

DEVELOPMENT OF AN ENRICHED METHOD FOR INTRODUCTORY  
PHYSICS LABORATORY WORK AND ITS EFFECTS ON STUDENTS  
LEARNING OUTCOMES

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For the sake of ALLAH  
may His blessing be upon the Prophet  
To my beloved mother, father, wife and children  
for the love, support and patience

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## ABSTRACT

In this study, an Enriched Method (EM) for Introductory Physics Laboratory Work (IPLW) which incorporates students' active engagement in pre-laboratory, in-laboratory, and post-laboratory activities to improve students' learning of physics was developed by the researcher. The EM enhances and extends the learning outcomes in physics Practical Assessment in accordance to the requirements of the Malaysia Qualification Agency (MQA) in preparing the students for university level laboratory work. Construction of concept maps in groups was a major pre-laboratory activity that attempted to bring about understanding of related concepts relevant for the ensuing experiments so that the students' experimentation will be meaningful. The EM was guided by a constructivist paradigm directed at cognitive restructuring based on social learning principle as promoted by scientific teaching. In order to determine the effectiveness of EM, the achievement of students' learning outcomes of the treatment (EM) group and the control (traditional) group (TM) were compared. Two instruments were used in this study: (1) the 33-item IPLW-Learning Outcomes Inventory (LOI) developed by the researcher that measured 5 categories of learning outcomes, namely, Category 1 – Measurement, Category 2 – Numerical Significance, Category 3 – Concepts and Applications, Category 4 – Graph Linearization and Category 5 – Uncertainty; (2) the 18-item IPLW-Attitude Survey (AS) adapted to determine the effects of EM and TM on the students' attitude towards physics and physics laboratory work. The results of IPLW-LOI and IPLW-AS pilot tests indicated reliability coefficients of 0.71 and 0.86 respectively. The study was conducted on 66 students in Semester 1 (July – October 2008) and 62 students in Semester 2 (January – April 2009) enrolled in an introductory physics course at a branch campus of a Malaysian public university who were randomly assigned into four respective Solomon Groups (SG). Analysis of the IPLW-LOI mean scores between pre-test and the post-test of the SGs showed no significant effect from the pre-test. The students' IPLW-LOI mean scores and Normalised Learning Gain (NLG) for both Semester 1 and Semester 2 showed a consistent trend that there was a significant improvement in the EM scores as compared to that of the TM groups in Category 1 to 4. There is no significant difference between the EM and TM groups in Category 5 – Uncertainty. As for the IPLW-AS, there is no significant different between the mean scores of the EM and TM groups for both semesters. This study shows that EM manage to improve only certain aspects of the students' learning outcomes, hence further research can be done to identify effective methods to enhance students' understanding of uncertainties in physical measurement as well as their attitude towards physics laboratory work.

## ABSTRAK

Dalam kajian ini, satu Kaedah Pengayaan (KP) Kerja Amali Fizik Pengenalan (KAFP) yang merangkumi penglibatan aktif pelajar dalam aktiviti pra amali, semasa amali, dan pos amali untuk meningkatkan pembelajaran pelajar dalam fizik telah di bangunkan oleh pengkaji. Kaedah Pengayaan (KP) mengukuhkan dan menambahkan hasil pembelajaran Pentaksiran Kerja Amali (PEKA) fizik selari dengan keperluan Agensi Kelayakan Malaysia (AKM) dalam menyediakan pelajar bagi tahap kerja amali peringkat universiti. Pembinaan peta konsep secara berkumpulan merupakan aktiviti pra amali utama yang memberikan kefahaman tentang konsep yang berkaitan dengan eksperimen yang akan dibuat, supaya aktiviti pelajar membuat eksperimen menjadi bermakna. KP berpandukan paradigm konstruktivis yang mengarah kepada penstrukturan kognitif berasaskan prinsip pembelajaran sosial seperti yang disarankan dalam pengajaran saintifik. Untuk menentukan keberkesanan KP, pencapaian hasil pembelajaran pelajar dibandingkan antara kumpulan eksperimen (KP) dengan kumpulan kawalan (tradisional) (KT). Dua instrumen telah digunakan dalam kajian ini: (1) KAFP- Inventori Hasil Pembelajaran (IHP) terdiri daripada 33 item yang dibangunkan pengkaji untuk mengukur 5 kategori hasil pembelajaran, iaitu, Kategori 1 – Pengukuran, Kategori 2 – Signifikans Berangka, Kategori 3 – Konsep dan Aplikasi, Kategori 4 – Linearisasi Graf, dan Kategori 5 – Ketakpastian; (2) KAFP- Soal Selidik Sikap (SS) terdiri daripada 18 item yang diadaptasi untuk menentukan kesan KP dan KT atas sikap pelajar terhadap fizik dan amali fizik. Hasil ujian rintis KAFP-IHP dan KAFP-SS masing-masing menunjukkan pekali kebolehpercayaan 0.71 and 0.86. Kajian ini telah dijalankan atas 66 pelajar Semester 1 (Julai – Oktober 2008) dan 62 pelajar Semester 2 (Januari – April 2009) yang mendaftar kursus fizik pengenalan di kampus cawangan sebuah universiti awam di Malaysia, masing-masing telah di pilih secara rawak menganggotai keempat-empat Kumpulan Solomon (KS). Analisis skor min KAFP-IHP antara pra ujian dan pos ujian bagi KS menunjukkan tiada kesan daripada pra ujian. Skor min KAFP-IHP dan Pertambahan Pembelajaran Ternormal (PPT) pelajar bagi kedua-dua Semester 1 dan Semester 2 telah menunjukkan corak yang konsisten iaitu terdapat penambahbaikan yang signifikan bagi skor kumpulan KP dibandingkan dengan skor kumpulan KT dalam Kategori 1 hingga 4. Tiada perbezaan signifikan antara kumpulan KP dengan KT dalam Kategori 5 – Ketakpastian. Bagi KAFP-SS pula, tiada perbezaan signifikan bagi skor min antara kumpulan KP dan KT untuk kedua-dua semester. Kajian ini mendapati KP dapat menambahbaik hanya aspek tertentu hasil pembelajaran pelajar, oleh itu, kajian lanjutan boleh dibuat untuk mengenalpasti kaedah efektif untuk meningkatkan kefahaman pelajar dalam ketakpastian pengukuran fizik, begitu juga untuk menambahbaik sikap pelajar terhadap kerja amali fizik.

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## LIST OF ABBREVIATIONS

AAPT	-	American Association of Physics Teachers
ACT	-	Achievement Test about Simple Electricity
ACVMI	-	Attitude towards Concept- and Vee-Mapping Inventory
ATS	-	Attitude Scale about Simple Electricity
ASM	-	Attitude to Science Measures
ANOVA	-	Analysis of Variances
CADAA	-	Computer Aided Data Acquisition and Analysis
CAD	-	Contrasting Alternatives Design
CLASS	-	Colorado Learning Attitudes about Science Survey
CSEM	-	Conceptual Survey of Electricity and Magnetism
EM	-	Enriched Method
FCI	-	Force Concept Inventory
FMCE	-	Force and Motion Conceptual Evaluation
GloLab	-	Global Web Laboratory
IE	-	Interactive-Engagement
IPLW	-	Introductory Physics Laboratory Work
IPLW-AS	-	Introductory Physics Laboratory Work – Attitude Survey
IPLW-LOI	-	Introductory Physics Laboratory Work – Learning Outcomes Inventory
ISLE	-	Investigative Science Learning Environment
IVPL	-	Internet Virtual Physics Laboratory
LAI	-	Laboratory Attitude Inventory
MBL	-	Microcomputer-Based Lab
MBT	-	Mechanics Baseline Test

MIT	-	Massachusetts Institute of Technology
MPEX	-	Maryland Physics Expectation Survey
NLG	-	Normalised Learning Gain
PER	-	Physics Education Research
PERG		Physics Education Research Group
PER@C		Physics Education Research at Colorado
PhET	-	Physics Education Technology
PSL		Problem Solving Laboratory
SAI		Scientific Attitude Inventory
SAS		Scientific Attitude Scale
SCL	-	Scientific Community Labs
SDI	-	Socratic Dialogue Inducing Labs
SG	-	Solomon Group
TEAL	-	Technology-Enable Active Learning
TEMC	-	Test of Energy and Momentum Concepts
TM	-	Traditional Method
TUG-K	-	Test of Understanding Graph in Kinematics
USA	-	United States of America
UK	-	United Kingdom
VASS	-	Views About Sciences Survey
WP	-	Workshop Physics

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## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 Introduction**

Introductory physics laboratory work (IPLW) which is traditionally attached to the theoretical part of an introductory physics course is always regarded by physics instructors and teachers as a necessary component in effective teaching and learning of physics. However, the efficacy of IPLW has been challenged by many writers and physics education researchers (Arons, 1997; Menzie, 1970; Redish, 2003; Richmond, 1979; Robinson, 1979; Toothhacker, 1983; White, 1979). As a result, many reform efforts have been introduced especially in colleges and universities in the United States and Europe as indicated by IPLW-related articles published in prominent journals like the *American Journal of Physics*, *The Physics Teachers*, *Physics Education*, *European Journal of Physics*, *Journal of College Science Teaching* and *Physical Review Special Topics – Physics Education Research*. However, the impact of these reform efforts on Asian universities is minimal since very few articles can be found or cited in the above-mentioned journals. In this study, an Enriched Method (EM) is introduced in order to determine if it can produce better learning outcomes, which include students' understanding of basic principles and concepts related to the experiments, the understanding of uncertainty analysis and the attitude of students towards physics laboratory work, than the Traditional Method (TM).

## 1.2 Background of the Problem

Students' physics laboratory work at the college level was first introduced at the end of 1860's at Massachusetts Institute of Technology in the USA and King's College in the UK (Melba, 1981). Since then, criticisms began to surface arguing that this traditional approach to students' laboratory work is not effective in bringing about meaningful learning. Some of these criticisms are: it is cookbook in nature, it does not resemble a research laboratory, the arts of experimental investigation is lost, it is routine, trivial, costly, not interactive, dull, not effective in producing conceptual learning gains and physical understanding, a complementary tool that cannot facilitate students' physics comprehension, and furthermore its effectiveness is difficult to substantiate (Kruglak, 1952a; Menzie, 1970; Redish, 2003; Richmond, 1979; Robinson, 1979; Royuk and Brooks, 2003; Siorenta and Jimoyiannis, 2008; Toothacker, 1983; White, 1979).

In Malaysia, several studies on physics laboratory work at the school and university levels also indicate the presence of some elements of the criticisms mentioned in the previous paragraph. In validating the Physics Laboratory Environment Inventory (Chan, 1995) applied to form four physics laboratory, Chan found that one dimension of the actual laboratory environment which is the "open-endedness" which he defined as the extent to which the laboratory activities emphasize the open-ended divergent approach to experimentation, is not what the students would prefer or had expected. This lack of open-endedness implies that the laboratory work implemented in 1995 at the form four level were traditional in nature. A study on physics laboratory manuals for the matriculation, certificate of higher education and diploma level, indicated that all of these manuals were traditional in terms of style and content (Abu Hassan, 2002). A study on the teachers' and students' perception towards the aims and importance of Physics Laboratory Work in MARA Junior Science College (Samsudin, 1999), revealed that the teachers and students both gave the same ranking to the following aim which is "to give practice in following a set of instruction". This indicates that the cookbook nature of physics laboratory instruction were still very much in the teachers' and students' paradigm.

A study on students' skill to operate and use measuring instruments such as vernier caliper, micrometer screw gauge, and triple beam balance in science laboratories (Anisah, 2004) revealed students weakness in reading the scales of measuring instruments followed by the technique to operate the instrument as stated in the following quotation,

“Based on the findings of the study, students level of skill in operating and using the laboratory measuring instruments is at the moderate level. The students weakest skill is in reading the scale of measuring instruments followed by the technique of operating the measuring instrument in the lab.”

(Anisah, 2004, p.5)

Passive involvement of form four students in their physics laboratory work was reported by Zaiton and Shaharom in 2008, where part of their report stated that,

“...in general students were passively involve in physics laboratory work. The result of this study implies that the practice of laboratory work among the students do not change even though the reviewed curriculum that emphasize thoughtful learning (pembelajaran berfikir) has been implemented since 2002.” (Zaiton and Shaharom, 2008, p44)

At the tertiary level, a study by Hanizah and Shaharom (2008) showed that the level of understanding of communication and experimentation skills of a second year Physics Education students remained unchanged after undergoing a Physics Education Laboratory I (Pendidikan Amali Fizik I) course as given in the following quotation,

“Overall the students' level of communication and experimentation skills are the same before and after undergoing Physics Education Laboratory I course. Henceforth, efforts to increase the students' level of understanding have to be implemented to produce excellent and quality individuals in the field of science and technology” (Hanizah and Shaharom, 2008, p1)

Studies by Chan (1995), Samsudin (1999), Anizah, 2004; Zaiton and Shaharom(2008), and Hanizah and Shaharom (2008) suggest that the deficiencies of traditional Introductory Physics Laboratory Work are also present in Malaysia. The results of these studies also warrants further research on the attitude of Malaysian students on physics laboratory work at introductory tertiary level to determine whether different laboratory approach would results in better students attitude towards the laboratory activities.

Insufficient knowledge of physics was identified by Nivalainen et al. (2010) as one of the challenges in planning laboratory work in physics for pre-service and in-service teachers attending a school laboratory course in Finland. Nivalainen et al. (2010) stated that,

“the challenges in practical or laboratory work consisted of the limitations of the laboratory facilities, *an insufficient knowledge of physics*, problems in understanding instructional approaches, and the general organization of practical work.” (Nivalainen et al., 2010, p.394)

Berry et al. (1999) observed that based on their research on two metropolitan Melbourne schools, students' lack of physics content knowledge prevented them to be mentally engaged in their laboratory work hence making it hard for them to draw meaning from the results of their experiments. Berry et al. (1999) concluded that,

“From our observations, an important factor effecting the extent to which students become mentally engaged in both open and closed laboratory work is *the extent to which they know the content knowledge* assumed by the task. ... students with little or none of the assumed content knowledge find it difficult to derive meaning from their results.” (Berry et al., 1999, p.29).

Lilia and Subahan (2002) discovered that poor content knowledge of the majority of a group of trainee teachers in Malaysia impeded their ability to create analogies that were free from misconceptions. Lilian and Subahan (2002) stated that,

“... the findings showed that a majority of the 12 trainee teachers had problems in understanding the scientific ideas themselves...due to a lack of understanding, they created analogies that embodies misconceptions. Their ability to transform the subject matter appropriately for pupils, in creating representations that convey the scientifically correct answers, were impeded by *their own poor content knowledge.*” (Lilia and Subahan, 2002, p.223)

The three studies by Nivalainen et al. (2010), Berry et al. (1999), and Lilia and Subahan (2002) points out that:

1. Insufficient physics knowledge is one of the factors that challenge students and teachers in carrying out meaningful laboratory work as well as in producing physics analogies free of misconceptions.
2. Lack of physics understanding among students as well as pre-service and in service teachers is quite universal considering the studies were carried out in Finland, Australia, and Malaysia.

Several studies have been carried out on Malaysian students' conceptions and difficulties of various physics topics at the pre-university level as well as at the first year level. A-level physics students' understanding of the concept of mechanics has been studied by Zawajer (2001) where she reported the percentage mean scores for the students' performance on the FCI was only 43.3%. This score is below the mean score of 60% considered to be the conceptual threshold for problem-solving competence in physics. The alternative conceptions on energy held by the first year physics students in a Malaysian public university were reported by Ahmad Nurulazam and Fauziah (1998) while the tenacity of students misconception in electrical circuit connection of students entering a university were reported by Beh and Tong (1992). Similar to insufficient physics knowledge that hampers meaningful laboratory engagement, physics learning difficulties are also universal in nature as exemplified by studies in China by Wang et al. (2007) and in Nigeria by Ogunleye (2009). Realizing the need to improve physics learning among students in introductory physics courses in Malaysia or other countries, a reformed and enriched laboratory approach presents a great opportunity to engage the students meaningfully in the laboratory activities.



To improve the learning of physics in the laboratory, various methods and approaches have been introduced. Some of these methods are: Removing the “Cook Book” from Freshman Physics Laboratory (Prescott and Anger, 1970), Teaching Physicists’ Thinking Skills in the Laboratory (Reif and St. John, 1979) Socratic Dialogue Inducing (SDI) Labs (Hake, 1992), Physics by Inquiry (McDermott, 1996), Workshop Physics (Laws, 1997a), Microcomputer-based Laboratories (Redish et al., 1997), Case Study Experiments in the Introductory Physics Curriculum (Arion et al., 2000), Problem Solving Labs (Heller, 2001), Concept Map in a Freshmen Physics Laboratory (Zieneddine and Abd-El-Khalick, 2001), Enhanced Students Learning in the Physics Laboratory (Cox and Junkins III, 2002), Classical Physics Experiments in the Amusement Park (Bagge and Pendrill, 2002), the Development of Virtual Laboratory on the Internet as Support for Physics Laboratory Training (González et al., 2002), Laboratory- and Technology-Enhanced Active Learning (Beichner et al., 2006), Laboratory Design for Physics for the Modern World Course (Larkin and Mathis, 2004), Web-based Laboratory (Mazlewski et al., 2007; De la Torres et al., 2011), Interactive Simulation by using Physics Education Technology (PhET) in Physics Teaching (Wieman et al., 2008a; 2008b; 2010), and Design and Reflection in Physics Laboratory (Etkina et al., 2010). A lot of reform efforts had successfully improved the effectiveness of physics laboratory work, however, the cookbook non-interactive traditional methods of physics laboratory work in introductory physics courses are still common (Redish, 2003). Handelsman et al. (2004), described the “cookbook” nature of most introductory laboratory work,

“However, most introductory courses rely on “transmission-of-information” lectures and “*cookbook*” *laboratory exercises* – techniques that are not highly effective in fostering conceptual understanding or scientific reasoning” (Handelsman et al., 2004, p.521)

Another issue in the Introductory Physics Laboratory Work is the variation in aims and goals of this laboratory activity. Most probably different instructors have different reasons for carrying out the students laboratory work. This problem is compounded with the assessment methods in physics laboratory work that does not necessarily directed towards measuring the stated aims and goals of the lab. To reduce this variation in the aims and goals of laboratory work, the American

Association of Physics Teachers (AAPT, 1998) has published the summary of the introductory physics laboratory goals, as stated below :

- (i) The art of experimentation.
- (ii) Experimental and analytical skills.
- (iii) Conceptual learning.
- (iv) Understanding the basis of knowledge in physics.
- (v) Developing collaborative learning skills.

A variety of goals for the physics laboratory are suggested by Redish (2003):

- (i) *Confirmation*. To demonstrate the correctness of theoretical results presented in lectures.
- (ii) *Mechanical Skills*. To help students attain dexterity in handling apparatus.
- (iii) *Device Experience*. To familiarize students with measuring tools.
- (iv) *Understanding Error*. To help students understand the tools of experiment as a method to convince others of your results: statistics, error analysis, and the idea of accuracy and precision.
- (v) *Concept Building*. To help students understand fundamental physics concepts.
- (vi) *Empiricism*. To help students understand the empirical basis of science.
- (vii) *Exposure to Research*. To help students get a feel for what scientific explorations and researches are like.
- (viii) *Attitudes and Expectations*. To help students build their understanding of the role of independent thought and coherence in scientific thinking.

The list of eight goals stated above are daunting (Redish, 2003), and in practice traditional laboratories only explicitly try to accomplish the first three goals. Even though, understanding error or measurement uncertainty is stated as a goal, traditionally it is only emphasized in the first experiment on measurement and then the interest to realize this goal dies off as the experiments proceed to the ensuing experiments. Several studies on first year physics students' difficulties in understanding measurement and uncertainty had been carried out by Deardoff (2001) and Abbott (2003) at North Carolina State University and Lipmann (2003) at University of Maryland. Lubben et al. (2001) from University of York, UK and University of Cape Town, South Africa research group has modeled students'

thinking on measurement data in terms of point and set reasoning. An extensive search on the Institutional Repositories and lists of thesis and dissertations of several public universities such as UM, USM, UKM, UPM and UTM carried out in the month of November 2011, revealed that there is no study on Malaysian students' understanding of measurement and uncertainties. By extending the universality of students' deficiency in measurement and uncertainty understanding reported elsewhere to students in Malaysia, hence it is imperative that part of a reform effort in laboratory work should also be directed towards improving the students' understanding and practice of uncertainty analysis.

The understanding of concepts through active construction of meaning by the learners facilitated by the teacher through an interactive engagement (Bonham, 2007; Gray and Madso, 2007; Keiner and Burns, 2010; Scott, 2011; Sorensen et al., 2011, Veronica, 2004) has been at the forefront of physics education today. Even though problem solving is still one of the primary means of testing the amount of learning that a student has acquired in physics, concept-based instruments that probe the conceptual understanding of students is becoming more popular especially towards evaluating the effectiveness of instructions (Hestenes et al., 1992; Maloney et al., 2000; Rosengrant and Singh, 2003; Thornton and Sokoloff, 1998). Therefore, concept mapping (Novak and Gowin, 1984) which was introduced by Novak based on the assimilation learning theory of Ausubel is chosen to improve the laboratory work. Even though, the study by Zieneddine and Abd-El-Khalick (2001) showed that the scores in concept tests of those students who used pre and post laboratory concept map over the control group who did not use concept map was not statistically significant, the scores of the treatment group was still higher than the control group. Furthermore, concept mapping has great potential for improving conceptual learning and collaborative learning skills as shown by other disciplines with non-laboratory set up (Edmondson, 1994; Romance and Vitale, 1999; Sadiyah et al., 2005; Wahidin, 2004). Five experiments on Length Measurement, Ballistic Pendulum, Acceleration due to Gravity, Energy and Power, and Basic Electrical Circuit are carried out with the two methods, the Traditional Method (TM) and the Enriched Method (EM).

In this study, the “learning outcomes” of a traditional students introductory physics laboratory work is compared to a laboratory that has been enhanced with pre-laboratory activities that includes answering questions related to the theory and relevance of the experiment, constructing concept maps related to the concepts involved in the experiment, and uncertainty analysis. The enriched version of the laboratory manual for five experiments is written with emphasis on the understanding the theory and relevance of the experiment to everyday phenomena in order to strengthen the understanding of physics concepts learned in lectures. A comparative study is chosen in order to determine to what extent that this enrichment of the traditional lab effect the students’ learning outcome. Furthermore, this modification is relatively not as resource intensive as compared to other changes like workshop physics and microcomputer-based laboratories.

The emphasis on formulating students learning outcomes in laboratory work is in line with the requirement of Malaysia Qualification Framework (MQF) administered by the Malaysian Qualification Agency (MQA) which was established on the 1<sup>st</sup> of November 2007 as a new entity responsible for quality assurance of higher education (MQA, 2008a). The MQF emphasizes eight domains of learning outcomes, which are significant for Malaysia:

- (i) knowledge;
- (ii) practical skills;
- (iii) social skills and responsibilities;
- (iv) values, attitudes and professionalism;
- (v) communication, leadership and team skills;
- (vi) problem solving and scientific skills;
- (vii) information management and lifelong learning skills; and
- (viii) managerial and entrepreneurial skills

(MQA, 2008a, p4)

Hence, the learning outcomes of physics laboratory work related to the domains outlined by the MQF such as knowledge, practical and scientific skills as well as attitudes as envisaged by the EM in this study are in line with the requirement of MQA.

Physics Practical Work Assessment (PEKA) is a school-based assessment introduced in 1999 by the Lembaga Peperiksaan Kementerian Pelajaran Malaysia (LPM) to facilitate the assessment of physics laboratory work at the Sijil Peperiksaan Malaysia (SPM) or form 4 and form 5 level. The main objectives of PEKA physics are to enable students to: Master scientific skills, strengthen knowledge and understanding of theories and concepts in physics, and inculcate scientific attitudes and noble values (LPM, 2003). Some of the problems in the implementation of PEKA faced by teachers were studied by Ruslina (2001) who identified the major problems were related to the amount of work load and time management followed by insufficient exposure to PEKA implementation course and large number of students in a class. The performance indicators and the instruments in PEKA Physics 1999 had undergone several changes in 2002 and 2004. A study by Muhammad Rashdan (2007) indicates that even though the teachers thought that performance indicators found in PEKA Physics 2004 to be systematic, detailed and easily understood by teachers and students, but they still faced time constraint when assessing the detailed performance indicators and the various instruments in this latest version of PEKA Physics. After ten years of implementation, there still exist some problems at the execution level as well as the teachers comprehension of PEKA Physics as stated by Shaharom and Suhailah (2010) in their problem statement on the study of the level of knowledge of pre-service teachers on PEKA Physics,

“PEKA Physics had been implemented for nearly a decade, however there are still many students who failed to achieve good physics grades in Sijil Pelajaran Malaysia. Furthermore, there are still teachers who do not know about PEKA Physics.”

(Shaharom and Suhailah, 2010, p2)

The result of the study by Shaharom and Suhailah (2010) also showed that pre-service Physics teachers have not fully comprehend PEKA Physics.

There are five constructs stated in PEKA Physics (LPM, 2004):

- Construct I : Planning of Procedures for Investigations or experiments.
- Construct II : Carrying out investigations or experiments.
- Construct III : Collecting and recording investigative and experimental data.
- Construct IV : Interpreting data and making conclusions.
- Construct V : Scientific skills and noble values.

These five constructs are accompanied by their respective performance indicators. While most of these performance indicators (PI) are appropriate for higher secondary school levels, three physical measurement concepts related to Construct III and Construct IV, are not visible: first, the concept of “uncertainty in all measurement” (McDermott, 1996, p.21), second, the idea of significant figures where “the last figure in reported data is to be the first uncertain one” (Arons, 1997, p.330), and third, the notion of “propagation of error (uncertainty)” (Loyd, 2002, p.10). Students’ understanding of the presence of uncertainty in any physical measurement by whatever types of measuring instruments, students’ comprehension of the importance of reporting the correct significant figures, and students’ knowledge that uncertainties propagate when several readings are involved in a mathematical operations such as addition, subtraction, multiplication and division are very important for meaningful data analysis and conclusions in most physics laboratory work. The PIs for Construct 4 mainly addressed the students’ required skill in drawing a straight line graph and extracting information from the gradient of the graph. However, this understanding of drawing a straight line graph can be strengthened by providing the rationale and principle of graph linearization.

In this study, the EM attempts to include considerable emphasis on significant figures, graph linearization, uncertainty and uncertainties propagation to complement the missing part as documented in PEKA physics.

Time is an important factor in learning where deep and meaningful learning takes considerable time and effort. In this respect, Berry et al (1999), recommended extended time for students physics laboratory work,

“... given the current ways of doing laboratory work do not appear to generate much learning, it may be more appropriate to *extent the time spent on individual laboratory tasks to enhance learning opportunities* rather than reducing time and learning in an effort to complete the curriculum.” (Berry et al., 1999, p.30).

According to Bransford et al. (2000), significant learning requires a considerable investment of time.

“Clearly, it was recognized that significant learning takes major investment of time” (Bransford et al. 2000, p.58)

Hence, the EM dedicated twice the amount of time of students active engagements in the lab compared to its traditional counterpart.

### **1.3 Problem Statement**

Traditional Introductory Physics Laboratory Work (IPLW) is not effective in improving students' physics learning (Hanizah and Shaharom, 2008; Kruglak, 1952a; Menzie, 1970; Redish, 2003; Richmond, 1979; Robinson, 1979; Royuk and Brooks, 2003; Siorenta and Jimoyiannis, 2008; Toothhacker, 1983; Trumper, 2003; White, 1979). Since most IPLW in Malaysia are traditional in nature (Abu Hassan, 2002; Chan, 1995; Samsudin, 1999) and Malaysian students difficulties in physics topics such as mechanics (Zawajer, 2001), energy (Ahmad Nurulazam and Fauziah, 1998) and electricity (1992) were already documented, a reformed IPLW is needed in order to enhance students learning of physics. This reformed IPLW should also emphasize the students' understanding of measurement and uncertainty (Abbot, 2003; Deardorff, 2001; Lipmann, 2003) despite the absence of significant previous research on Malaysian students performance in this category of learning outcomes. One of the reasons why students fail to have meaningful engagements in IPLW is due to their insufficient physics knowledge (Berry et al., 1999; Nivalainen et al.

2010). Hence, a strategy that enhance the students understanding of the physics related to the ensuing experiment prior to their engagement in the lab, during the lab as well as after the lab work needed to be developed. The technique of “*Pre-lab, Lab work and Post-lab*” as elaborated by Nurzatulshima et al. (2009) and concept mapping (Novak, 1998; Novak and Gowin, 1984; Wahidin, 2004) are examples of suitable ways of enhancing the learning in the labs. Other contributing factors such as the nature of activities in the Pre-Lab, In- Lab and Post-Lab, the way the laboratory manual is written (Abu Hassan, 2002; Yip, 2005), feedback and the length of time allocated for the activities (Bransford et al. 2000), the clarity of aims and purpose (Berry et al., 1999) and learning outcomes (MQA, 2008a) needed to be considered. Considering the limitations of the resources and time, a reasonable approach to improve students physics laboratory work is by developing an Enriched Method (EM) which increased the focus on pre-laboratory, in-laboratory and post-laboratory activities. This EM should still operate within the traditional framework with minimal resource investment and the least deviation from the traditional practice that can make a significant difference to students’ learning outcomes. Furthermore, instruments should be developed to measure students learning outcomes in the following area: knowledge related to the topics covered in the IPLW experiments, students’ understanding of measurement and uncertainty analysis, as well as the attitudes towards IPLW as a result of this reform effort. A comparative study between the experimental group using the enriched method and the control group using the traditional method needed to be designed so that the efficacy of the reformed approach can be measured.



#### 1.4 Purpose of the Study

The objectives of this study are:

- (i) To develop an Enriched Method (EM) in Introductory Physics Laboratory Work (IPLW) to improve students' physics learning.
- (ii) To compare the physics knowledge related to the experiments between students carrying out their physics laboratory work using *Traditional Method* (TM) and *Enriched Method* (EM).
- (iii) To compare the students' understanding of uncertainty analysis between the TM and EM groups.
- (iv) To compare the students' attitude toward physics and the laboratory work between the two groups.

#### 1.5 Research Questions

After developing and implemented the EM approached to IPLW, this study subsequently attempts to answer the following questions.

- (i) Is there a significant difference between students in the EM and TM groups in their understanding of related physics concepts?
- (ii) Is there a significant difference between students in the EM and TM groups in their understanding of uncertainty analysis?
- (iii) Is there a significant difference between students in the EM and TM groups in their attitude towards physics and physics laboratory work?

## 1.6 Conceptual Framework

This study was developed based on cognitive view of learning (Ausubel, 2000) where the existing cognitive structure influences the ability of learners to assimilate new learning material that results in new structure that is meaningful to the learners. In this study, learning is viewed as a “constructive activity that the students themselves have to carry out” (von Glasersfeld, 2005, p.7) and “individuals build their knowledge by making connections to existing knowledge” (Redish, 2003, p.30). The pre-lab activities that includes concept map (Novak and Gowin, 1984) acts like an advanced organizer (Ausubel, 2000) that creates meaningful physical concepts that are relevant to the experiments. The emphasis of EM in important basic understanding in IPLW such as significant figures and linearization of graphs extend the performance indicators in Construct III (Collecting and Recording Investigative or Experimental Data) and Construct IV (Interpreting Data and Making Conclusion) of PEKA Physics (LPM, 2004) that stressed only decimal places and the mechanics of graph plotting. The importance placed on specifying learning outcomes in all the activities of EM is in compliance to the requirements outlined by the Malaysian Qualification Framework (MQF) “developed to unify and harmonise all Malaysian qualifications” (MQA, 2008c) formulated by the Malaysian Qualification Agency (MQA, 2008a) responsible for monitoring the quality of qualifications and accrediting programs by Higher Education Provider in Malaysia.

Recipe-type traditional physics laboratory manual was criticized as not effective in bringing about the intended physics learning since students are given detailed step by step procedure that destroys the essence of experimentation (Menzie, 1970; Millikan, 1903; Redish, 2003; Toothacker, 1983; Trumper, 2003). A non-cookbook lab manual is written for this study that replaced the traditional cookbook manual which guides the students in carrying out the experiments. Post-lab activity is held in order to enhance students’ knowledge related to the experiments and uncertainty comprehension for the treatment group as well as provide a consistent feedback of their written laboratory reports. This continuous “feedback has long been identified as important for successful learning...” (Bransford et al., 2000, p.59). Most of the activities in the EM were done in group to exploit the effectiveness of group

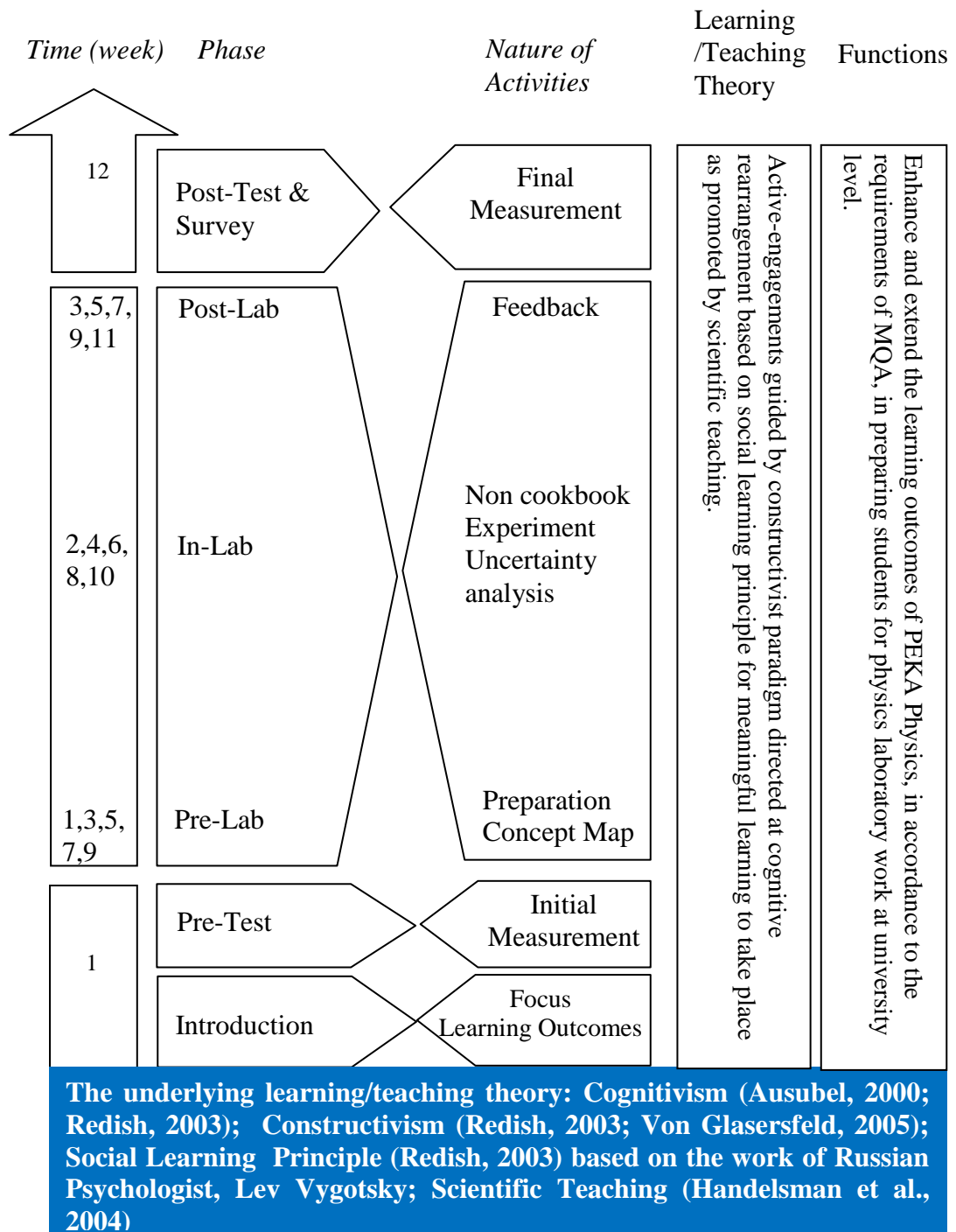
learning founded on the social learning principle where “for most individuals, learning is most effectively carried out via social interaction” (Redish, 2003, p.39) based on the ideas of Russian psychologist, Lev Vygotsky.

The laboratory time for the IPLW of this foundation physics course for this Pre-Diploma Science program has traditionally been a two-hour lab carried out for five consecutive weeks since the inception of the program in 1999. Therefore the five-week laboratory time allocated for the TM in this study was the actual time of students’ laboratory work before the introduction of EM. Therefore when the EM was designed, one of the factors that was considered to improve students’ learning was a longer face-to-face interaction time in the laboratory. The need for time extension to improve learning was recognized by Bransford et al. (2000), who stated that, “Clearly, it was recognized that significant learning takes major investment of time.” (Bransford et al. 2000, p.58) and recommended by Berry et al. (1999), “... given the current ways of doing laboratory work do not appear to generate much learning, it may be more appropriate to *extend the time spent on individual laboratory tasks to enhance learning opportunities* rather than reducing time and learning in an effort to complete the curriculum.” (Berry et al., 1999, p.30). Since one semester consists of 14 weeks, therefore a designation of a 12-week IPLW for the EM is reasonable which then immediately followed by the challenges of filling this longer laboratory time with activities that improve students’ physics learning. Therefore, in this study, longer IPLW time for the EM is purposely chosen for the treatment group compared to the time TM allocated for TM which naturally maintain the 5-week traditional laboratory sequence. Time extension alone most probably does not improve learning because what counts are the nature of activities within the stipulated time span which support or hinder learning.

The achievement of students’ learning outcomes, which are stated for the pre-in-post lab activities are measured by the computation of the mean scores and normalized learning gain (Hake, 1992) of a learning outcomes inventory instrument specifically developed to test the content associated with of the five experiments in this study. An attitude survey is adopted to test the differences between the treatment and control groups towards physics and physics laboratory work. The results of this

study is useful in improving the laboratory curriculum as well as the teaching approaches as envisaged by the research and redesign wheel of Redish (2003).

The conceptual framework for the development of the Enriched Method for IPLW is given in Figure 1.1.



**Figure 1.1:** The Conceptual Framework that governs the EM which activities were based on cognitivism, constructivism, social learning principle, and scientific teaching as the underlying learning/teaching theories.

## 1.7 Significance of the Study

Despite some interesting research results on students learning outcomes in the laboratories ( Allie and Buffler, 1998; Allie et al., 1998; Cox and Junkins III, 2002; Johnstone et al., 1998; Reif and St. John, 1979; Séré et al., 1993, Zieneddine and Abd-El-Khalick, 2001) there have been little published research results on what is happening in university introductory physics laboratory work in Asia. Several studies on problems related to students laboratory work at the school as well as at the university in Malaysia (Chan, 1995; Rohana and Shaharom, 2008; Samsudin, 1999) do not question whether fundamental learning such as students' understanding of physics concepts, scientific measurement and uncertainty analysis had resulted from laboratory activities. Currently, there is no reported study at any university in Malaysia that questioned the efficacy of their traditional physics labs hence there is no visible reformed effort such as Investigative Science Learning Environment (ISLE) at University of Rutgers, Scientific Community Lab (SCL) at the University of Maryland, Workshop Physics at Dickinson College and Socratic Dialogue Inducing (SDI) Labs at Indiana University. The absence of reported deficiency in students' traditional physics laboratory work in Malaysia does not necessarily mean that everything goes well here. The universality of students physics learning difficulties can be established by comparing similar reports from studies in Malaysia (Ahmad Nurulazam and Fauziah, 1998; Beh and Tong,1992; Zawajer, 2001), in Nigeria (Ogunleye, 2009) and even in China (Wang et al., 2007). Similarly, the insufficiency of students learning in physics laboratory reported by many studies carried out especially in universities in the United States may also be true in Malaysia. Therefore, this study which was carried out at one of our public universities can be considered as an initial effort to introduce limited reform into IPLW in Malaysia. This nature of study can be further extended to other IPLW at other Malaysian Universities as well as our neighboring countries just like the evaluation of laboratory work performed in five European countries based on "Labwork in Science Education" funded by the European Union (Psillos and Niedderer, 2002).

In this research, an EM approach to performing IPLW was developed and quantitative comparison on the achievement of learning outcomes of the EM (treatment) groups is compared to that of the TM (control) group who employed the traditional lab method. Hence, it is an attempt to quantify the extent that the enrichment, which basically still operates within the traditional framework, can improve students' learning in the labs. The results of this research will encourage a rethinking on appropriate approaches that can enhance students physics learning in the laboratory. Therefore, the investment of time, money and effort on this 150-year old laboratory teaching method could be further substantiated and justified.

The reform efforts like Workshop Physics at Dickinson College and Technology Enabled Active Learning (TEAL) at MIT are very resource intensive where the Lecture-Tutorial-Lab has been merged into a workshop or studio. All students' face to face interaction in their learning of physics took place in the workshop or studio resulting in significantly better students achievement. However, the EM in this study still operates within the traditional Lecture-Lab format where the laboratory work and lecture are carried out at different location and time. If significant students' physics learning in EM is achieved, then a more expensive option might not be needed, otherwise alternative methods should be researched on.

The emphasis on the evidence of the achievement of students learning outcomes by the Malaysian Qualifications Agency (MQA) as outlined in the Malaysian Qualification Framework (MQF) can most probably be met by the approach of EM which stressed active students involvement in the understanding of the concepts and analysis of the physics experimentation as measured by the specifically created instruments.

The introduction and use of validated instruments to measure students achievement of learning outcomes is another dimension of EM which can be applied in other areas of physics such as electricity and magnetism, thermodynamics and quantum mechanics.

## 1.8 Operational Definitions

The operational definitions of important terms in this study are:

(i) Enriched Method (EM)

This laboratory approach begins with an introduction to IPLW that accentuate the clarity of aims and purpose (Berry et al., 1999) as well as the learning outcomes (MQA, 2008) expected of the students doing introductory physics laboratory work. This approach emphasizes active students engagement in the “*Pre-lab, Lab work (In-Lab) and Post-lab*” (Nurzatulshima et al., 2009) activities. The pre-lab activities engage students in group effort in answering pre-lab questions and constructing concept maps (Novak, 1998; Novak and Gowin, 1984; Romance and Vitale, 1999; Wahidin, 2004) to enhance the understanding of physics concepts related to the on-coming experiment. During the pre-lab phase the students also discussed the detailed procedures to successfully carry out the approaching experiment. The in-lab experimentation is guided by a non-recipe type manual (Abu Hassan, 2002; Aron, 1997) that provides minimal general guidance which emphasizes understanding of physical concepts and uncertainty analysis (Deardoff, 2001; Abbot, 2003; Lipmann, 2003). In this in-lab phase the students have to write their own procedure of the experiment (Arons, 1997) and submit a lab report including the uncertainty analysis at the end of the lab hour. Post-lab activities involve discussion of returned corrected reports and model report to provide feedback (Bransford et al. 2000) to the students. The amount of time dedicated for the EM activities is double compared to the time for the traditional lab in order to ensure significant learning takes place (Berry et al., 1999; Bransford et al., 2000).

(ii) Traditional Method

This is the conventional laboratory approach with detail written procedures (Karelina and Etkina, 2006; Prescott and Anger, 1970; Redish, 2003; Robinson, 1979) without prescribed pre-lab and post-lab activities with no



emphasis on calculation of uncertainty and its propagation (Kung, 2005). Students active engagement in the lab are minimal with almost no discussion on the “physics to be extracted” or the “limitations of the measurement” (Redish, 2003, p163). According to Berry et al. (1999), in traditional investigation the students’ focus is on the procedure which they follow as they would a recipe for a cake, where the main goal is to finish the investigation, and the secondary goal is to achieve the ‘right’ answer.

(iii) Learning Outcomes – knowledge

These outcomes include the understanding of significant figures, accuracy, precision (Arons, 1997), linearising graphs, reading vernier caliper and micrometer (Anizah, 2004), reporting measurement and comprehension of the physics concepts and principles involved in the experiment (Berry et al. 1999). Since the categorization of skill-based, rule-based and knowledge-based human behavior represents a continuum (Rasmussen, 1983), all the above-mentioned students’ learning outcomes are classified under “knowledge”. In the context of IPLW-LOI, knowledge measured are categorised under Category 1 – Measurement, Category 2 – Numerical Significance, Category 3 – Concepts and Applications, and Category 4 – Graph Linearization.

(iv) Learning Outcomes – uncertainty

These outcomes include the understanding of differences between random and systematic uncertainty, the purpose of repeated measurements carried out in an experiment, and the calculations of basic uncertainty propagation (Bevington and Robinson, 2003). In this study, these outcomes are measured under Category 5 – Uncertainty of the IPLW-LOI.

(v) Learning Outcomes - attitude

These outcomes include how the students feel towards physics as a subject and its laboratory work as well as the learning that they have managed to

grasp. (Veath, 1988). In this study, these outcomes are measured by the 18-item IPLW-AS.

(vi) Introductory Physics Laboratory Work (IPLW)

The laboratory component of an introductory physics course usually attached to a theory component where in the context of Malaysia includes the upper secondary school, matriculation, the first year and even the second year university level. This is in line with the studies in physics education in Malaysia where the respondents are mostly selected from students in Form 4 (Chan, 1995; Yati, 1996; Zaiton and Shaharom, 2008), Form 4 and 5 (Samsudin, 1999), Form 6 Ganespathy, 1988), Matriculation (Ananda, 2004; Aziz, 2004; Zawajer, 2001), first year (Ahmad Nurulazam and Fauziah 1998; Beh and Tong, 1992) and second year (Hanizah dan Shaharom, 2008) university students. In presenting his Theoretical Framework for Physics Education Research: Modeling Student Thinking, Redish (2004) had chosen to include high school and university students in his framework of study where he stated that,

“I choose to focus on what appears to me to be the central issue: the behavior and functioning of individual adults – *high school and college students* – particularly in the context of the learning of science (and of that, particularly learning physics, from which most of my examples will be drawn)” (Redish, 2004, p3).

Similar studies that include students from upper secondary to university level were also done in Europe as reported by Niedderer et al. (2002),

“The method (category-based analysis of videotapes – CBAV) was used in five studies of labwork in France and Germany in *upper secondary school and university physics classes*” (Niedderer et al., 2002, p.31)

Hence, operationally defining IPLW that incorporates students from high school (Form 4) to university level is in accordance with the practice of physics education research in Malaysia, in the United States as well as in France and Germany.

(vii) Concept Map

This is a schematic tool to relate two concepts via appropriate linking words that is hierarchical in nature to enhance understanding developed by Novak (Novak and Gowin, 1984). In this study, students had to construct eight concept maps on the following topics related to the experiments: measuring instruments, volume of a sphere and a cuboid, linear momentum, mechanical energy, acceleration due to gravity at different latitudes on earth, analysis of a straight line graph, energy and power, and simple electrical circuit.

## 1.9 Summary

The background of the problem concerning the inadequacies of IPLW in Malaysia as well as in other developed countries with respect to its nature, objectives and implementation has been described. The main objectives of the study are: to develop an Enriched Method (EM) of IPLW that improves students' physics learning outcomes in agreement with the requirement of MQA, that extends the learning in PEKA physics and furthermore adequately prepares students to do an investigative laboratory work at the tertiary level; and to compare the learning outcomes in terms of "knowledge, uncertainty analysis and attitudes" of the treatment group (EM) and the control group (TM). This study is significant in attempting to introduce a reform effort to improve students physics learning in Malaysia and contribute to the understanding of students physics learning in the laboratory in general.

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