THE INFLUENCE OF INQUIRY-BASED MATHEMATICS TEACHING ON 11th GRADE HIGH ACHIEVERS: FOCUSING ON METACOGNITION

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This study investigates the influence of inquiry-based mathematics teaching on high achievers’ metacognitive abilities. The research subjects were 28 eleventh graders high performance in learning mathematics. A mixed methodology combing qualitative and quantitative approaches was used to investigate students’ metacognition in an inquiry-based classroom environment. The main research instrument for collecting quantitative data was the Metacognition Inventory questionnaire which was conducted before and after the inquiry-based lessons. The qualitative data, such as interviews with students, videotaped classroom teaching, students’ work sheets and feedback sheets, and teacher’s journals, were also collected and analysed. Results indicated that there was weak but no significant correlation between student’s mathematics achievement and their metacognition. Besides, students could develop significantly better metacognitive capacities after receiving the three-month inquiry-based mathematics teaching. Moreover, we also discussed how inquiry cycle is related to metacognitive components.

INTRODUCTION

How teachers can help students participate in the process of knowledge construction has been a central issue in the debate on mathematics education (e.g., Ben-Chaim, Fey, Fitzgerald, Benedetto & Miller, 1998; Inagaki, Hatano & Morita, 1998; Lampert, 1990). Within the contribution to this debate, educators and researchers are convinced that students need to have ample opportunities to progress from concrete to abstract ideas, rethink their hypotheses and adapt and retry their investigations and problem solving efforts (Hinrichsen & Jarrett, 1999). Teachers ought to provide certain kinds of experiences in which students are able to work as young mathematicians or researchers. In short, students should develop their mathematical knowledge through inquiry-based teaching. The inquiry teaching methodology is built on the Principles and Standards for School Mathematics (National Council of Teachers of Mathematics [NCTM], 2000) and the report of Project 2061’s benchmarks (American Association for the Advancement of Science [AAAS], 1993). They both assert that inquiry as a high-quality teaching to engage students in the processes of learning and creating mathematics and also recommend that students should have the ample opportunities to utilise inquiry cycle in carrying out their own mathematical investigations when learning mathematics. The essential traits of inquiry that can be generated from some reports (e.g. AAAS, 1993; Hinrichsen & Jarrett, 1999) are concluded as follows:
connecting former knowledge and experiences with the problem as learners have, designing procedures (plans) to find an answer to the problem, investigating phenomena through conjecture, constructing meaning through use of logic and evidence and reflection.

Metacognition takes on importance in mathematical classroom because research evidence has shown that enhancing students’ metacognition could lead to corresponding improvements in learning outcomes (e.g., Baird & Northfield, 1992). The concept of “metacognition” is defined as one’s knowledge concerning one’s own cognitive processes and awareness of a mathematical problem that involves the process of planning, monitoring and evaluation of a specific problem solution (Flavell, 1976, 1992). Following Flavell’s studies, researchers investigated many aspects of metacognition in mathematics education, such as Schoenfeld’s work (1987, 1992) on comprehensive analysis of metacognitive processes in problem solving, which put more emphasis on mathematical thinking and problem solving processes. Recent studies appeared some major common elements which can characterise good instructions that enhance students’ metacognition (e.g. Kramarski, Mevarech & Arami, 2002; Mevarech & Fridkin, 2006). These instructions should focus on: (a) comprehending the problem; (b) constructing connections between previous and new knowledge; (c) considering strategies appropriate for solving the problem; (d) reflecting on the processes and solution. By means of analysing the essential traits of inquiry compared with these suggested instruction focuses, it seems reasonable to hypothesise that inquiry-based teaching may promote students’ metacognition.

As we mentioned above, research has proven high metacognition could produce high achievement. However, Alexander, Carr and Schwaneflugel’s (1995) indicate that research does not support the viewpoint that high achievers have vastly better or more advanced metacognitive abilities in all areas of metacognition, but it appears that high and low achievement children are equally capable of using some metacognition. The result of International Assessment of Educational Progress [IAEP], a large-scale international achievement survey, reveals that Taiwanese students were with high performance in mathematics but weakness in higher order thinking skills. The main reason might be most schools in Taiwan tend to remain a conservative pedagogy with behaviourist paradigms to teach mathematics. Therefore, this study is designed to explore how the inquiry-based mathematics teaching influences on high achievers’ metacognition developing.

**THEORETICAL FRAMEWORK**

**Inquiry-based mathematics teaching**

The inquiry based-teaching could be supported by the use of inquiry cycle (Siegel, Borasi & Fonzi, 1998). Lawson, Abraham, and Renner (1989) proposed an E-I-E (Exploration, Invention, and Expansion) inquiry cycle which has long term been considered within inquiry teaching and modified or refined into various frameworks. In Exploration phase, it should provide students with the opportunity to bring out prior
knowledge, explore a range of phenomena for themselves, and experience a confrontation to their own way of thinking. In Invention phase, it should help students organise their information from the Exploration phase. Besides, the teacher should consider how the idea or skill is modelled or demonstrated. In Expansion phase, the goal is to help students finish restructuring old beliefs, old knowledge structures and it is also important to help students apply and transfer the new idea to new situations. Although there are some later frameworks of inquiry cycle using different terms to elaborate their structures, the basic theoretical backings still seem to fit under the core ideas of the E-I-E model. Therefore, for simplifying and effectively applying the inquiry cycle, we do not consider the later frameworks but adopt E-I-E model as the main approach to address our inquiry-based teaching.

**Metacognition**

Flavell (1979) defines metacognition as “thinking about thinking”, and elaborates metacognition as (i) awareness of how one learns; (ii) awareness of when one does and does not understand; (iii) knowledge of how to use available information to achieve a goal; ability to judge the cognitive demands of a particular task; (iv) knowledge of what strategies to use for what purposes. He also distinguishes between two components of metacognition: (a) knowledge of cognitive processes and products; and (b) ability to control, monitor, and evaluate cognitive processes. Flavell argues that knowledge of cognition depends on the following inter-related components: metacognitive knowledge about self, the task and strategies; knowledge about how to use the strategies; and metacognitive experience. The later refers to one’s feeling about being successful (or unsuccessful) in performing the task. According to this model, the metacognitive knowledge leads to strategy use which in turns affects the metacognitive experience that affects the acquisition of metacognitive knowledge and so on. Corresponding to Flavell’s focusing on metacognitive knowledge, Brown (1987) outlines metacognition as (i) an awareness of one’s own cognitive activity; (ii) the methods employed to regulate one’s own cognitive process and (iii) a command of how one directs, plans and monitors cognitive activity. Stating differently, metacognition is made up of active checking, planning, monitoring, testing, revising, evaluating, and thinking about one’s cognitive performance.

**METHODOLOGY**

**Subjects**

The research subjects of this study were twenty-eight 11th graders (all girls) who were selected from the whole grade with the best performance in mathematics in a famous girl’s senior high school in Taiwan. These students were graded within 93% in mathematics in the national high school entrance examination.

**Data collection**

For the quantitative data, we collected students’ average mathematics scores in last academic year (10th grade) and student’s performance on Metacognition Inventory.
questionnaire [MI] (adopted from Chang, 1994) which was administered at the beginning (pre-test) and end (post-test) of the three month inquiry-based teaching practice. The instrument, MI was designed to assess student’s metacognition with six subscales: (i) Selective Attention (SA): deciding to attend to specific aspects of input; (ii) Organising (O): the act of rearranging the information which one gets from SA; (iii) Strategising (S): planing or using appropriate strategies in solving the problem; (iv) Self-Testing (ST): assessing how much one understands by self-questioning; (v) Self-Monitoring (SM): the activities that moderate the current progress of learning; (vi) Self-Correction (SC): correcting errors and implementing remedial or changing strategies. The MI comprised 48 items distributed across the six subscales (8 items per subscale) on a 4-point Likert scale reflecting student’s metacognitive behaviours as “1” means strongly disagree, whilst “4” means strongly agree. Furthermore, this questionnaire was piloted with 138 alternative high achievers from the same school and obtained acceptable Cronbach’s α coefficients as follows: SA, 0.665; O, 0.797; S, 0.736; ST, 0.723; SM, 0.732; SC, 0.771; total scale, 0.927.

On the other hand, for the qualitative data, we collected videotaped classroom teaching, teacher’s journal, students’ semi-structured interview results, and feedback sheets after each class. These qualitative data were analysed to explain or elaborate the quantitative results for interpreting the relationship between inquiry-based teaching and student’s metacognition growth. In particular, the semi-structured interviews were conducted individually to the subjects who were considered as worth of further investigation for 15-30 minutes after each inquiry-based lesson (totally five) and also after they completed MI in the beginning and the end of this study.

**Procedures**

Strictly speaking, this study spent almost two years which was from January 2005 to December 2006. The whole research can be categorised into three periods: (a) the first period (January 2005 ~ February 2006) serves as a warm up and preparation for the participant teacher implementing inquiry-based teaching. The teacher joined a university-based professional development project which was funded by National Science Council in Taiwan. This project aimed to enable in-service teachers to apply inquiry-based mathematics teaching in their classrooms. After over one year of participation, the participant teacher was recognised having enough skills to teach through inquiry. (b) In the second period (February ~ August 2006), the participant teacher collaborated with a mathematics educator and a group of mathematics teachers to design curricula that are suitable for inquiry-based teaching. Meanwhile the participant teacher also started to introduce collaborative learning in his classroom for encouraging students to engage in sense-making and discussions. Because literature indicates that inquiry method is high correlated with collaborative learning strategies, taking place collaborative leaning could enhance inquiry-based teaching. (c) In the final period (September ~ December 2006), inquiry-based teaching was conducted in the subject class. The students answered the MI as pre-test and post-test before and
after this period. All the qualitative and quantitative data were also collected during this period.

RESULTS AND DISCUSSION

Table 1 reports the relationship between students’ mathematics average scores in last academic year and the scores in the pre-test of the MI. Analysis of the data showed that there was weak but no significant correlation ($r=0.201$, $p=0.15$) between student’s mathematics achievement and their metacognition. The only significance appeared in Selective Attention ($r=0.334$, $p<0.05$) and it remained weak. These results may imply that the linear relationship between mathematics achievement and metacognition did not occur with these high achievers. It seems reasonable to claim that these high achievement students did not correspond to high metacognition capabilities. This claim might be consistent with the typical Taiwanese high achievers’ performance as mentioned earlier in this paper. In addition, based upon their initial MI scores ($M=2.66$ in pre-test, see Table 2) and the qualitative data we collected, our claim seems to be confirmed:

T: Although my students could obtain high mathematics test scores, they did not perform well in dealing with open tasks; most students could only apply straightforward and limited strategies. They weakly showed metacognitive awareness. (20060910 teacher’s journal)

S12: I thought I am lack of this kind of ability (metacognition). I am not good at organising the problem information and pursuing my thinking approaches. I think it is better that the teacher can directly talk about what I don’t know. (20060901 interview)

S10: I was used to waiting for teacher’s solution but now I find more chances to explore and analyse the problem by myself and our team. (20061109 interview)

Table 1: Correlations between mathematics achievement and metacognition subscales

<table>
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<tr>
<th></th>
<th>MA (N=28)</th>
<th>SA</th>
<th>O</th>
<th>S</th>
<th>ST</th>
<th>SM</th>
<th>SC</th>
<th>Total</th>
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<tbody>
<tr>
<td></td>
<td>.334*</td>
<td>.162</td>
<td>.069</td>
<td>.216</td>
<td>.021</td>
<td>.209</td>
<td>.201</td>
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2. *, $p<0.05$

Table 2 exhibits means and standard deviations on MI (including sub-scales) of both pre-test and post-test. The difference of total scale between the pre-test and the post-test was highly statistically significant ($t=4.56$, $p<0.001$). In other words, students performed better metacognition including all components in the post-test than in the pre-test. Subsequent analysis of subscale scores also revealed highly significant changing form pre-test to post-test. This result appears to suggest that inquiry-based teaching was effective in helping students’ development of metacognitive abilities.

S23: I feel I’m better on understanding the problem because the new teaching method is not only interesting to me but also helpful to think more deeply. (20060915 feedback sheet)

S10: I was used to waiting for teacher’s solution but now I find more chances to explore and analyse the problem by myself and our team. (20061109 interview)
S1: In inquiry teaching, I have more opportunities to try different approaches to a problem and discussion which can also inspire me with new ideas. (20061109 interview)

<table>
<thead>
<tr>
<th></th>
<th>Pre-test Mean (SD)</th>
<th>Post-test Mean (SD)</th>
<th>T</th>
<th>p</th>
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<tbody>
<tr>
<td>A</td>
<td>2.91 (.35)</td>
<td>3.12 (.28)</td>
<td>3.35</td>
<td>.002**</td>
</tr>
<tr>
<td>O</td>
<td>2.64 (.41)</td>
<td>2.89 (.39)</td>
<td>3.04</td>
<td>.005**</td>
</tr>
<tr>
<td>S</td>
<td>2.89 (.42)</td>
<td>3.17 (.41)</td>
<td>3.17</td>
<td>.004**</td>
</tr>
<tr>
<td>ST</td>
<td>2.25 (.50)</td>
<td>2.61 (.40)</td>
<td>4.60</td>
<td>.000***</td>
</tr>
<tr>
<td>SM</td>
<td>2.56 (.43)</td>
<td>2.97 (.45)</td>
<td>4.43</td>
<td>.000***</td>
</tr>
<tr>
<td>SC</td>
<td>2.73 (.52)</td>
<td>2.94 (.44)</td>
<td>2.56</td>
<td>.016*</td>
</tr>
<tr>
<td>Total</td>
<td>2.66 (.36)</td>
<td>2.95 (.32)</td>
<td>4.56</td>
<td>.000***</td>
</tr>
</tbody>
</table>

*, p< 0.05; **, p< 0.01; ***, p< 0.001

Table 2: Means and standard deviations of pre-test and post-test

Comparing all subscale’s scores in the pre-test, Self-Testing appears the lowest scores (M=2.25) within these six sub-scales. Although it significantly increased in post-test (t=4.60, p< .001), it still remains as the lowest over all subscales in the post-test (M=2.61). It seems that students were less likely to examine how much they already know or to determine whether they truly understand. This finding was also parallel to the research which indicates that this kind of regulated ability develops slowly and is quite poor in children and even adults (Pressley & Ghatala, 1990). In further analysis of the items within this subscale (Table 3), we found that the items 2 and 5 show lower mean scores in pre-test (M^{item2}=1.25; M^{item5}=1.50) and post-test (M^{item2}=1.82; M^{item5}=1.96). This result might indicate students were less likely to assess what they know by questioning themselves. The following quotation of the teacher’s journal could be a note:

T: Students are used to solving given problems but have fewer experiences to pose problems by themselves. I think this is the reason why they obtain lower ST scores. However, in inquiry-based teaching, they could have more opportunities to generate new problems. This may encourage them to ask problems for checking what they have learned. (20061211 teacher’s journal)

Moreover, the post-test score of item 4 (M=2.00) is slightly lower than the pre-test (M=1.96). Unexpectedly, it seems that students were less likely to examine their understanding by extra mathematics problems, both before and after the inquiry-based teaching. The reason might be that they would rather focus on fewer problems which seem worth undertaking than practice too many routine problems. The following response of a student could offer some evidence:

S6: It’s great when we work together to investigate a worth undertaking problem. I can take advantage from discussing with my team members. I suggest not to work on too many problems but to have more time on thinking or discussing with others. (20061031 feedback sheet)
In addition, after analysing all the qualitative data, we also tried to identify how the inquiry-based teaching was related to metacognition subscales which occurred in this study. Some results might be concluded as follows: “Selective Attention”, and “Organising” seemed to take place during the Exploration phase of the inquiry cycle; “Strategising” and “Self-Testing” appeared in the Invention and Expansion phases; and “Self-Monitoring” and “Self-Correction” happened across all the phases. For example, when students engaged in the lesson “Circle and Sphere”, they needed to recall their prior knowledge about circle (Exploration-O), focusing on how circle can be defined and their properties (Exploration-SA), discussing and modeling their thinking (Invention-S & ST), applying their conclusion to Sphere (Expansion-O & S).

CONCLUSION

Enhancing students’ metacognition is not a straightforward process by any means. A key factor influencing students’ propensity to enact their metacognitive capacities is their perception of the classroom environment, including how they are taught and also the broader culture within the classroom. In this study, we constructed an inquiry-based learning environment for the students who were asked to personally construct their own understanding by posing questions and considering how investigations will proceed and how findings are analysed and communicated (Hinrichsen & Jarrett, 1999). The results support that these arrangements are meaningful in stimulating student’s metacognition growth. Although there seems no enough direct evidence to prove that the inquiry-based mathematics teaching is a warranty for student metacognition development, it still can be a useful guide for helping teachers to make the most of metacognitive learning experiences for students. Therefore, we might be able to argue that the inquiry-based mathematics teaching method may serve as a catalytic metacognitive experience that informed students about what was for some an alternative conception of learning.

References


Chin, Lin, Chuang & Tuan


