INTERDISCIPLINARY LEARNING AND PERCEPTIONS OF INTERCONNECTEDNESS OF MATHEMATICS

Ng Kit Ee Dawn, Gloria Stillman and Kaye Stacey
University of Melbourne, Australia

This paper studies the effect of interdisciplinary project work on Singapore students’ perceptions of mathematics. Interdisciplinary project work aims to prepare students for the knowledge-based economy, emphasise links within and between school subjects and core skills such as communication. Two scales measuring perceptions of the interconnectedness of mathematics were completed by 409 students aged from 12 – 14, in 3 schools, before and after participating in a 12 – 16 week project. Amongst statistically significant changes was a relatively moderate increase in scores on the interconnectedness scale after project work. Students in different ability streams perceived and used interconnectedness in different ways both before and after the project work. Teaching emphasis on conscious integration of subject areas is needed.

INTERDISCIPLINARY PROJECT WORK IN SINGAPORE

Interdisciplinary project work (PW) was introduced as an educational initiative in Singapore in 1999 to prepare students to meet the demands of a knowledge-based economy (CPDD, 2001). To stay relevant in such an economy, in-depth knowledge of specific subjects is insufficient. Students need to integrate ideas from various disciplines for problem solving. Curriculum planners in various parts of the world (e.g., McGuinness, 1999; NCTM, 1995), including Singapore, have begun to emphasise explicit links between school subjects. PW is seen as a platform for incorporating core skills and values, and integrating subject-specific knowledge in innovative ways (Chan, 2001).

PW contributes to the Singapore vision of Thinking School Learning Nation (Quek, Divharan, Liu, Peer, Williams, & Wong et al., 2006). Coping with a knowledge-based economy requires meaningful integration of various subject-specific content areas for problem solving. Thus, the Singapore Ministry of Education is moving away from sole dependence on paper and pencil examinations, and including holistic, student-centred learning activities and authentic assessment modes. PW is considered as a “paradigm shift” (Quek et al., 2006, p. 14) from teacher-dependent to student-initiated learning. The learning outcomes of PW are stated in 4 domains: communication, collaboration, independent learning, and knowledge application, which include emphasis of the interconnectedness of what is learned (CPDD, 2001).

PW tasks are mainly adapted from Ministry resources or designed specifically by teachers according to yearly themes set by schools. Every PW task anchors in at least two or more curriculum subject areas. Ideally a team of at least two teachers from these subject areas are allocated to the class. A typical PW task consists of a major driving question involving a real-life problem or scenario. Critical intellectual activities are generated from the task, with purposeful integration of content from its various anchor
subjects. PW is different from the interdisciplinary or integrated curricula espoused by many schools in the West (see Jacobs, 1991), where content learning derives from thematic-related project tasks and investigations. In Singapore, the necessary content and skills are taught during traditional subject-specific lessons, and PW teachers provide “just-in-time instructions” (CPDD, 2001) so that groups can work independently and creatively while applying the knowledge and skills taught.

**Aims of this study**

The work reported here is part of a mixed methods study into the nature of the thinking that students engage in during PW and the effects of PW on their mathematical learning. Close analysis of selected groups of students as they work on a project enables a study of the interplay between cognitive, metacognitive, and social processes during PW.

A quantitative survey-based study has also been conducted to measure changes in various affective measures as students participate in PW, and to observe differences between groups of students. A review of the literature relating to links between affect and problem solving, of goals and expectations of PW in Singapore, and extensive statistical analysis of draft scales led to the identification of three constructs as being especially relevant to interdisciplinary learning:

- confidence in mathematics scale
- value of mathematics scale
- interconnectedness of mathematics (ICS) scale, incorporating 2 subscales of inter-subject learning (ISL) and beliefs and efforts in making connections (BEC).

This paper will report only results from ICS scale. Results for the other scales can be found in Ng and Stillman (2006). Perceptions of the interconnectedness of mathematics have not been measured before, to our knowledge. We will report on the construction of the scales, differences between groups (gender and educational stream), and the impact of PW on students’ perceptions of ICS.

**INTERCONNECTEDNESS IN MATHEMATICS**

One aim of implementing PW in Singapore schools is to make explicit the interconnections of subject-specific knowledge so that learners can “transcend subject boundaries and make connections between the various subject areas” (CPDD, 2001, p. iii). Proponents of the interdisciplinary curriculum (e.g., NCTM, 1995) emphasise the importance of drawing links between content and skills of school subjects to encourage holistic learning.

Beliefs, self-confidence, and value in mathematics have been examined by researchers (e.g., Schoenfeld, 1989) to draw inferences on students’ affect and problem solving. Though there are other Singapore studies on PW, Tan (2002) was the only study to date relating mathematics attitudes to PW. He found that a problem-based approach to PW improved most of the six dimensions of mathematical attitudes studied from his
all-male sample in two educational streams. However, he did not look into students’ perceptions of the interconnectedness of mathematics.

Despite growing emphasis on interdisciplinary learning in curricula, no literature to date has been dedicated to quantifying the perceptions of interconnectedness between subjects. This study began by examining the Singapore PW goals and identifying three components of interconnectedness namely, how students perceive (a) mathematics content and skills in relation to other subjects; (b) the usefulness of mathematics in understanding other subjects; and (c) the complementary relationship between mathematics and other subjects in problem solving. These components represent a continuum, from awareness of interconnectedness, to consideration of use, to actual use.

Items were constructed for these three components. For example, for the first component, item BEC2 (see Table 1, which gives the final version only) may indicate high personal sensitivity to interconnectedness of mathematics. The second component arises from assertions among interdisciplinary proponents that students’ understanding of one subject can be reinforced by another (Jacobs, 1991). Items focussed on links such as whether students recognise the possibility of transferring knowledge across subjects (e.g., ISL4). Knowing that interconnectedness exists between subjects does not imply action, however. Boix Mansilla, Miller, and Gardner (2000) assert that interconnectedness require that students combine discipline-based knowledge to solve problems, so the third component (e.g., ISL6) measures the application of mathematics and other subjects to solve real life problems, which are usually interdisciplinary in nature. High scores here imply flexible integration of knowledge across disciplines, the epitome of the goals of interdisciplinary education.

Although conceived as three components, extensive trialling of the scales, as described below, resulted in two subscales for ICS, with good statistical properties. We tried to encapsulate the differences in the factors in the two names Inter-subject Learning (ISL) and Beliefs and Efforts in Making Connections (BEC). All items from BEC scale derived from those proposed for the first component above. ISL items derived from all 3 components. The final items and scales are shown in Table 1.

**METHODOLOGY**

**Construction of the scales**

The first version of the confidence, values and interconnectedness scales comprised of 45 five-point Likert items. Two expert panels from Singapore and Australia vetted the initial items. The three scales were constructed in three phases with 283 students in the target age range (12 – 14) from 7 Singapore secondary schools. Care was taken to trial with students of a range of English language abilities from government neighbourhood schools, to be similar to the 3 schools which undertook the PW study.

First, items were face-validated by 9 students from three streams in individual interviews, who explained their responses and rephrased problematic items. Rephrased
versions were re-tested on subsequent interviewees. The 45 items were then administered to another group of 36 students twice within one week and 13 students with high response inconsistency attended individual face-to-face interviews to identify confusing statements for deletion. The scales were reduced to 41 items. Second, two schools held a large-scale trial (n = 204). Factor analyses were conducted separately on the three scales. Varimax rotation revealed a total of eight subscales, including two (ISL and BEC) for ICS as noted above. Table 1 shows basic statistics for the scales. Third, test-retest reliability was checked with 34 students who responded twice in one month. All subscales displayed moderate to high stability. Future studies could add to the development of the ICS scale pioneered by this study. Full details of the development of the scales are given by Ng and Stillman (2006). In the final questionnaire, the items were given with others that elicited background information. Students were told to respond with reference to their most recent classroom experiences.

---

### Interconnectedness of Mathematics Scale (ICS) (Variance explained = 44.85%)

<table>
<thead>
<tr>
<th>Subscale</th>
<th>Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inter-subject Learning (ISL) (α = 0.787; Test-retest r = 0.62)</td>
<td>ISL1: I have used math while working in another subject before.</td>
</tr>
<tr>
<td></td>
<td>ISL2: I can see links between some math topics and other subjects.</td>
</tr>
<tr>
<td></td>
<td>ISL3: Sometimes I use math to help me understand another subject.</td>
</tr>
<tr>
<td></td>
<td>ISL4: I can use math to help me learn another subject better.</td>
</tr>
<tr>
<td></td>
<td>ISL5: I use another subject to help me learn math sometimes</td>
</tr>
<tr>
<td></td>
<td>ISL6: Sometimes, I combine what I know from math and other subjects to solve problems.</td>
</tr>
<tr>
<td></td>
<td>ISL7: Math may share some common topics and skills with other subjects.</td>
</tr>
<tr>
<td>Beliefs &amp; Efforts in making Connections (BEC) (α = 0.587; Test-retest r = 0.53)</td>
<td>BEC1: I don’t try to make connections between math and other subjects when I learn.</td>
</tr>
<tr>
<td></td>
<td>BEC2: It is important to relate math to other subjects when learning.</td>
</tr>
<tr>
<td></td>
<td>BEC3: I find learning more meaningful when math and other subjects have common topics.</td>
</tr>
<tr>
<td></td>
<td>BEC4: Math has no connections with the other subjects I am studying.</td>
</tr>
</tbody>
</table>

Table 1. The items of the Interconnectedness of Mathematics Scale

---

**The project work**

The main study centred on the implementation of PW in three Singapore schools. PW lessons are incorporated into the normal timetable and students work in groups of 4 or 5, consulting teachers at least once a week for about 13 weeks, and they also work outside class time. Sixteen classes undertook the PW with a total of 632 students, of
whom 409 agreed to submit data to the study. In Singapore, students are streamed on entry to secondary school. The 16 classes were from the highest (Express) and middle (NA = normal-academic) overall abilities in language, mathematics, and science. One school had one teacher (mathematics) for PW in each class and the others had two.

The first author created a PW task on environmental conservation. Ng (2006) describes the task “Designing an environmentally friendly building” in detail. The task formally combined mathematics, science and geography and aimed to enhance students’ environmental consciousness. The flexibility, scope, and breadth afforded by the task enabled students from differing ability streams to participate. Extensive design and support materials were provided for the teachers. For their final products, students constructed physical scale models of their buildings using recycled materials. Mathematical concepts and skills include estimating dimensions, making appropriate scale drawings, constructing 3-D scale models, costing and evaluating.

The classes used the project-based approach. They were given a scenario to explore, brainstorm, and plan their own schedules for completion. Students collaborated in decision making, research, and constructing the prototypes of their buildings. Assessment of the task evaluated the process (e.g., drafts) and products produced. Each member of the group presented a portion of their work orally to the class. Individual and group scores were awarded based on rubrics.

RESULTS

Table 2 gives the means and standard deviations for the scores on the two subscales of interconnectedness (ISL and BEC) for the whole sample and various subsamples. All the means are in the range 3.25 – 3.75, indicating that these groups of students were on average about halfway between neutral and agreement on the five point scale. The overall ISL mean and the ISL means of all of the subgroups in Table 2 improved after the PW experience. The overall BEC mean shows very little change after the PW experience, with some the subgroups making a small increase and some making a small decrease from pre-task to post-task.

The statistical significance of the differences in the table were tested with a general linear model (GLM) i.e. a multi-factorial repeated measures ANOVA. The repeated measures were the dependent variables (ISL and BEC) scores pre-task and post-task (time factor), and there were 3 independent factors: gender, stream and school.

School differences. The school differences were not statistically significant, and so students from the three schools are put together to make one sample.

Pre-task to post-task differences. The change in ISL on the whole sample was statistically significant at the 5% level (Wilks’ Lambda = 0.966, F(1, 391) = 13.760, p = .000, η_p^2 = .034). The effect size of 0.034 (measured by η_p^2) is between Cohen’s (1988) limits of 0.01 for small and 0.06 for moderate effect. The change in BEC from pre-task to post-task was not statistically significant (Wilks’ Lambda = 1.00, F(1, 390) = 0.014, p = .906, η_p^2 = .000).
Gender differences. The BEC subscale showed a small but significant gender difference favouring males (F(1,1) = 4.460, p = 0.035, df = 1, $\eta^2_p = .011$) but the ISL scale did not (F(1,1) = 0.032, p = 0.858, df = 1, $\eta^2_p = .000$). Time-gender interaction effects were not significant, implying that gender was not a factor for reaction to the PW experiences, but a factor for between-subject differences.

Stream differences. There were significant differences of relatively moderate effect size between Express and NA students for both ISL (F(1,1) = 10.891, p = 0.001, df = 1, $\eta^2_p = .027$) and BEC (F(1,1) = 11.713, p = 0.001, df = 1, $\eta^2_p = .029$), with express students scoring higher. There was no time-stream interaction effect for either ISL or BEC, indicating that PW affected the attitudes of each stream in the same way.

<table>
<thead>
<tr>
<th>Sample Groups</th>
<th>Inter-subject Learning (ISL)</th>
<th>Beliefs and Efforts at making Connections (BEC)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-task</td>
<td>Post-task</td>
</tr>
<tr>
<td></td>
<td>mean</td>
<td>s.d.</td>
</tr>
<tr>
<td>All (n = 409)</td>
<td>3.52</td>
<td>0.58</td>
</tr>
<tr>
<td>Males (n = 206)</td>
<td>3.51</td>
<td>0.58</td>
</tr>
<tr>
<td>Females (n = 203)</td>
<td>3.53</td>
<td>0.58</td>
</tr>
<tr>
<td>Express (n = 295)</td>
<td>3.59</td>
<td>0.57</td>
</tr>
<tr>
<td>NA (n = 114)</td>
<td>3.35</td>
<td>0.57</td>
</tr>
<tr>
<td>School 1 (n = 151)</td>
<td>3.56</td>
<td>0.51</td>
</tr>
<tr>
<td>School 2 (n = 94)</td>
<td>3.40</td>
<td>0.59</td>
</tr>
<tr>
<td>School 3 (n = 163)</td>
<td>3.56</td>
<td>0.63</td>
</tr>
</tbody>
</table>

Table 2. Means and Standard deviations for ISL and BEC scores.

DISCUSSION AND CONCLUSION

This study has pioneered the quantitative measurement of perceptions of interconnectedness of mathematics, providing information about students in various groups, and before and after an experience of project work which has appreciation of interconnectedness as one of its goals.

Through a careful process of test development, it was found that perceptions of interconnectedness could be summarised in two factors which had good statistical properties: inter-subject learning (ISL) and beliefs and effort in making connections (BEC). Further research by others on the measurement of perceptions of interconnectedness would be welcome, to test this factor analysis beyond Singapore secondary school students. Since increasing appreciation of interconnectedness and promoting interdisciplinary learning are common goals of school systems, a robust analysis of the concept should be very useful.
There were differences of relatively moderate effect size between the two ability streams, favouring higher ability students, before and after PW. Express students tend to perceive the interconnectedness of mathematics more than NA students, and are likely to make efforts at making connections such as engaging in using mathematics for inter-subject learning. Students in different ability streams seem to define and make use of the connections between subjects for their learning in different ways. Although the ISL and BEC subscales are still in developmental infancy, information on this would assist future facilitation of interdisciplinary learning for students in different educational streams.

Administration of the two subscales showed that there was a small gender difference favouring males on BEC, but not on ISL. This provided further evidence that the two subscales are indeed different, and added further information to the knowledge of gender differences in mathematics in an Asian setting.

In accordance with the goals of project work, there was a small improvement of scores to ISL after participating in the interdisciplinary project. Students after the project work were somewhat more likely to appreciate mutual reinforcement of learning among mathematics and other subjects. They did not, however, report an increased effort to make such connections (BEC). We have no good explanation of why there should be an improvement in one of the subscales but not the other, although the qualitative data gathered in the study may soon provide some clues.

An improvement in appreciation of interconnectedness would be expected because of the nature of the project experience, which required students to use mathematics in conjunction with other subjects. In two schools, students had teachers from different subject areas facilitating PW groups. There are also some reasons why the effect may have been small. About half of the students had done project work before, and about a third had used mathematics (usually only arithmetic) in their previous PW, so they may already have developed some ideas about interconnectedness.

Classroom observations and teachers’ reports were that the open task was appropriate for classes of both ability levels, because the students were largely able to set the mathematical demands of the task for themselves. The main mathematical difficulties were in fixing the scales for the building and making the 3-D model from 2-D drawings. Often these mathematical tasks were delegated to ‘experts’ within the group, so that not all group members necessarily had experience of using mathematics in the real, interconnected situation. This may have contributed to the small effect size on interconnectedness scales. Teachers have to be aware that relevant and conscious knowledge application of subject content and skills into the interdisciplinary task is not automatic. Similarly, successful integration of the various knowledge and skills from different subjects, used together in the task depends heavily on the nature of teacher facilitation and close monitoring of student progress. The challenge is to strike the right balance in providing guidance within the scope and depth of the theme.
Finally, we acknowledge that there are many goals of PW beyond those on which this paper has reported. It is not possible to judge the success of either this task in particular, or PW in general, from the interconnectedness measures alone.

Acknowledgement

We acknowledge the assistance of Associate Professors Yap Sook Fwe and Fan Liang Huo, Dr Graham Hepworth, Ewa Karafilowska, teachers and students.

References


