

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

¹*Sopiah Abdullah & ²Merza Abbas*

¹Science Department
Gaya Teacher Training College
88805, Kota Kinabalu, Sabah, Malaysia
snyetmoi@yahoo.com

²Central for Instructional Technology & Multimedia
Universiti Sains Malaysia
11800, Penang, Malaysia
drmerza@yahoo.com

Abstract

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 other students 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.

INTRODUCTION

The development of thinking ability in individuals has always been recognised to be of great importance to enable them to make decisions wisely and to solve a problem efficiently. Acclaiming the importance of the development of thinking ability in students, Malaysian Curriculum Development Centre introduced thinking skills as one of the major goals of Secondary School Revised Science Curriculum that was implemented in 2003 (Ministry of Education, 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).

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. 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). 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. 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). 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.

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. 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. 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 (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. In this view, members of cohesive groups who like the other group members, feel that they are part of the group, are satisfied with their group membership, and want to remain in the group are typically more committed to help one another learn and want one another to succeed because they care about one another. 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 students relatively high and low in reasoning abilities 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). Therefore, the purpose of this study was threefold. Firstly, it 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) believes 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 believes 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.

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 can 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 to resolve their cognitive conflict through visualization of physical phenomena via dynamic computer simulation and peer support and interaction in cooperative learning group. This will make them to recognize in what ways their current thinking fall short and reorganize their personal beliefs and theories, as well as to go beyond their current thinking capability. Students' active participation in collecting and analyzing data via computer simulation and 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 or learning cycle. 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 integration of the Learning Cycle approach to computer-based simulations and cooperative learning can increase the level of performance of concrete and formal operational students in scientific reasoning and conceptual understanding in physics.

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 & 2: 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 3 & 4: 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 5 & 6: 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 7 & 8: 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.

METHODOLOGY

A quasi-experimental method that employed the 3 x 2 Factorial Design was applied in the study. The independent variable was the three instructional methods: HACL method, FCL method, and TG method. The dependent variables were the learner's scientific reasoning ability and conceptual understanding. Reasoning ability was measured by the Lawson's revised Classroom Test of Scientific Reasoning Skills, CTSR (Lawson, 2000) and Roadrangka's Group Assessment of Logical Thinking, GALT (Roadrangka, Yeany, & Padila, 1983). 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 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. Conceptual understanding was assessed by the Gas Laws Performance Test (GLPT). 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 moderator variable was the learners' scientific reasoning ability which was designated EI and HD levels. This 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.

The experimental study was conducted during the second semester of the school year 2004. The sample consisted of 301 Form Four pure science students who were randomly selected from three classes from each of four different Smart Schools in Kedah and Penang. They studied "Gas Laws", one of the topics in the syllabus of Form Four Physics. The participating students 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 four members of their class with whom they most preferred or desired to work together. To determine whether FCL groups whose members chose to work together were perceived as cohesive, all students completed a nine-item Group Cohesiveness Questionnaire at post test. The Cooperative Learning Survey Questionnaire (CLSQ) was constructed to survey the perceptions of participants in the HACL and FCL groups toward their performance measures on four elements of Kagan's cooperative learning structures used during gas laws activities. 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. 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. To ensure that active and equal participation occurred in a cooperative learning group, each student was assigned to perform a specific role. 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. For the TG group, some students chose group members whom they knew personally, whereas others grouped with those who sat in the same part of the classroom. No intervention on the part of the teachers was made in the formation of TG groups and the group size. 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.

In this study, all groups received identical instructional packages: Gas Laws Simulation package. 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. 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 teachers in HACL, FCL and TG group 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. The gas laws simulation activities were administered in four separate sessions in different week, with 70-80 minutes for each session. At the end of the teaching session four in each school, the entire class in all instructional groups 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. Throughout the study, the researcher visited the two experiment groups' and the control groups' teachers for every class session to ensure fidelity to the treatment.

RESULTS

The data were compiled and analyzed using SPSS for Windows (version 11.5). Alpha was set at 0.05 level of significance. A two-way Multivariate analysis of variances (MANOVA) was performed to examine if there were significant statistical differences among students' mean scores on pre-SR and pre-CU across the three instructional groups. On the other hand, a two-way multivariate analysis of covariance (MANCOVA) was performed to examine the main effects of three instructional groups and two levels of reasoning ability, as well as the interaction effects between the instructional groups and reasoning level on scientific reasoning and conceptual understanding, using both pre-CU and pre-CU as covariates. The post-hoc comparison technique using the /lmatrix command was performed to determine which group means differ significantly from others for each dependent variable and reasoning level. Eta square values of .01, .06, and .14 that represent small, medium, and large effect sizes, respectively (Green, Salkind, & Akey, 1997), and an effect size (the standardized mean difference between the two groups) in the twenties and in the eighties that indicates a treatment produces a relatively small effect, and a powerful treatment, respectively (Gay & Airasian, 2003) were used in the discussion of results.

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 ($\chi^2 = 4.76$, $p = 0.093$), thus the Pillai's trace was used to evaluate the multivariate differences. The results of MANOVA indicated that the HD participants across the three groups are equivalent in scientific reasoning and conceptual understanding of gas laws ($F = 2.105$, $p = .129$ and $F = 0.140$, $p = .870$ respectively). Similarly the results indicated that the EI participants across the three groups are equivalent in scientific reasoning and conceptual understanding of gas laws, with an F ratio of 2.505 ($p = .084$) and 1.210 ($p = .300$) respectively.

The Experimental Study Results

Testing of Hypothesis 1 and 2 (HACL > FCL > TG)

The results of MANCOVA revealed a significant main effect for instructional group ($F(4,586)=11.019, p=0.00$). Follow-up univariate ANCOVAs indicated a significant effect for the instructional method on SR ($F(2, 294) = 13.731, p=.00$, Partial Eta squared, $\eta_p^2 = .085$), and on CU ($F(2, 294) = 21.037, p =.00; \eta_p^2 = .125$). This suggests that the type of instructional method does significantly influence student's scientific reasoning and conceptual understanding of gas laws.

Scientific reasoning: Performed Post hoc pairwise comparison using the /lmatrix command indicated that students taught via HACL method (Mean = 60.49, SD = 16.009, Adj. mean = 59.351) perform significantly higher than students taught via FCL method ($p = .001$) and TG method ($p = .000$), with a mean difference of 6.099 and 10.961 respectively. Similarly, the FCL group (Mean = 51.96, SD = 14.511, Adj. mean = 53.556, $p = .009$) performed significantly higher than students taught via TG method (Mean = 47.58, SD = 12.340, Adj. mean = 48.614) with a mean difference of 4.861. Therefore Hypothesis 1 was supported.

Conceptual Understanding of Gas Laws: Students taught via HACL method (Mean = 61.69, SD = 13.843, Adj. mean = 60.398, $p = .000$), perform significantly higher than students taught via FCL method and TG method, with a mean difference of 7.011 and 12.436 respectively. Similarly, FCL group (Mean = 53.25, SD = 13.434, Adj. mean = 53.375, $p = .002$) perform significantly higher than students taught via TG method (Mean = 48.08, SD = 11.822, Adj. mean = 48.260) with a mean difference of 5.425. Therefore Hypothesis 2 was supported.

An effect size in the eighties for comparing HACL and TG group indicates that the HACL method is a very 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.

Testing of Hypothesis 3 and 4 (HACL_{HD} > FCL_{HD} > TG_{HD})

The results of MANCOVA revealed a significant main effect for instructional group ($F(4,146)=4.251, p=0.03$). Follow-up ANCOVA revealed a significant group difference for HD students' SR ($F(2, 32)=4.449, p =.015, \eta_p^2 = .107$), and HD students' CU ($F(2, 32) = 9.057, p =.00, \eta_p^2 = .197$). This suggests that the type of instructional method does significantly influence HD students' scientific reasoning and conceptual understanding of gas laws.

Scientific reasoning: The HACL (Mean = 68.35, SD = 15.338, Adj. mean = 68.054) group HD students performed significantly higher than the FCL and TG group HD students, with a mean difference of 6.479 and 11.745 respectively. There were statistically significant differences between HD students in HACL group and HD students in TG group ($p = .004$), however, there were no statistically significant differences between HD students in HACL group and HD students in FCL group ($p = .107$). The FCL (Mean = 61.41, SD = 12.428, Adj. mean = 61.665) group HD students performed higher than the TG group HD students (Mean = 56.09, SD = 13.986, Adj. mean = 56.296) with a mean difference of 5.266. However, there were no statistically significant differences between HD students in FCL group and HD students in TG group ($p = .224$). Therefore Hypothesis 3 was partially supported.

Conceptual Understanding of Gas Laws: The HACL (Mean = 63.06, SD = 13.904, Adj. mean = 63.317) group HD students performed significantly higher than the HD students in FCL (Mean

= 55.14, SD = 11.581, Adj. mean = 54.586, $p = .008$) group and the HD students in the TG group (Mean = 50.14, SD = 10.091, Adj. mean = 50.288, $p = .000$), with a mean difference of 8.458 and 12.730 respectively. However, there were no statistically significant differences between HD students in FCL group and HD students in TG group ($p = .219$), with a mean difference of 4.271. Therefore Hypothesis 4 was partially supported.

An effect size in the eighties for comparing HACL and TG group indicates that the HACL method is a very effective instructional method for promoting scientific reasoning and conceptual understanding among HD students. Overall, the HD students taught via HACL group outperformed HD students taught via FCL group with a relatively moderate difference on performance in conceptual understanding

Testing of Hypothesis 5 and 6 ($HACL_{EI} > FCL_{EI} > TG_{EI}$)

The results of MANCOVA revealed a significant main effect for instructional group ($F(4,436)=9.739$, $p=0.00$). Follow-up ANCOVA revealed a significant group difference for EI students' SR ($F(2, 261) = 13.443$, $p = .000$, $\eta_p^2 = .109$), and EI students' CU ($F(2, 261) = 17.086$, $p = .00$, $\eta_p^2 = .135$). This suggests that the type of instructional method does significantly influence EI students' scientific reasoning and conceptual understanding of gas laws.

Scientific Reasoning: The HACL (Mean = 56.49, SD = 14.920, Adj. mean = 55.503) group EI students performed significantly higher than the FCL and the TG group EI students with a mean difference of 6.120 ($p = .004$) and 10.961 ($p = .000$) respectively. Similarly, the FCL (Mean = 49.33, SD = 14.007, Adj. mean = 50.188) group EI students performed significantly higher than the TG group EI students (Mean = 45.14, SD = 10.738, Adj. mean = 45.123) with a mean difference of 4.841 ($p = .018$). Therefore Hypothesis 5 was supported.

Conceptual understanding of gas laws: The HACL (Mean = 60.97, SD = 14.267, Adj. mean = 59.713) group EI students performed significantly higher than the FCL and TG group EI students, with a mean difference of 6.510 ($p = .002$) and 12.247 ($p = .000$) respectively. The FCL (Mean = 53.03, SD = 13.748, Adj. mean = 53.678, $p = .005$) group EI students performed significantly higher than the TG group EI students (Mean = 47.96, SD = 11.894, Adj. mean = 47.633) with a mean difference of 5.737. Therefore Hypothesis 6 was supported.

An effect size in the eighties for comparing HACL and TG group indicates that the HACL method is a very effective instructional method for promoting scientific reasoning and conceptual understanding among EI students. Overall, the EI students taught via HACL group outperformed EI students taught via FCL group with a relatively moderate difference on performance in scientific reasoning and conceptual understanding

Testing Hypothesis 7 and 8

The results of MANCOVA showed that there was no significant interaction effect between instructional method and 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 7 and 8 was rejected.

DISCUSSION

Effects of the Instructional Methods on Conceptual Understanding of Gas Laws and Scientific Reasoning

The results of this study found that students who worked in HACL method outperformed those who worked in FCL and TG methods on a conceptual understanding test. The positive effects

of HACL method in supporting the construction of individual conceptual understanding of Gas Laws are consistent with cognitive elaboration theory that holds that explaining the material to someone else is the most effective means of learning (Slavin, 1987). In the present study, students constructed a deeper understanding of gas laws when they were to provide explicit explanation to group members regarding the physical phenomena at the microscopic level and the plot pattern obtained in the graph. Through the act of tutoring, the students not only had the chance to reinforce their understanding of the material, but also typically discovered some new ideas or concepts which they wouldn't have discovered if they hadn't had the opportunity to teach the material to someone else. In this effort, on one hand, the HD students who held accountable to teach others 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). 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. As a result, students in HACL groups developed a better conceptual understanding of gas laws than students who taught via the FCL groups. 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, wider perspective in discussing materials to arise, or for explaining processes to take place. Therefore, students working in FCL group were unable to develop as much conceptual understanding as students working in HACL group.

The results 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. This form of novice-expert cooperative learning represents Vygotskian theory, whereby HD students have provided the EI students with opportunity to develop the potential to acquire HD reasoning skills.

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 and later those of the teacher, to resolve potential conflicts during collaborative activity. 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 while doing the gas laws activities and opportunities to challenge their own and others' hypotheses to explain the evidence, students constructed more appropriate concepts and became increasingly skilled in the reasoning patterns used in concept construction. Saxe, et al. (1993: 118) state that via this process 'knowledge is constructed by individuals ... (and) accordingly, peers in interaction may present different perspectives that may lead children 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. In contrast, the students in the FCL groups worked with their similar ability peers, and they would suffer from a lack of appropriately behavior role models to provide successful methods and strategies. This was evident by perceived less active engagement of FCL group's students in providing elaborate explanations and proposing successful learning strategies to their group members from the cooperative learning questionnaire data as compared to those in the HACL group. As a result, the students in the FCL group would not develop as much scientific reasoning as their peers in the HACL group.

Effects of the Instructional Methods on Scientific Reasoning and Conceptual Understanding of Gas Laws Based on Reasoning Ability Levels

The HD students taught via the HACL method significantly outperformed the HD students taught via the FCL and TG method in conceptual understanding. This study confirms earlier research that providing elaborated explanation can help high-achieving students to benefit from cooperative learning (Johnson & Johnson, 1989; Webb, 1989; Lou et al., 1996). 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. In contrast, the HD students taught via FCL group had less emphasis on the four elements of Kagan's cooperative learning structures as indicated by the lower mean scores compared to those in HACL group. As such, the HD students did not engage fully in the behaviors such as discussing and sharing their ideas, exploring their conceptions, or recognizing and filling in gaps in their understanding. As a result, the HD students taught via FCL group were unable to develop as much conceptual understanding as their peers working in HACL group.

On the other 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 results suggest 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 or make use of cognitive activities that pay explicit attention to the unfamiliar problem scenario that required the use of more sophisticated scientific reasoning regardless of maturational level.

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. According to researchers (Cattell, 1951; Homans, 1961; Thibaut & Kelley, 1959), interaction is particularly important when it is accompanied by interdependence which involve

the group members to be mutually dependent upon each other to work together to successfully accomplish a task. 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). Consequently, the cohesiveness-performance relationship is primarily 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 evidenced by the student's responses in cooperative learning questionnaire. As a result their cohesiveness decreases performance in conceptual understanding and scientific reasoning.

The findings of this study showed that the EI students taught via the HACL method outperformed their counterparts taught via the FCL and TG method in scientific reasoning and conceptual understanding. Results of this study support the findings of Mills & Durden (1992) who indicated that low ability students benefit at the expense of their more knowledgeable partners. Within HACL setting, the opportunity of EI students to work with HD students increased their ability to develop more complex level of understanding as well as modeling the reasoning processes of HD students. For example, the gas laws simulation engaged EI students to ask help from their HD group members in their attempts to construct an explanation which implied what was observed. Helps were also sought 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 such way, the EI students were able to move forward and continued to develop more complex of reasoning ability and new concepts than their peers in FCL group. In contrast, the EI students in the FCL group worked with their similar ability partners, and they might suffer from a lack of appropriately behaving role models and capable peers to provide explanations. As a result, the EI students would not receive as good a stage as their peers in HACL group for elaborated explanations, appropriate learning strategies, and wider perspective in discussing materials. As such, the EI students working in the FCL group were unable to develop as much conceptual understanding and scientific reasoning as their peers working in HACL group.

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. The EI students taught via the FCL method worked with their friends whom they most preferred or desired to work together to complete the tasks in gas laws worksheet. As each group members liked the other 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 such as challenging each other's conclusions and reasoning in order to promote higher quality decision making and greater insight into problems being discussed, and hence promoted each other's success. As EI members of FCL groups engaged in frequent and open discussion and accurate understanding of each other's perspective, 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 results showed that 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. This could be explained by the low mean scores from the Cooperative Learning Questionnaire results that indicate that students taught via TG method lacked understanding on how to perform the four basic principles of Kagan's cooperative learning to group learning. 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. 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, until much later the newly introduced concepts and reasoning skills were applied to a variety of contexts. 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, rather than short-term instruction which was employed in the present study. 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. Overall, the students taught via HACL group appear to outperform those taught via the FCL group with a relatively moderate difference on performance in scientific reasoning and conceptual understanding of gas laws. These results imply that merely assigning students by friendship is insufficient, the teachers should 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 in an attempt to yield better results.

The result of the present study shows that 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. Cooperative learning is insufficient as an instructional method if group composition is not manipulated according to heterogeneous ability. 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".

REFERENCES

- Asch, S. (1952). *Social psychology*. New York: Prentice-Hall.
- Cadmus, R. R, Jr. (1990). A video technique to facilitate the visualization of physical phenomena. *American Journal of Physics*, 58, pp. 397-399.
- Cattell, R. (1951). New concepts for measuring leadership, in terms of group syntality. *Human Relations*, 4, pp. 61-184.
- Cavallo, A. M. (1996). Meaningful learning, reasoning ability, and students' understanding and problem solving of topics in genetics. *Journal of Research in Science Teaching*, 33, pp. 625 – 656.

- Chiu, M. H. (2001). Algorithmic problem solving and conceptual understanding of Chemistry by students at a local high school in Taiwan. *Proc. National. Science Counsel. ROC(D)*, Vol.11, No.1. 2001, pp. 20-38. [Online]. [Accessed Jun 10, 2003]. Available from World Wide Web: <http://herdsa.org.au/vic/cornerstones/pdf/Chiu.PDF>
- Collins, A. & Stevens, A. L. (1982) Goals and strategies of inquiry teachers. In: R. Glaser, (Ed). *Advances in instructional psychology*, Hillsdale, NJ: LEA., 2, pp. 65-119.
- Escalada, L.T. & Zollman, D. A. (1997). An investigation on the effects of using interactive digital video in a physics classroom on student learning and attitudes. *Journal of Research in Science Teaching*, 34(5), pp. 467-489.
- Evans, C. R., & Dion, K. L. (1991). Group cohesion and performance: A meta-analysis. *Small Group Research*, 22, pp. 175-189.
- Gay, L. R., & Arasian, P. (2003). *Educational research: Competencies for analysis and applications*. 7th ed. New Jersey: Merrill Prentice-Hall.
- Green, S. B., Salkind, N. J., & Akey, T. M. (1997). *Using SPSS for Windows: Analyzing and understanding data*. Upper Saddle River, NJ: Prentice-Hall.
- Homans, G. (1961). *Social behavior: Its elementary forms*. New York: Harcourt Brace Jovanovich.
<http://www.thirteen.org/online/concept2class/w5-resources.html#a15>
- Inhelder, B., & Piaget, J. (1958). *The growth of logical thinking from childhood to adolescence*. New York: Basic Books.
- Inhelder, R., et al. (1979). Genetic Epistemology and Equilibration. [Online]. [Accessed Jan 26, 2004]. Available from World Wide Web: <http://tomweston.net/piagetweb.htm>
- Johnson, D. W., Johnson, R.T. (1989). *Cooperation & Competition: Theory and research*. Edina, MN: International Book Company.
- Johnson, R. T., & Johnson, D. W. (1986). Action research: Cooperative learning in the science classroom. *Science and Children*, 24, pp. 31-32.
- Kagan, S. (1994). *Cooperative learning*. San Juan Capistrano, CA: Kagan Cooperative Learning.
- Kementerian Pelajaran Malaysia (2002) *Huraian sukatan pelajaran Fizik KBSM Tingkatan Lima*. Kuala Lumpur: Pusat Perkembangan Kurikulum.
- Kerr, N. & Bruun, S. (1983). The dispensability of member effort and group motivation losses: Free-rider effects. *Journal of Personality and Social Psychology*, 44, pp. 78-94.
- Kwon, Y., & Lawson, A.E. (2000). Linking brain growth with the development of scientific reasoning ability and conceptual change during adolescence. *Journal of Research in Science Teaching*, 37(1), pp. 44-62.

- Lawson, A. E., et al. (2000). What kinds of scientific concepts exist? Concept construction and intellectual development in college biology. *Journal of Research in Science Teaching*, 37, pp. 996 – 1018.
- Lawson, A. E. & Bealer, J. M. (1984). The acquisition of basic quantitative reasoning skills during adolescence: learning or development? *Journal of Research in Science Teaching*, 21(4), pp. 417-423.
- Lawson, A. E. (1975). Developing formal thought through biology teaching. *American Biology Teacher*, 37(7), pp. 411.
- Lawson, A. E. (1995). *Science teaching and the development of thinking*. California: Wadsworth Publishing Company.
- Lou, Y., et al. (1996). Within-Class Grouping: A Meta-Analysis. *Review of Educational Research*, 66(4), pp. 423-458.
- Mills, C. J. & Durden, W. G. (1992). Cooperative learning and ability grouping: An issue of choice. *Gifted Child Quarterly*, 36(1), pp. 11-16.
- Mullen, B. & Copper, C. (1994). The relationship between group cohesiveness and performance: An integration. *Psychological Bulletin*, 115, pp. 210-227.
- Nakhleh, M. B. (1993). Are our students conceptual thinkers or algorithmic problem solvers? *Journal of Chemical Education*, 70, pp. 52-55.
- Nurrenbern, S. C. & Pickering, M. (1987). Concept learning versus problem solving: Is there a difference? *Journal of Chemical Education*, 64 (6), pp. 508-510.
- Piaget, J. (1952). *The origins of intelligence in children*. New York: International Universities Press.
- Piaget, J. (1964). Cognitive development in children: development and learning. *Journal of Research in Science Teaching*, 2, pp. 176-186.
- Poh, S. H. (2003). *Pedagogy of science 1: Science Curriculum*. Kuala Lumpur: Kumpulan Budiman SDN BHD.
- Roadrangka, V., Yeany, R. H., & Padila, M. J. (1983) *The construction and validation of a group assessment of logical thinking (GLAT)*. Paper presented at the meeting of the National Association for Research in Science teaching, Dalla, TX.
- Rosenshine, B. & Meister, C. (1992). The use of scaffolds for teaching higher level cognitive strategies. *Educational Leadership*, April, pp. 26-33.
- Roth, W. & Roychoudhury, A. (1993). The Development of Science Process Skills in Authentic Contexts. *Journal of Research in Science Teaching*, 30(2), pp. 127-152.
- Sharan, S. & Sharan, Y. (1976). *Small group teaching*. Eaglewood Cliffs, N.J.: Educational

Technology Publications.

Shayer, M. & Adey, P. S (1993). Accelerating the development of formal thinking in middle and high school students IV: Three years after a two-year intervention. *Journal of Research in Science Teaching*, 30, pp. 351 – 366.

Slavin, R. E. (1987). Cooperative learning and the cooperative school. *Educational Leadership*, 45(3), Pp. 7-13 [Online]. [Accessed January 19, 2004]. Available from World Wide Web:

Sweeney, J. (1973). An experimental investigation of the free-rider problem. *Social Science Research*, 2, pp. 277-292.

Thibaut, J., & Kelly, H. (1959). *The social psychology of groups*. New York: John Wiley.

Vygotsky, L. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, Mass: Harvard University Press. Wadsworth Publishing Company.

Webb, N. M. (1982). Peer interaction and learning in small cooperative groups. *Journal of Educational Psychology*, 74, pp. 642-655.

Webb, N. M. (1989). Peer interaction and learning in small groups. *International Journal of Educational Research*, 13, pp. 21-39.