PBI1@SCHOOL: DEVELOPING AND IMPLEMENTING AN INQUIRY-BASED CURRICULUM FOR SPEED AND DENSITY

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ABSTRACT

Physics by Inquiry (PbI) by the Physics Education Group at the University of Washington is a research-validated self-contained, laboratory-based curriculum designed to help teachers teach physics in a way that engages students in the process of science. But could the success of the PbI curriculum and approach for teacher preparation be transferred to effective learning of physics for the secondary students in our local context? This paper describes our attempt to do so in the research project PbI@School. It outlines the development and trial implementation of a guided inquiry curriculum and approach adapted from PbI for delivering lessons on Speed and Density in the secondary one science classroom in Singapore. The 3-year project to be done in three phases take into account factors such as the existing syllabus content, the availability of time, identified student learning difficulties from specially-designed pre-tests, students’ and teachers’ experiences in learning and teaching by inquiry, and school resources. The paper also discusses the challenges and modifications made to the pilot curriculum package to support the research site school’s effort to implement the curriculum package for all its 11 secondary one classes with about 440 students.
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INTRODUCTION

Physics by Inquiry (PbI) is a set of curriculum specially developed by Prof. L.C. McDermott (1996) and the Physics Education Group (PEG) at the University of Washington to be used in classes for teachers. The PbI curriculum is designed to:

- strengthen subject matter background in physics and physical science topics that are highly relevant for school teachers using a hands-on, inquiry-oriented method of instruction;
- emphasize the development of fundamental concepts and reasoning skills through laboratory experience; and
- meet the needs of teachers with varying levels of preparation in science and mathematics.

At workshops conducted by the PEG at University of Washington, teachers typically work in pairs on carefully sequenced experiments and exercises in the PbI curriculum, facilitated by experienced instructors, to develop a functional understanding of the subject matter and experience first-hand learning by inquiry so as to be prepared to teach science as a process of inquiry rather than by presentation and explanation of facts. In addition to the experiments and exercises, the PbI curriculum for the workshops for teachers consists of an intensive structured process of pre-tests, checkout interviews, homework, practice problems, paper assignments and examinations at appropriate points.

Since 2005, Prof McDermott and her team have conducted introductory PbI teacher workshops for Singapore teachers. MOE curriculum officers and teachers have also adapted various activities from the PbI curriculum materials and used them in the classroom. Their
experiences have generally been positive, with teachers and students finding this approach both enriching and engaging. However, teachers commonly encountered certain challenges in using the PbI curriculum. These included:

1. Adapting selected materials to meet their students’ needs and abilities.

   Teachers found it difficult and time-consuming to adapt the PbI materials in a coherent manner to allow for student construction of their own conceptual understanding of essential curriculum topics through experimentation and reasoning, and to pitch the level of the material appropriately to match their students’ abilities.

2. Preparation of apparatus for lab-based learning through experimentation.

   The PbI approach requires students to come up with their own evidence-based conclusions and explanations of their experimental results. Thus, extra time and effort is needed to ensure that the apparatus provided is sufficient for small group exploration, and are carefully tested and modified where necessary to ensure good experimental data can be collected.

3. Implementing the PbI processes for our classroom.

   One major challenge in implementing PbI is the large class size of typically forty students. Instead of pair work, students are usually grouped in fours in order to meet the demand for lab apparatus while still allowing for active participation by all students. Even so, teachers find it difficult to juggle the facilitation of the PbI processes of checkout interviews and questioning for ten groups of students, and to monitor all their students’ progress in learning.

4. Adjustment in teaching style.

   Teachers need to make adjustments to their current teaching practices. As the PbI approach to teaching and learning is to guide students in carrying out self-inquiry, teachers must now learn to act as facilitators, guiding their students’ learning through
skilful questioning rather than by telling, and be able to manage the different learning needs of each group.

**PBI1@SCHOOL PROJECT**

Recognizing the difficulties teachers have in using the PbI approach in schools, the research team embarked on the PBI1@School project in an effort to support schools in adopting the teaching and learning of science by inquiry. The main objectives of the project are to:

- develop suitable activities and assessment materials that emphasise a guided inquiry approach for teaching and learning of lower secondary physics topics for secondary one students through a process modelled after the “research-development-instruction” iterative cycle by the Physics Education Group at the University of Washington,

- develop workshops for teachers that will help them deepen their understanding of the subject matter, and to teach science lessons through the process of inquiry, and

- disseminate the results of the project through workshops and papers in order to share the findings and obtain feedback for further work.

The three research questions guiding the project are:

1. What are the favourable modifications in adapting the Physics by Inquiry (PbI) approach and materials for improving the learning of lower secondary science in Singapore?

2. What are the differences in the learning outcomes when students learn physics through the inquiry approach as compared to the standard classroom practices?
3. What are the perceptions of teachers and students on teaching and learning physics by inquiry in the classroom?

This paper focuses on the first research question and presents the research team’s effort in adapting and implementing the PbI materials for the teaching and learning of the topics of speed and density. The research-development-instruction process was carried out through three phases: Phase 1 - Baseline study (2009), Phase 2 - Pilot intervention (2009 - 2010), and Phase 3 - Refined intervention (2010 - 2011).

Phase 1-Baseline Study

In the first year of the project (2009), a baseline study was carried out on about 240 students from six secondary one classes in the research school site in Singapore to obtain their views of science, their reasons for liking or disliking science, and their understanding before and after instruction of five lower secondary physics topics: Basic scientific measurements, Speed and density, Force and pressure, Forces at work, and Effects of heat energy.

This study served as a research base to guide the development of adapted PbI materials which would match the needs and abilities of our students. The research instruments used for this study consisted of open-ended pre-tests and post-tests, and science attitude survey, each serving different purposes. The pre-tests were used to find out students’ enthusiasm in learning a new topic and whether they are able to forecast their learning difficulties even before learning the topic, to find out students’ preconceptions which will influence the curriculum development, set the stage for the lessons and to motivate students to ask more questions to satisfy their curiosity and clear their doubts. The concept questions in
the pre-tests were designed based on common everyday phenomena but without the use of scientific terms that were unfamiliar to the secondary one students.

The post-tests, administered after instruction, were used to assess students’ understanding of the topic’s concepts and to have the students evaluate their learning experiences and challenges they encountered during instruction. The science attitude survey was administered before and after the intervention to determine the degree of improvement of students’ attitude towards physics after our intervention using the PbI approach. The survey was used as a gauge to measure the effectiveness of our PbI intervention compared to conventional teaching approaches practised in the school.

These tests and survey were developed mainly by research team members responsible for the topics, but reviewed by the whole research team and the physics teachers of our research school on the suitability of the questions in terms of difficulty level, language and format. In these tests and survey, students were expected to support their answers with reasons, to enable the team to assess their preconceptions on the relevant scientific ideas in the topic.

Data collection, data coding and analysis

The pre-tests were administered prior to teaching of each topic. The four teachers involved in the baseline study typically conducted their lessons mainly using theory lessons and practice worksheets with one lab-experiment conducted at the end of each topic. Field notes and lesson materials were collected for comparison among the teachers’ lessons. At the end of the topic, a post-test was administered before beginning on a new topic.

Rubrics were formulated for the pre-tests and post-tests based on the concepts and ideas that were reflected in the students’ answers, rather than on “model answers” crafted by
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Teachers and researchers, more commonly known as a “marking scheme”. After validation by the research team, these rubrics were used to code the students’ answers, responses and drawings. Coding was first done by two research team members and then discussed with other research team members during research team’s meetings to reach a consensus and final outcome. The codes were then analysed using general statistical analysis to obtain measures of students’ understanding of the concepts in the five lower secondary physics topics.

A comparison of pre-test and post-test was done on the students’ coded answers to highlight the main concepts that students demonstrated improvements in, showed no improvement in or even deteriorated in after instruction. Through this process, we were able to identify some serious conceptual and reasoning difficulties present at the beginning of instruction that were just as prevalent after instruction. Apparently, these difficulties were not successfully addressed by the standard presentation of material in the traditional secondary one science lessons (Munirah, Foong & Lee, 2010; Munirah et al, 2009; Wong, Lim, Foong & Munirah, 2009).

**Phase 2-Pilot Intervention**

Taking into consideration the baseline study findings from the pre-tests and post-tests of students’ difficulties in lower secondary physics topics, and from consultations with our external collaborator, Prof McDermott, the team decided to adapt the PbI materials for two topics: Basic scientific measurements as well as Speed and density for the project. The selection of these two topics allowed us to merge measurement techniques with speed and density concepts. We hoped such merging will enable the students to have an appreciation the importance of learning how to take accurate measurements and subsequently be motivated to do so. In our adaption process, we attempted to address some of the challenges faced by
teachers in using the PbI approach by scoping and sequencing the curriculum materials appropriately to ensure coherence in learning, carefully sequencing self-inquiry and experimentation activities, and designing assessment tools to measure students’ progress in their conceptual understanding of the physics concepts in the selected topics. We also incorporated teachers’ inputs on the learning outcomes and concepts that may be explored through inquiry and trialed the draft worksheets with ten secondary one students to check the suitability of the worksheets in terms of the nature of the activities as well as the language used.

The team members also modified and sourced for lab apparatus and resources to improve the effectiveness of the experimental results of the inquiry activities. Two workshops introducing the PbI approach were then conducted for the four teachers and one allied educator who would be participating in the pilot intervention the following year. The teachers role-played as students to work through the worksheets and in the process, familiarizing themselves with the activities and any non-standard (such as those made by the research team) lab apparatus, while the researchers role-played as facilitators demonstrating the facilitation process in guiding student learning through inquiry.

**Implementation of pilot intervention**

In the second year of the project (2010), the adapted PbI instructional materials were implemented over a period of eight weeks (20 hours) in six secondary one classes of about 40 students each. They were taught by the four teachers and the allied educator who attended the PbI workshop the previous year. Five secondary one classes served as a control group, with teachers in these classes teaching their lessons in the normal way, namely using mainly theory lessons with practice worksheets and a lab-experiment at the end of each topic. Pre-
tests and post-tests were administered for the Speed (with measurement) and the Density (with measurement) topics.

Following the implementation, the team started analyzing the effectiveness of the PbI instructional materials from the student data collected as well as from teacher feedback and field notes from the lessons. Although the inquiry lessons managed to engage students and promote greater self-inquiry in learning, a few concerns surfaced that needed to be addressed in the next intervention phase.

Teachers felt that the materials could be made more student-friendly and further cuts were needed as students took too long to do the PbI activities, resulting in some groups failing to obtain the required experimental data that allowed them to make useful connections and conclusions in their construction of the physics concepts. The longer time spent also meant that the experimental group classes and the control group classes differed in their progression in content topics covered over a term, making administration of common level tests and assignments difficult. As the PbI intervention was lab-intensive, the PbI curriculum needed to be modified before a full scale implementation involving the entire secondary one level classes is feasible due to the constraint in the number of science laboratories\(^1\) available.

**Phase 3-Refined Intervention**

In the third (final) year of the project (2011), the cycle of the second year was repeated using refined curriculum materials on a new batch of secondary one students. The curriculum materials were refined based on the feedback given by the teachers and students involved in the pilot intervention the year before, test results, as well as observations and reflections by members of the research team. Refinements made included:

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\(^1\) In our research site school, there are 22 lower secondary classes (secondary one and two) sharing two science laboratories during curriculum time each week. A typical time-table in the school only allows a class to have a science lab-lesson once a week.
1. Certain activities that did not successfully address students’ learning difficulties were modified and enhanced with more guiding questions.

2. Activities that were too easy were scaled up to make them more challenging yet interesting for the students, and activities found not to be very useful yet too time-consuming were removed from the curriculum.

3. The activity worksheets were made more student-friendly and to take over part of the role of the facilitator. 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 forty students. This also helped to reduce the loss of learning experiences for students who were absent or called up by other teachers during the lessons.

In an attempt to scale up the implementation of the project as well as to address concerns raised from the pilot intervention phase as to why some classes were left out from this engaging way of learning, the refined intervention was implemented in the following year (in 2011) for all eleven classes in the secondary one level. The refined intervention package comprises lesson materials for 6 hours of lessons on Speed and another 6 hours of lessons on Density.

During the planning process, we found out that only two science laboratories were available for all the eleven classes. Due to this constraint in lab availability, the students can spend only one-third of their physics lesson hours in the lab. This necessitated another change in this phase, namely to have Lab Follow-up and Classroom Sessions in addition to the Lab Session. The Lab Follow-up session, done after the lab activity, serves as a platform for students to share their data findings with the class. There were also questions in the lab follow-up worksheet to reinforce students’ construction of their conceptual understanding by
providing scenarios and problems similar to the lab activities that may include some pre-
given data. Classroom session materials were designed to be flexible in that it can be 
conducted either before or after the lab activities, depending on the class time-table. They 
serve to provide opportunities for students to discuss and debate in groups of three or four 
students about their differing conceptual ideas, share strategies to solve given problems and 
analyse data. There are also computational exercises for students on the concepts introduced 
in the topic to allow the students to practise solving quantitative problems as well.

The refined intervention package lessons materials implemented during curriculum 
time comprises 2 hours of laboratory sessions (venue: science laboratory), 2 hours of follow-
up laboratory sessions (venue: classroom or laboratory depending on its availability) and 2 
hours of classroom sessions (venue: classroom), for each topic of speed and density. The 
package also includes homework materials, and teachers requested that these materials be 
discussed during curriculum time. The teachers also chose to administer the pre- and post-
tests during curriculum time, thus the intervention went beyond the planned intervention 
period of five weeks. Figure 1 illustrates how the package is implemented for “Class A”, in 
the research site school, over the intervention period. The text in bold represents the time-slot 
in the class’ time-table that gave the class access to the science laboratory.

<table>
<thead>
<tr>
<th>Wk6 7 – 11 FEB</th>
<th>Wk 7 14 – 18 FEB</th>
<th>Wk 8 21 – 25 FEB</th>
<th>Wk 9 28 Feb – 4 Mar</th>
<th>Wk 10 7 – 11 Mar</th>
<th>TERM 2 Wk 1 21 – 25 Mar</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Class Session 1:</strong> Speed (8 Feb 1120 h)</td>
<td><strong>Lab Session 2:</strong> Speed (15 Feb 1020 h)</td>
<td>Class Session 2: Speed (22 Feb 1120 h)</td>
<td><strong>Lab Session 3:</strong> Density (1 Mar 1020 h)</td>
<td><strong>Class Session 4:</strong> Density (8 Mar 1120 h)</td>
<td>Discussion: Speed Post-test &amp; Homework 2 (23 Mar 1020 h)</td>
</tr>
<tr>
<td><strong>Lab Session 1:</strong> Speed (9 Feb 1120 h)</td>
<td>Lab 2 Follow-Up: Speed Issue Homework 1 (17 Feb 1220 h)</td>
<td><strong>1. Homework 1:</strong> Discussion: Speed 2. Pre-Test 2 (23 Feb 1120 h)</td>
<td>Lab 3 Follow-Up: Density (3 Mar 1220 h)</td>
<td><strong>Lab Session 4:</strong> Density (9 Mar 1120 h) Issue Homework 2</td>
<td><strong>Lab 4 Follow-Up:</strong> Density (con't) (24 Mar 1320 h)</td>
</tr>
<tr>
<td>Lab 1 Follow-Up: Speed (10 Feb 1220 h)</td>
<td><strong>Note to teacher:</strong> Homework 1 is on Speed</td>
<td>Class Session 3: Density (24 Feb 1220 h)</td>
<td>1. Lab 4 Follow-Up: Density 2. Speed Post-Test (10 Mar 1220 h)</td>
<td></td>
<td><strong>Note to teacher:</strong> Homework 2 is on Density</td>
</tr>
</tbody>
</table>

**FIGURE 1:** Time-Table² of Class A during PbI @ School Intervention 2011

² Our research site school follows a 2-week cycle time-table, where even and odd weeks follow different time-
tables and every school-term experiences a different set of time-table. A typical time-table in the school sees a 
secondary one class having 5 periods of science lessons every 2 weeks, with every period stretching for 1 hour.
Based on further data and analysis from the refined intervention phase, the research team will finalise the PbI@School package which includes the PbI instructional materials for the Speed and Density topics comprising pre-tests, lab activities, lab follow-up activities, classroom session materials, homework, and post-tests. The package will provide the research site school and its physics teachers with the curriculum resources to continue inquiry lessons with other batches of secondary one students. Other schools interested in using the package may also be able to do so after attending training sessions conducted by experienced practitioners or by the research team members, and after making or acquiring the necessary lab apparatus and materials.

CONCLUSION

The research team, over the past two and a half year period, has modified and adapted the Physics by Inquiry (PbI) materials and instructional approach for a research school site, with the implementation of the adapted materials to a whole level of eleven secondary one classes in the final year of the project. Three main areas of modifications will be evident in the final adapted PbI@School package. These are:

1. Guided format of inquiry activity worksheets

Secondary one students require a lot of guidance through the use of simple diagrams or tables in the activity worksheets in order to be able to carry out the required inquiry activities. They were also more comfortable in giving short sentence responses and explanations as opposed to writing their explanations in long open-structured sentences. Hence, the format of the activity worksheets was made more guided and requiring less unstructured written responses.

2. Use of classroom session materials and lab follow-up activities
In order to manage the scheduling of science lab facilities for all the classes in the level, the package has included classroom session materials which may be conducted before or after lab activities. This provides teachers with the flexibility to conduct classroom lessons when the lab facilities are not available. Lab follow-up activities are also included to enhance students’ development of concepts through experimental data and class discussions.

3. Use of classroom checkouts and embedded probing questions

The PbI @School package is designed to be conducted by one teacher in a typical class of forty students. A necessary modification to the process of guiding and extending students’ understanding by questioning is to use classroom checkouts in addition to group checkouts. This allows teachers to be able to hold class discussions when there is insufficient time for individual group checkouts during a lesson. In addition, probing questions are included in the inquiry worksheets to facilitate student discussion and thinking in place of having the teacher moving from one group to another to facilitate the discussions.

REFERENCES

