

Pbl@School

A Large-scale Study on the Effect of “Physics by Inquiry” Pedagogy on Secondary 1 Students’ Attitude and Aptitude in Science

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THE MAIN AIM of this 3-year project was to develop, implement and evaluate a guided-inquiry curriculum in a local secondary school using the Physics by Inquiry (Pbi) “research–development–instruction” iterative approach. Our study showed that students’ interest in Science is a key predictor of future aspiration to learn the subject and reinforces the need to shape positive attitudes towards Science, especially at the lower secondary level. Overall, students and teachers held favourable perceptions regarding the inquiry-based curricula and instruction, citing hands-on activities, self-directed learning, learning from peers, and opportunity for consolidation as important features in engaging them in learning. Students’ conceptual understanding and reasoning abilities were also enhanced after the intervention. These findings suggest that the curriculum materials have been effective in providing structured guidance to students to promote their learning of Science through evidence-based reasoning, problem solving and argumentation.

INTRODUCTION

The teaching of science as inquiry has been advocated by various science educators for well over a decade. One of the most widely cited descriptions of “inquiry” is offered in the National Science Education Standards (National Research Council, 2000). The inquiry approach aligns closely with the activities and processes scientists engage in: focusing on scientific theories and models, asking investigable questions, forming hypotheses, gathering evidence, generating explanations from evidence, and justifying

KEY IMPLICATIONS

- Inquiry-based teaching and learning can be supported by research-validated curriculum materials that are developed to suit our local school context.
- Effective implementation of inquiry-based curriculum materials and instruction can enhance students’ conceptual understanding, reasoning abilities and interest towards Science learning.
- Active involvement in the process of curriculum making and adaptation is important for teachers to develop a deeper understanding of how to better facilitate inquiry-based learning.

claims and explanations. The inquiry approach is also consistent with constructivist beliefs, where students are challenged to form deep understandings about natural phenomena by engaging in the construction and critique of scientific knowledge and evidence through an active process of investigation. The term “inquiry” hence refers to both what scientists do and how students learn, the corollary of this being how teachers teach.

In Singapore, the national Science curriculum has placed “science as an inquiry” as the core emphasis in guiding curriculum design and instruction in schools. Part of the professional development effort has been to provide teachers with good models of inquiry-based science instruction and to equip them with the knowledge and skills to facilitate inquiry-based learning in schools. In particular, from 2005, teachers were introduced to the Physics by Inquiry (Pbi) curriculum (McDermott, Shaffer, Rosenquist, & Physics Education Group, 1996) developed by the Physics Education Group at the University of Washington.

The Pbi curriculum is primarily designed for in-service teachers to strengthen their subject matter knowledge in physics/physical science topics, with an emphasis on the development of fundamental concepts and reasoning skills through first-hand laboratory-based experience. The teachers go through the reasoning in-depth and are guided in synthesizing what they have learned into a coherent conceptual framework (McDermott, Heron, & Shaffer, 2005). An extensive list of publications (see <http://www.phys.washington.edu/groups/peg/pubs.html>) gives strong evidence of the effectiveness of the Pbi approach in developing deep conceptual understanding in various topics for undergraduates as well as prospective and practising teachers.

But can the success of the Pbi curriculum and approach for teacher professional development be transferred to effective learning of Physics for secondary students in the Singapore context? This was a key question and our hope was for this project to contribute towards the relatively scant literature on the implementation and effectiveness of the Pbi approach at the secondary school level, where “effectiveness” is evaluated based on both cognitive and affective aspects.

The research questions guiding the project were: (1) What are the perceptions of teachers and students

on teaching and learning Pbi in the classroom? (2) What are the differences in the learning outcomes when students learn physics through the inquiry approach as compared to standard classroom practices? (3) What are the favourable modifications in adapting the Pbi instructional approach for improving student learning of lower secondary science in Singapore?

RESEARCH DESIGN

The project was conducted in a local secondary school involving 8 teachers and over 1,000 students from 3 successive Secondary 1 cohorts in the Express stream. The Pbi “research–development–instruction” design approach was adopted in three phases, where refinements to the curriculum and instruction were made iteratively over time based on ongoing feedback by teachers and students, and evaluation by the research team in the light of classroom observations and research data.

The first phase (2009) involved a baseline study of the learning and teaching of lower secondary science, looking into the kinds of difficulties students encountered for various Physics topics after traditional instruction as well as their attitudes towards learning science. The guided inquiry curriculum was subsequently designed based on the findings of the baseline study, focusing on two topics: Speed and Density. The second phase (2010) followed a quasi-experimental pre-test–post-test control group design, where the developed laboratory-based inquiry curricula materials were piloted with 6 classes as the experimental group and with the other 5 classes acting as the control group. The third phase (2011) involved a scaling up of the intervention for all 11 classes of the new cohort of students using the refined curricula package. This followed a quasi-experimental one-group pre-test–post-test design, which allowed the effectiveness of the two successive interventions to be measured and also compared against the control group from the 2010 cohort.

The data sources for this study included field notes from interactions with teachers, classroom observations, pre-tests, post-tests, surveys, and interviews with students and teachers. The pre-test questions focused on qualitative understanding of concepts as demonstrated by students’ ability to explain the reasoning for their answers and did not require application of formulae and mathematical calculations. The pre-tests were administered to students during curriculum time prior to formal

instruction and served to set the stage for learning and to elicit students' pre-conceptions about the topic. To study students' attitudes towards Science, a survey instrument was developed which comprised factors such as self-efficacy, competence, interest, inquiry, engagement, job opportunity, career aspiration, and educational aspiration (Yeung et al., 2010). Students and teachers were also surveyed and interviewed about their perceptions regarding the inquiry-based curricula and instruction.

KEY FINDINGS

Students' Views and Attitudes Towards Science (Physics)

The baseline study on students' attitudes towards Physics found that the students' self-concepts in learning Physics and their perceived parental expectations in Physics affected their engagement and educational aspiration to learn Physics, with interest in Physics being a key predictor of whether the student will likely aspire to learn Physics in future. This reinforced previous findings which indicated that the early years of secondary education were most critical in shaping students' attitudes towards Science (Osborne, Simon, & Collins, 2003). The goal then of the inquiry curriculum is not only to advance students' understanding of scientific concepts and procedures, but also to personally engage them and shape positive perceptions and attitudes towards Science, particularly at the lower secondary level.

Students' and Teachers' Perceptions of the Pbl Curricula and Instruction

Overall, both students and teachers held favourable perceptions regarding the inquiry-based curricula and instruction, citing hands-on activities, self-directed learning, learning from peers and opportunity for consolidation as the key features of the intervention that supported their learning. The experiential nature of the curriculum made the students more engaged and focused and helped them to better understand the concepts and visualize phenomena in real life.

The students in the experimental group were observed to be more independent and confident after the Pbl intervention. They were more task-oriented and better prepared to do experiments on their own, with minimal supervision. A notable impact on teachers was the tendency for them to withhold giving answers directly to students but to ask more questions in class. They became more aware of the different kinds of questions they could ask in order to clarify, probe and extend student thinking.

On the whole, students valued small-group discussions where they learn from each other, clarify their doubts and share their ideas with team members. However, group dynamics is an important consideration which may deter some students from group work for fear of encountering uncooperative and disruptive team members. Interestingly, fewer students valued the learning arising from discussion with other teams, and still preferred the security of having the teacher's answers directly, rather than viewing the whole class as a community of learners.

Consolidation in the form of small-group and whole-class check-outs (where teachers asked questions to check on student understanding and to ensure that they were on the right track) and homework in the Pbl intervention was another key feature which played an important role in ascertaining if students were on the right track and had learned the requisite concepts as designed in the worksheets.

Effect on Students' Conceptual Understanding

Students' common pre-conceptions of and difficulties with several topics were uncovered. For example, prior to formal instruction, about half of the students were not able to distinguish among the concepts of mass, volume and density, with many thinking that heavy objects sink and light objects float. Results from the first intervention in 2010 showed that there was improvement of students' conceptual and reasoning abilities after the intervention, with the experimental group slightly outperforming the control group. Using the refined curriculum materials in 2011, learning gains similar to the pilot intervention were achieved.

Favourable Modifications to the Pbl Curricula Adaptation

Over a 3-year period, the research team adapted the Pbl materials and instructional approach for Secondary 1 students. Three main areas of modification are evident in the final Pbl@School package. Firstly, the inquiry activity worksheets were made more student-friendly and with a more structured format (e.g., through the use of diagrams and tables). Secondly, there was an integrated use of laboratory-based and laboratory follow-up activities with classroom-based materials. A balance was sought between students having to physically carry out the activities to collect their own "messy data" (so as to have an idea of the associated experimental constraints and measurement errors) versus giving students "clean data" so that the focus was on the analysis and interpretation of the

data, without the fear and distraction of the noise and reliability of the data affecting their conclusions. Thirdly, there was the use of whole-classroom check-outs and embedded probing questions. The activity worksheets included more guiding questions to facilitate students' inquiry learning. Higher-order thinking questions, normally asked by the facilitator, were incorporated in the worksheets to make the facilitation process less manpower-intensive since there was only one teacher to facilitate the learning of 40 students.

IMPLICATIONS

For Policy

There needs to be a continued effort in nurturing students' interest in Science early and through the lower secondary school years, given that it is a key predictor of future aspiration to learn the subject. Inviting overseas experts to conduct workshops on innovative inquiry-based curricula and instruction has been a useful starting point to support teachers in implementing "science as an inquiry" in our national curriculum. This study has shown that inquiry-based teaching can be supported by research-validated curriculum materials developed through adapting existing overseas instructional approaches to our local secondary school context. Hence, more support could be given to teachers to actively participate in curriculum making and adaptation for other parts of the lower secondary Science curriculum.

For Practice

This study has shown that once teachers overcome the confidence barrier, they are capable of effectively facilitating inquiry-based learning. This was done through an iterative, collaborative process with colleagues in the school and with the help of a team of researchers to provide the crucial impetus for curriculum adaptation and the development of teaching kits. This process takes time and begins with a small step involving a few classes at the start. When teachers gain the necessary mastery experiences to conduct inquiry, the implementation can then be scaled up to all classes, taking into account the existing school context.

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For Teacher Training

Prospective and practising teachers should be exposed early to good models of inquiry-based Science teaching so they have the necessary experience and repertoire of strategies to draw from. Having inquiry curriculum materials that have been adapted for use in our local classrooms helps to reduce barriers and shorten the learning curve for other teachers who might plan to embark on their own inquiry-based teaching. However, there is still a need for these teachers to go through the process of adapting and customizing existing curriculum materials for their own students. It is important that they work through the curriculum materials in a manner that is consistent with how their students learn and be cognizant of the flow and progression of concepts behind the materials to support students' construction of ideas. Without this deep understanding, teachers might inadvertently short-circuit the students' learning process and construction of a coherent conceptual framework necessary for a functional understanding of the science concepts.

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