awareness of inadequacies in their existing schemas (Collins & Stevens, 1982). When students gave

the explanations, they needed to digest, connect, and combine the understood and newly developed concept they learned. According to Piaget (1952), this interaction with group members enable HD students to discover further application of newly developed concept, thus providing opportunities for cognitive restructuring to occur. On the other hand, EI students benefited from the immediate feedback and individual guidance that HD students provided, consequently helped them to clarify their own mental models and foster better understanding of gas laws. For example, the gas laws simulation engaged EI students to ask help from their HD group members to decide the best way of representing and interpreting the quantitative data.

Thus, the opportunity of EI students to work cooperatively with HD students in HACL groups increased their ability to think in HD form. In contrast, the students with homogeneous ability grouping in the FCL group might suffer from a lack of appropriately role models to provide explanation, thus they did not create as good a stage as students in HACL group for elaborate thinking, or for explaining processes to take place. As a result, students in FCL groups did not develop a better conceptual understanding of gas laws than students who taught via the HACL groups.

The results also showed that students who worked in HACL groups made significantly greater gains on the scientific reasoning test than those who worked in FCL and TG groups. The effectiveness of HACL method in promoting the scientific reasoning of students is consistent with cognition theories of Piaget and Vygotsky that social interaction is a force in mental development (Inhelder, et al., 1979; Vygotsky, 1978). In the present study, the HD students taught via HACL method acting as experts, developed or proposed methods and strategies that were successful in solving the given problems. The EI student was then given the opportunity to model these successful methods and strategies, while the HD students offering hints, scaffolding, and providing feedback to further develop the EI student's ability in hypothetical-deductive reasoning. Through the process of demonstrating appropriate strategies of approaching a problem, these HD students became more aware of the thinking processes they were using. At the same time, the EI students were given opportunities to compare - contrast their knowledge, reasoning in a specific domain with those of their HD peers. In this study, the Gas Laws Simulation provided interactive experience with physical phenomena that contradict students' prior conceptions. For example, some of the students had the idea that the speed of the particles increase as the volume of the container decrease, thus increasing the temperature; simulations allowed them to observe that there was no change in the average kinetic energy when the volume changed, therefore the particles could not be moving faster and there was no change in temperature. When the results of an investigation contradicted with what students had expected or with their prior concepts, mental disequilibrium occurred. With exposure to evidence that they gathered from Gas Laws simulation and different perspectives presented by their HD peers, EI students were able to reconceptualise their own thinking. This form of peer-peer cooperative learning represents Piagetian theory that provided EI students with the opportunity to extend themselves to higher levels of reasoning. Consequently, HACL method helped students to reason scientifically better than those taught via the FCL and TG method.

On one hand, the HD students in HACL group generally achieved at the same levels as did their counterparts in FCL group in scientific reasoning. The similar performances of HD students indicated that students had undergone brain growth plateau at age 16 and 17 (mean age 16.42 years). This could be explained by the view that improvements in scientific reasoning are a product of both neurological maturation and experience (physical and social) (Kwon and Lawson, 2000). With regard to the development of adolescence and early adult thought, for example, Inhelder and Piaget (1958) stated: "...this structure formation depends on three principal factors: maturation of nervous system, experience acquired in interaction with the physical environment, and the influence of the social milieu" (p.243). Therefore, the present study suggests that instructional methods in promoting scientific reasoning among HD students can be effective if it is timed to occur after the plateau period in brain maturation.

The HD students taught via FCL instructional method did not perform significantly higher than their peers taught via TG instructional method in conceptual understanding and scientific reasoning. The results of this study are consistent with the results reported by Mullen & Cooper (1994) who found that, on average, correlational studies revealed a negative relationship between social cohesiveness and performance. Webb (1982) indicated that high ability students in homogenous groups might suppose that every one understands and then they reduce the interaction. In this regard, there was the potential that HD students in FCL groups who were cohesive became too confident about the ability of their group members to perform well and did not fully discuss the issues of importance or seek participation of all members to help them make decisions. Evans & Dion (1991) are also of the view that cohesiveness and productivity are negatively related as long as group norms discourage high productivity. A norm is a way of thinking, feeling, or behaving that is perceived by group members as appropriate (Asch, 1952; Sherif, 1936). Consequently, the cohesiveness-performance relationship is primary due to fact that the HD students of a FCL group developed norms that limited group member's participation to share their ideas and opinion. As a result The HD students taught via FCL method did not perform significantly higher than their peers in TG group in conceptual understanding and scientific reasoning.

The positive effects of FCL method on EI student's performance in scientific reasoning and conceptual understanding can be related to social cohesion perspectives that posit that students help one another learn because they care about one another and want one another to succeed (Slavin, 1995). As each group members wanted to stay in the group, and worked well

together socially, they were dependent on one another, and hence promoted positive social interdependence among group members. This positive social interdependence, in turn, according to social interdependence theory, lead to promotive interaction as EI students within FCL group encouraged and facilitated each member's learning and output (Johnson & Johnson, 1989). It follows that the group members engaged in active learning behaviors, and hence promoted each other's success. As EI members of FCL groups engaged in frequent and open discussion, they increased their ability to develop more complex level of understanding and reasoning and therefore they outperformed their counterparts who taught via the TG method in scientific reasoning and conceptual understanding.

The students taught via TG method had significantly lower mean scores than those in the HACL and FCL methods in scientific reasoning and conceptual understanding. In this study, students taught via TG group were assumed to know how to work together and to be interested in participating and learning. Responses on the cooperative learning questionnaire indicate that the students responded very negatively to the fact that they were given an equal opportunity to participate to the group's task and that they were individually accountable for his or her contribution to the group work. The students taught via TG group were given a task to complete without the provision of structures that promoted the active and equal participation of all members. According to Kagan (1994), when the group did not structure for equal participation, the group discussion session could involve participation exclusively by the high achieving or extroverted students. When low achieving or introverted students saw their efforts as dispensable for the group's success, they reduced their efforts (Kerr & Bruun, 1983; Sweeney, 1973). Emerging from this, the students taught via TG group were not responsible for the part of the task and did not become individually accountable to their partners for doing their share and therefore group work resulted in some students doing most or all the work while others engaged as free rider. In addition, the students taught via TG group were given a task with no structuring or roles, and consequently group work did not hold each individual accountable to the group for his/her contribution. When group work did not structure for individual accountability, the students did not engage in the behaviors that increase performance by helping each other and encouraging each other to put forth maximum effort (Slavin, 1995). It follows that the interaction behaviors, including giving and receiving help, discussing, and sharing were lacking in a TG group. Consequently students had limited opportunities to discuss and share their ideas, or resolve contradictions between their own and other students'

perspectives. As a result, students taught via TG group did not benefit much from group interaction than students did in HACL and FCL group.

The results of the study showed that the student's reasoning ability level did not significantly affect the performance of the instructional method. i.e., the EI and HD students benefited equally in SR and CU after learning in HACL or FCL or TG methods. Lawson & Bealer (1984) argued that successful qualitative reasoning arises as a consequence of the process of equilibration or self-regulation, that is an internal cognitive process whereby an individual's mental structures and some confusing external experiences interact over a period of time to eventually allow for the modification of previously incomplete and inadequate mental structures and the satisfactory "internalization" of the experiences (p. 421). In this regard, the acquisition of concepts and reasoning skills which was initiated by specific short-term instruction, as introduced in this study, did not become internalized. In other words, for EI students to progress dramatically from what Vygotsky called their "actual developmental level" to their "level of potential development", would require more long-term developmental processes. From the intellectual development viewpoint, the HD students have become increasingly capable of using a wide range of reasoning patterns (Lawson, 1995). Thus, despite working cooperatively and involved in self-regulation, they did not benefit as much from the instructional methods in scientific reasoning and conceptual understanding.

CONCLUSIONS AND IMPLICATIONS

In conclusion, the present study has found support for the hypotheses that the inquiry-based computer simulation with heterogeneous-ability cooperative learning method (HACL) is an effective mean of promoting students' scientific reasoning ability and conceptual understanding of gas laws in science classroom. The teachers should therefore manipulate the group's membership heterogeneously, as well as constantly monitor that the four elements of Kagan cooperative learning are being adhered to by each group for maximum effectiveness. The FCL method had a positive effect on EI students but not HD students. The EI students adopted norms for more positive behavior by engaging them in Kagan's cooperative learning structures than HD students did. The cohesiveness provided by EI membership in the FCL group promoted positive social interaction and promotive interaction that increased their ability to develop more complex level of understanding and reasoning than their peers in the TG group. Less effort in encouraging others from participating and not fully considering or responding to others' contributions in group task, all

apparently interfered with the processes necessary for HD students to perform effectively in FCL group. The results of this study also indicated that learning groups need a clear cooperative goal structure if teachers wish to maximize performance on learning tasks when placing students in groups.

The findings of this study suggest that the HACL method is effective in enhancing scientific reasoning and conceptual understanding of gas laws for students of both EI and HD reasoning level. Therefore, the teachers need to become adept at recognizing the cognitive levels of their students, as well as how they interact with each other. Cooperative groups that composed of students of heterogeneous abilities need to be carefully formed after the teacher has built up knowledge of students' personalities, interests, skills and abilities before incorporating cooperative learning method into computer based instruction. In addition, teachers should provide EI students more opportunity and guide and assist them through HACL method. The EI students can perform almost as HD students as the findings of this study if they were lead appropriately. The teachers should engage students to think as scientists do as they analyze data and create theories and hypotheses. This could take the form of teaching thinking via web-based computer simulation which is available and easy to access. The instructional design should be refined in such a way as to push students to ask inquiry-based questions and create adequate alternative explanations for their findings that go beyond "our experiment didn't work".

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