

THE EFFECTS OF TECHNOLOGY- ASSISTED
CONTEXTUALIZED INQUIRY INSTRUCTION (TACII)
ON MALAYSIAN FORM TWO STUDENTS
SCIENTIFIC LITERACY

BY

ABDUL HAM D I N ABDUL RAHMAN

A thesis submitted in fulfillment of the requirement for the
degree of Doctor of Philosophy in Education

Kulliyah of Education
International Islamic University Malaysia

MARCH 2022

ABSTRACT

This quasi-experimental study examined the effects of a technology-assisted contextualized inquiry-based instruction (TACII), designed as an integrated approach to teach science concepts, on Form Two students' PISA-aligned science competencies and overall scientific literacy. It adopted the pretest-posttest non-equivalent control group design involving 1,380 Form Two students in nine selected mainstream and high performing schools in Kuala Lumpur and Selangor. The intervention covered the topics of friction, force, and motion with TACII being used to teach the treatment group ($n = 738$), while the traditional method of science learning was used with the control group ($n = 642$). The intervention took four (4) weeks to complete, and the treatment teachers were trained to use TACII over a cumulative period of one week. A set of parallel tests were used before (pre-test) and after the intervention (post-test) as the instruments to assess the subjects' overall scientific literacy and mastery of the science competencies. The data were then analyzed using independent samples t-tests and a hybrid Structural Equation Modeling (SEM). Statistically significant differences were further tested with Cohen's d effect size estimation. The results indicate that TACII was able to affect substantial and statistically significant increases in students' abilities to explain natural phenomena scientifically (Cohen's $d = .68$), evaluate and design scientific inquiry (Cohen's $d = .77$), and interpret data and evidence scientifically (Cohen's $d = .70$), all of which showed practical but moderate effects of the intervention. The SEM results point to the significant role of prior knowledge in influencing students' scientific literacy, but ruled out gender, school locality (rural versus urban) and school type (mainstream versus high performing) as moderating variables. In fact, prior knowledge was discovered to be significantly more influential than TACII in determining students' scientific literacy. With these results, the study has provided a compelling body of evidence on the importance of teaching science through technology-assisted inquiry and contextualization and students' having the right amount of prior knowledge for science learning as well as on the importance of training teachers to use these integrated strategies to deliver meaningful science lessons that meet the standards of PISA.

خلاصة البحث

تهدف هذه الدراسة شبه التجريبية إلى اكتشاف آثار التدريس المستند على الاستفسار السياقي باستخدام تكنولوجيا التعليم (TACII)، المصمم كمدخل متكامل لتدريس مفاهيم العلوم والكفاءات العلمية المتوائمة والقراءة العلمية (PISA) بشكل عام لطلاب الصف الثاني الثانوي، وقد تبنت هذه الدراسة اختبارين؛ قبلي وبعدي، وتم تطبيقهما على مجموعتين غير مكافئتين على عينة عددها 1,380 طالبًا من الصف الثاني الثانوي في تسع من المدارس ذات الأداء السائد والمدارس عالية الأداء في كوالالمبور وسيلانجور. وغطت التجربة موضوعات الاحتكاك، والقوة، والحركة باستخدام (TACII) لتدريس العلوم للمجموعة التجريبية وعددها (n=738) بينما تم استخدام الطريقة التقليدية لتدريس المجموعة الضابطة وعددها (n=642) واستغرق التجربة أربعة (4) أسابيع لاستكمالها، وتم تدريب المعلمين لإجراء التجربة على استخدام (TACII) لمدة أسبوع واحد. وتم استخدام اختبارين متوازنين قبل التجربة (الاختبار القبلي)، وبعد التجربة (الاختبار البعدي) كأداتين لتقييم المعرفة العلمية الشاملة للموضوعات وإتقان الكفاءات العلمية، و تم تحليل البيانات باستخدام اختبارات t (t-tests) للعينات المستقلة، و نموذج المعادلة الهيكلية (SEM). وتم اختبار الفروق ذات الدلالة الإحصائية مع تقدير حجم التأثير ل كوهين (د) - (Cohen's d). و تشير النتائج إلى أن التدريس المستند على الاستفسار السياقي باستخدام تكنولوجيا التعليم (TACII) له تأثير كبير وزيادة جوهرية دلالة إحصائية على قدرات الطلاب في شرح الظواهر الطبيعية علمياً (Cohen's $d = .68$)، وتقييم وتصميم الاستفسار علمياً (Cohen's $d = .77$)، وتفسير البيانات وإثبات الأدلة علمياً (Cohen's $d = .70$)، وكلها أظهرت تأثيرات عملية ولكن معتدلة التأثير. وأن نتائج (SEM) تشير إلى الدور الهام للمعرفة السابقة في التأثير على المعرفة العلمية لدى الطلاب، ولكنها استبعدت الجنس، وموقع المدرسة (الريف مقابل الحضر)، ونوع أداء المدرسة (الأداء السائد والأداء العالي) كعوامل مؤثرة. وفي الواقع، كشفت النتائج أن المعرفة السابقة أكثر تأثيراً وبشكل ملحوظ من التدريس المستند على الاستفسار السياقي باستخدام تكنولوجيا التعليم (TACII) في تحديد معرفة القراءة والكتابة العلمية للطلاب. ومن خلال هذه النتائج، قدمت الدراسة مجموعة من الأدلة الواضحة على أهمية تدريس العلوم من خلال الاستناد على الاستفسار السياقي باستخدام تكنولوجيا التعليم، وحصول الطلاب على المقدار المناسب من المعرفة السابقة لتعلم العلوم، وكذلك أهمية تدريب المعلمين على استخدام هذه الاستراتيجيات المتكاملة لتقديم دروس علمية هادفة تُلي معايير (PISA).

APPROVAL PAGE

The thesis of Abdul Hamid bin Abdul Rahman has been approved by the following:

Tunku Badariah Tunku Ahmad
Supervisor

Mohamad Sahari Nordin
Co-Supervisor

Joharry Ohman
Internal Examiner

Azidah Abu Ziden
External Examiner

Saipi Man
Chairman

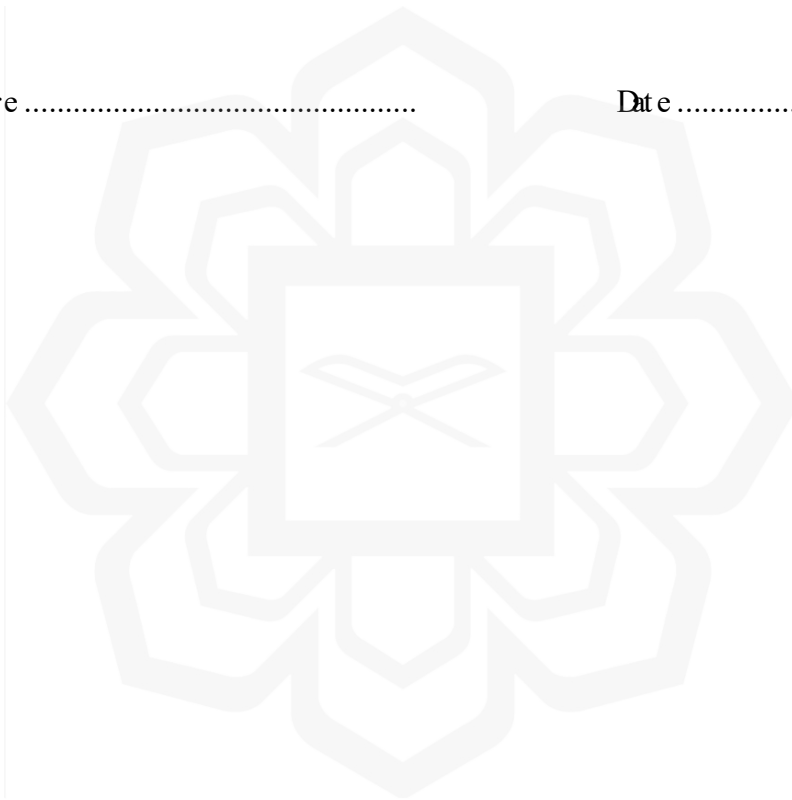
DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Abdul Hamid bin Abdul Rahman

Signature

Date



INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

**DECLARATION OF COPYRIGHT AND AFFIRMATION OF
FAIR USE OF UNPUBLISHED RESEARCH**

**THE EFFECTS OF TECHNOLOGY- ASSISTED
CONTEXTUALIZED INQUIRY INSTRUCTION (TACII) ON
MALAYSIAN FORM TWO STUDENTS' SCIENTIFIC LITERACY**

I declare that the copyright holders of this thesis are jointly owned
by the student and IIUM

Copyright ©2022 Abdul Hamid bin Abdul Rahman and International Islamic University Malaysia
All rights reserved.

No part of this unpublished research may be reproduced, stored in a retrieval system
or transmitted, in any form or by any means, electronic, mechanical, photocopying,
recording or otherwise without prior written permission of the copyright holder
except as provided below

1. Any material contained in or derived from this unpublished research may
only be used by others in their writing with due acknowledgment.
2. IIUM or its library will have the right to make and transmit copies (print
or electronic) for institutional and academic purposes.
3. The IIUM library will have the right to make, store in a retrieved system
and supply copies of this unpublished research if requested by other
universities and research libraries.

By signing this form I acknowledged that I have read and understand the IIUM
Intellectual Property Right and Commercialization policy.

Affirmed by Abdul Hamid bin Abdul Rahman

.....
Signature

.....
Date

This thesis is proudly dedicated to ...

Al marhumah Yuhani s Ismail, Al marhum Abdul Rahman It hni n,

and

Al marhumah Gkgu Norlia Mhammed

*Thank for your endless love, sacrifice,
prayers, support and advice.*

ACKNOWLEDGEMENTS

All praise and thanks be to Allah, the Almighty, for His blessings throughout my research work, and for the strength He granted me to complete the research successfully.

I would like to express my sincere gratitude to my supervisor, Associate Professor Dr. Tunku Badariah Tunku Ahmad, for the invaluable ideas, insights, and assistance on this research. Her patience is unbelievable—when I thought that others would have just given up on me—babysitting a senior student to the maximum study period allowed. I truly appreciate her contribution to this research and I sincerely pray that Allah reward her with all of His blessings.

To my co-supervisor, Professor Dato' Dr. Mhammad Sahari Nordin, who triggered the initial research idea. He taught me the research methodology needed to execute this study and helped in making sense of the data and analysis. A real privilege and a gem to work with. I would also like to thank Prof. Sahari for his humbleness, endless positivity, friendship and great sense of humour.

A special thank you to all my learned teachers and friends at the Kulliyah of Education, IIUM—Assoc. Prof. Dr. Mohd Burhan Ibrahim, Assoc. Prof. Dr. Joharry عثمان, Assoc. Prof. Dr. Ismael Hassanein Al Mhammed, Prof. Dr. Ismail Sheikh Ahmad, Prof. Dr. Anol Madziah Zubairi and Dr. Azmah Ghaus for their support and kind words.

My sincere appreciation to the Chairman of the committee of examiners, Assoc. Prof. Dr. Saupi Man, the committee members and examiners, the Centre for Postgraduate Studies, and the staff of the Postgraduate Office of KOED for all the assistance since time immemorial.

My gratitude goes to Prestariang Bhd. for the trust and opportunity to collaborate with partners such as Twig Education (UK) Ltd and World Class Arena's (UK) expert Dr. Martin Ripley, which made the research possible. My thanks to the EPRD of MOE and the science teachers involved in the study for the passion to improve science teaching and learning and for their support towards the initiative.

A personal thank you three iron ladies—Rahayu Abdul Hamid, Dayang Shuzaidah Abduluddin, and Hj. Nor Azmah Chong—for their contributions towards the completion of this study. Last but not least, a warm appreciation my family—my wife and kids—for understanding my years of physical and mental clutter. May Allah bless all of you with endless happiness!

TABLE OF CONTENTS

Abstract	ii
Abstract in Arabic	iii
Approval Page.	iv
Declaration.	v
Copyright	vi
Dedication	vii
Acknowledgements	viii
List of Tables	xiii
List of Figures.	xv
CHAPTER ONE: BACKGROUND TO THE STUDY	1
1.1 Global Trends in Declining Science Performance	1
1.2 PISA and the Assessment of Students' Scientific Literacy.	4
1.3 Didactic Teaching Disengaged Students and Declining Scientific Literacy	7
1.4 Improving Science Learning and Scientific Literacy Through Inquiry, Contextualized Instruction and Technology	9
1.5 Statement of the Problem.	15
1.6 Research Objectives	20
1.7 Research Questions	22
1.8 Research Hypotheses.	23
1.9 Significance of the Study	23
1.10 Theoretical Underpinnings	25
1.10.1 Constructivism	25
1.10.2 Inquiry.	27
1.10.3 Contextualized Instruction (CI).	29
1.11 Conceptual Model	31
1.12 Delimitations of the Study	32
1.13 Operational Definitions of Terms	34
1.14 Summary of the Chapter.	41
CHAPTER TWO: LITERATURE REVIEW.	43
2.1 Introduction.	43
Part One: Theoretical Review.	43
2.2 Challenges to Effective and Meaningful Science Teaching and Learning.	43
2.3 PISA- Science Learning Standards	47
2.4 Constructivism and Its Pedagogical Principles	51
2.5 Teaching Science through Inquiry	53
2.6 Teaching Science through Contextualization	61
2.7 Contextualizing Science with Movies, Video and Short Films	64
2.8 Using Educational Science Resources	67
2.9 An Islamic Perspective of Science Teaching and Learning	70
2.9.1 Observation of Natural Events and Phenomena as a Means of Learning	71

2.9.2 Use of the Mental Faculty to Reflect, Think Critically and Reason.	75
2.9.3 Asking Questions that Lead to Useful Knowledge	78
2.9.4 Consideration of Proof and Evidence Prior to Making a Conclusion.	80
Part Two: Empirical Review.	82
2.10 Effects of Inquiry on Science Learning Outcomes: A Synthesis	83
2.10.1 Results of Previous Meta-Analyses	83
2.10.2 Synthesis of Previous Studies: A Systematic Review.	85
2.11 Effects of Contextualized Instruction on Science Learning Outcomes	87
2.12 Empirical Support for Technology-Assisted Contextualization of Science Content	94
2.13 Influence of Prior Knowledge on Science Learning	98
2.14 Gender Differences in Science Learning Outcomes	102
2.15 Rural versus Urban Science Performance.	108
2.16 School Type and Differences in Science Learning Outcomes.	111
2.17 Formulation of the Study's Research Hypotheses.	112
2.18 The Study's Conceptual Model	114
2.19 Conclusion	115
CHAPTER THREE: RESEARCH METHODOLOGY.	117
3.1 Introduction.	117
3.2 Research Design.	118
3.3 Research Variables	119
3.4 Population and Sample	120
3.5 Sample Selection.	122
3.6 Subjects of the Study	123
3.7 Random Assignment	124
3.8 The Intervention	127
3.8.1 TACII Lessons: Treatment Groups	127
3.8.2 Traditional Science Lessons: Control Groups	128
3.8.3 Short Films for Contextualization	129
3.9 Materials.	131
3.9.1 Science Content (Lesson Units)	131
3.9.2 Lesson Plans (Teachers' Notes)	134
3.9.3 Student Worksheets	134
3.10 Instruments	136
3.10.1 Pre-test.	136
3.10.2 Post-test	139
3.10.3 Marking Guides	141
3.11 Data Collection.	142
3.11.1 Permission to Conduct Research from EPRD.	142
3.11.2 Access and Entry into the Participating Schools	142
3.11.3 Teacher Training	143
3.11.4 Experimental Procedures	146
3.12 Validity.	147
3.12.1 Content Validity of the Short Films	147
3.12.2 Validity of the Instructional Resources	148

3.12.3	Validity of the Test Items	149
3.13	Reliability	149
3.14	Pilot Study	151
3.14.1	Subjects	151
3.14.2	Procedures	151
3.14.3	Results of Pilot Study	152
3.15	Data Analysis	155
3.15.1	Independent Samples T-Test.	155
3.15.2	Structural Equation Modeling (SEM)	155
3.16	Summary of the Methodology	156
CHAPTER FOUR: RESULTS OF THE STUDY		158
4.1	Introduction.	158
4.2	Characteristics of the Subjects.	158
4.3	Preliminary Analysis	160
4.3.1	Distributions of the Dependent Variables	160
4.3.2	Tests of Homogeneity of Variance	161
4.3.3	Maximizing Information	162
4.4	Main Effects of the TACII Intervention.	163
4.4.1	Ability to Explain Natural Phenomena Scientifically.	163
4.4.2	Ability to Evaluate and Design Scientific Inquiry.	164
4.4.3	Ability to Interpret Data and Evidence Scientifically.	165
4.5	Assessment of a Model for Science Learning and Scientific Literacy	167
4.5.1	Adequacy of a 2-Factor Determinant of Students' Scientific Literacy.	167
4.5.2	TACII, Prior Knowledge and Students' Scientific Literacy Model	169
4.5.3	Moderators of Students' Scientific Literacy.	170
4.5.3.1	Gender Invariant Analysis	170
4.5.3.2	Location-Invariant Analysis	172
4.5.3.3	Invariance Analysis of School Type	174
4.6	Summary of the Key Findings	177
CHAPTER FIVE: DISCUSSION AND CONCLUSION		181
5.1	Introduction.	181
5.2	Summary and Discussion of the Key Findings	182
5.2.1	Research Question 1: Effect of TACII on Students' Ability to Explain Natural Phenomena Scientifically	183
5.2.2	Research Question 2: Effect of TACII on Students' Ability to Evaluate and Design Scientific Inquiry	186
5.2.3	Research Question 3: Effect of TACII on Students' Ability to Interpret Data and Evidence Scientifically	189
5.2.4	Research Question 4: Effect of TACII on Students' Overall Scientific Literacy	191
5.2.5	Research Question 5: Influence of Prior Knowledge on Students' Scientific Literacy	193
5.2.6	Research Question 6: Effects of TACII by Gender	194
5.2.7	Research Question 7: Effects of TACII by School Locality (Rural versus Urban)	195

5.2.8	Research Question & Effects of TACII by School Type (High Performing versus Mainstream)	198
5.3	Recommendations for Systematic Reforms	201
5.3.1	Improving Science Teachers' Understanding of the PISA Science Standards	201
5.3.2	Implementing PISA-Aligned Science Assessment	203
5.3.3	Developing Science Reading Skills in Students	204
5.4	Suggestions for Future Research	205
5.4.1	Test TACII with Primary School Students	205
5.4.2	Compare the Effects of TACII with Subjects from Different Geographical Locations	206
5.5	Conclusion	207
REFERENCES		210
APPENDIX 1: SAMPLE OF THE LESSON PLAN TEACHERS NOTE (BAHASA MELAYU VERSION)		235
APPENDIX 2: SAMPLE OF STUDENTS WORKSHEET (BAHASA MELAYU VERSION)		236
APPENDIX 3: PRE-TEST SAMPLES		238
APPENDIX 4: STRUCTURE OF POST-TEST ITEMS BY CATEGORY, MARKS ALLOCATION AND COGNITIVE DEMAND		242
APPENDIX 5: POST-TEST SAMPLES		243
APPENDIX 6: MARKING GUIDANCE		247
APPENDIX 7: RESEARCH APPROVAL AND AUTHORIZATION BY EPRD		249
APPENDIX 8: APPROVAL LETTERS FROM THE SELANGOR STATE EDUCATION DEPARTMENT		250
APPENDIX 9: APPROVAL LETTERS FROM THE WILAYAH PERSEKUTUAN KUALA LUMPUR STATE EDUCATION DEPARTMENT		251
APPENDIX 10: CONTENT MAPPING AND VALIDATION OF SHORT FILMS		252
APPENDIX 11: POST TEST ITEMS INTER RATER SHEET		254
APPENDIX 11A: AN EXCERPT OF SUMMARY OF EXPERT VALIDATION AGREEMENT FORM TACII POSTTEST-COURSE TEST ITEM		255
APPENDIX 12: TW G BOX SETUP ON SCHOOL LAN		257

LIST OF TABLES

<u>Table No.</u>		<u>Page No.</u>
2.1	Phases of the Learning Cycle, 5E and 7E Inquiry Models (Vick, 2018).	56
2.2	Four Levels of Inquiry	59
2.3	Summary of the Four Inquiry Levels	60
2.4	Effects of Inquiry on Students' Learning Outcomes in Science	90
2.5	Gender Differences in Students' Science Learning Outcomes	105
3.1	The Study's Non-Equivalent Pretest-Posttest Control Group Design	119
3.2	The Study's Main Variables and Operational Definitions	120
3.3	The Study's Population by School Category, Location and Number of Students	121
3.4	List of Participating Schools in Kuala Lumpur and Selangor	123
3.5	Description of the Subjects by Category, Location, Number of Classes and Gender	124
3.6	Random Assignment of Experimental Groups	126
3.7	Contents of the Short Films to be Used in the Study	130
3.8	Lesson Unit Content of the Quasi-Experiment	131
3.9	PISA Competencies and Skills covered in TACII Lesson Units 1 to 5	133
3.10	Structure of the Pre-test by Item Category, Allocation of Marks and Sample Question	137
3.11	Structure of the Post-test by Item Category, Allocation of Marks and Cognitive Demand	140
3.12	Score and Percentage Distributions of Test Items by Science Competency	140
3.13	Content of the Study's Teacher Training	144
3.14	The Experimental Procedures of TACII	146

3.15	Inter-Rater/Grader Correlation Index	150
4.1	Distribution of Subjects and Sample Characteristics Across Analysis	159
4.2	Mean Scores of Students' Ability to Explain Natural Phenomena Scientifically (N = 51)	163
4.3	Mean Scores of Students' Ability to Evaluate and Design Scientific Inquiry (N = 51)	164
4.4	Mean Scores of Students' Ability to Interpret Data and Evidence Scientifically (N = 51)	166
4.5	Invariance Analysis of Gender	171
4.6	Invariance Analysis by Urban-Rural Locality	173
4.7	Invariance Analysis by School Type	175
4.8	The Study's Research Questions and Hypotheses	178
4.9	Results of the Study by Research Hypothesis	180

LIST OF FIGURES

<u>Figure No.</u>	<u>Page No.</u>
1.1 The Learner's Sweet Spot (Gregory & Kaulfelt, 2012)	12
1.2 Typical Steps in the Inquiry Process (YouthLearn, 2016)	27
1.3 Four Levels of Inquiry (Banchi & Bell, 2008)	29
1.4 The Study's Proposed Conceptual Model	32
2.1 PISA 2015 Item Measuring the Competency of Explaining Phenomena Scientifically	49
2.2 A Sample Conventional Test Item Measuring Mere Recall and Recognition of Scientific Phenomena	50
2.3 Compendium of Twigg's STEM Education Short Films	68
2.4 The Model of Prior Knowledge in Influencing Learning (Hailikari et al., 2007)	100
2.5 The Study's Conceptual Model and Hypothesized Relationships	114
3.1 TACII Lesson Structure for the Treatment Group	128
3.2 The Control Group's Traditional Lesson Structure	129
3.3 Sample Student Worksheet	135
3.4 Sample Marking Guide	141
4.1 Path Diagram of the Effects of the TACII Intervention on Students' Scientific Literacy Abilities	168
4.2 Adequacy of the Scientific Literacy Model	169
4.3a Multiple Group Analysis of Gender-Invariant Scientific Literacy Model: Male	172
4.3b Multiple Group Analysis of Gender-Invariant Scientific Literacy Model: Female	172
4.4a Multiple Group Analysis of Location-Invariant Scientific Literacy Model: Urban	174
4.4b Multiple Group Analysis of Location-Invariant Scientific Literacy Model: Rural	174

4.5a	Multiple Group Analysis of School Type-Invariant Scientific Literacy Model: High Performing school	176
4.5b	Multiple Group Analysis of School Type-Invariant Scientific Literacy Model: Mainstream school	177
5.1	Framework for PISA 2015 Scientific Literacy Assessment	203



CHAPTER ONE

BACKGROUND TO THE STUDY

1.1 GLOBAL TRENDS IN DECLINING SCIENCE PERFORMANCE

Regardless of the age we live in, science is a very important subject. Science gives us an understanding of important things in life, like how our voices are carried over phone lines and how fertilizers, when paired with pesticides, can dramatically increase the yield of grains harvested in a single field. This understanding is crucial; it improves our productivity and boosts the quality of our lives. But while it is important, science is also a difficult subject to learn due to its very nature. According to the Understanding of Science website (University of California Museum of Paleontology, 2019),

"Science is different from many other ways of learning because of the way it is done. Science relies on testing ideas with evidence gathered from the natural world" (p. 1).

Doing science is *an act and a process of discovery*; therefore, it cannot and should not be taught through traditional, didactic methods of teaching like rote learning and lecturing. Due to the nature and demands of proper science understanding, teachers struggled to teach the subject and students struggled to learn it.

Against the backdrop of the global Covid-19 pandemic being scientifically literate is hugely important in the effort of combating the pandemic. In Southeast Asia, Malaysia and Singapore were quick to adopt new-age technologies such as contact tracing applications, virtual health consultations and adoption of simple

procedure of self-distancing masks wearing and self-quarantine to maintain and keep tab on its public health and safety (McGuigan, 2020).

The pandemic highlighted the impact of scientific literacy on personal decision-making and action (Schmidt, 2021). A recent research study shows that both perceived scientific literacy and perceived understanding of COVID-19 vaccines were positively associated with attitudes toward COVID-19 vaccinations and preventive behaviors (Motoki, Saito & Takano, 2021). In relation to this, it indicates the paramount importance of science in today's living and to students' academic success. Good understanding of science and being scientifically literate are highly emphasized and hugely crucial towards their future well-being or even survival.

Despite the irrefutable importance of science, global trends over the past few decades showed a consistent decline in science performance and literacy among secondary school students in many countries across the world. Even in advanced and traditionally high performing countries, like Australia and Finland, students' achievements in science were below national expectations. In Australia, for example, students' science performance "continues to slide due to ineffective, traditional teaching practices and an outdated curriculum which led to students' becoming disengaged with the subject" (Tytler, 2016). The latest Trends in International Mathematics and Science Study (TIMSS) results showed that in both Mathematics and Science, Australia has fallen behind countries traditionally regarded as their inferiors. Australia has far fewer students performing at high reasoning levels and far more students not reaching minimum scientific literacy standards than the top performing countries. The situation in Finland was likewise. In Europe, Finland was outperformed by Liechtenstein, Switzerland, the Netherlands and Estonia in PISA 2012, countries typically regarded as having lower quality education. The Finnish

Ministry of Education and Culture reported that the scientific literacy of Finnish school students continued to deteriorate markedly in PISA 2013. In an earlier 2006 survey, Finland's average scientific literacy dropped drastically by 18 points. In the United States, there were concerns about the mediocre performance of American school children on international science tests, which later contributed to the slowing down of US production of scientific research and articles. As a result, the share of world science contributed by the United States has dwindled.

Declining standards in science performance and literacy were also observed in third world countries. In Tanzania, there was a heightened emphasis on the teaching of science in the early years as a foundation for later education. The call for science to be taught in innovative ways very early on resulted from concerns over the declining standards of science achievement among Tanzanian children since the country gained its independence (King'Aru, 2014). Science subjects, at the ordinary level in secondary schools in Tanzania, are among the high-profile subjects, yet the sciences are not compulsory for all ordinary level students except for Biology, leading to the low achievement in general science subjects.

This has initiated innumerable efforts to improve students' performance in Science through an improved curriculum and innovative pedagogy. Likewise, in Jamaica, the situation is not any better. Jamaican students have declined in their performance in science subjects in the 2017 Caribbean Secondary Education Certificate or CSEC (MDEY, 2017). A report from the World Economic Forum Executive Opinion Survey (2018) placed Jamaica at position 73 out of a total of 137 countries in terms of the quality of science and mathematics education, as one of its indicators in terms of Jamaica's Global Competitiveness Index (GCI). Closer to home, PISA 2012 results showed that Indonesia, Malaysia, and Thailand all underperformed

and were positioned in the bottom third out of 65 participating countries for mathematics, science and reading literacy (Thien *et al.*, 2015).

1.2 PISA AND THE ASSESSMENT OF STUDENTS' SCIENTIFIC LITERACY

PISA stands for the Program for International Student Assessment. Organized by the Organization for Economic Co-Operation and Development (OECD) since the year 2000, it is a triennial international survey that aims to evaluate education systems worldwide by testing 9th graders' (15-year olds') performance in mathematics, science, and reading. The first PISA survey was launched in 2000, followed by the second one in 2003, and later in 2006, 2009, 2012, and 2015. The most recent one was conducted in 2018, the results of was released in December 2019 with reading as the main focus. In each cycle, PISA assesses three key domains of knowledge and skills, namely Reading, Mathematics and Science. PISA helps to monitor trends in students' acquisition of knowledge and skills across countries and economies.

Its results are sought after by participating nations as they offer insights for the development of educational policies and effective classroom practices. More specifically, PISA provides reliable empirical evidence to identify the strengths and weaknesses of current education systems and presents examples of good practices for standards setting and benchmarking (Prenzel *et al.*, 2013).

PISA does not really test science 'content' or students' mastery of it the way TIMSS does. Rather, it challenges students' "**ability to apply**" their science knowledge and reason about scientific phenomena. As Bybee, McGrae and Laurie (2009) put it:

“In PISA 2006 Science, the essential *qualities of scientific literacy* include the ability to apply scientific understandings to life situations involving science. The central point of the PISA 2006 Science assessment can be summarized as follows: the assessment focused on *scientific competencies* that clarify what 15-year-old students should know and be able to do within appropriate personal, social, and global contexts. (p 866)

Therefore, the *testing of science mastery in PISA* means assessing students' *scientific literacy*. Typically, across the years in PISA, Asian countries tend to show better performances than their western counterparts. In PISA 2012 and 2015 notably, Asian countries (i.e., Singapore, Hong Kong, Japan, Macau, Taiwan, China, South Korea and Taipei) were among the top highest performing nations. Scholars and researchers attribute Asian students' high performance in these literacy areas to the traditional Chinese or oriental ways of teaching and learning (Li, 2004; Schneider & Lee, 1990). Over the years, Singapore has steadily maintained its position as a top performer. Vietnam has overcome the odds and evolved from a war-torn nation into a high performer in reading, mathematics and scientific literacy. In PISA 2012, Vietnam was positioned 17th out of 65 participating countries, although it slipped slightly to number 21 in PISA 2015, sharing the same spot as the United States. In contrast, neighbouring Indonesia, Malaysia, and Thailand ranked in the bottom third in PISA 2012.

The mean scores of Mathematics, Science and Reading for Indonesia, Malaysia and Thailand were relatively lower than the corresponding OECD average in PISA 2012. The science score for Malaysia was only 420 points, which was 81 points below the OECD average (501) (Lee & Nurzatulshima, 2014). This was equivalent to one year of schooling which means that in PISA 2012, Malaysian 15-year-olds were

one year behind their counterparts in some countries in terms of scientific literacy and high-order science competencies.

Malaysia now faces the challenge to improve its students' scientific literacy following their dismal performance in PISA 2012 and a disqualification in 2015 due to a biased sample of schools (Hwa, 2017). In 2012, Malaysia was ranked 52nd among 65 participating countries. It also scored well below the international averages in Mathematics and Science in TIMSS 2011. Reportedly, between TIMSS 1999 and 2011, Malaysia's Mathematics and Science scores dropped drastically more than any other country (Hwa, 2017), causing a great cause of concern for many, especially the Ministry of Education, so much so that "rising from the bottom third to the top-third of countries in international assessments like PISA and TIMSS" was made a key target in the Ministry of Education Malaysia (MOE, 2013, p. 7). Using Malaysia's discouraging performances in PISA 2009+ and TIMSS as part of the arguments for educational change, the Malaysia Education Blueprint 2015-2025 explains at length why this change is necessary:

"... international assessments suggest that Malaysian student performance is declining in absolute terms... Over the past two decades, international student assessments, such as the Program for International Student Assessment (PISA) and the Trends in International Mathematics and Science Study (TIMSS), have emerged as a means of directly comparing the quality of educational outcomes across different systems.

These assess a variety of cognitive skills such as application and reasoning. When Malaysia first participated in TIMSS in 1999, its average student score was higher than the international average in both Mathematics and Science. By 2011, the last published cycle of results, the system's performance had slipped to below the international average in both Mathematics and Science with a commensurate drop in ranking. Critically, 35% and 38% of Malaysia's students failed to meet the minimum proficiency levels in Mathematics and Science in 2011, a two to fourfold up from 7% and 13% respectively in 1999. These students

were identified as possessing only limited mastery of basic mathematical and scientific concepts.

The results from PISA 2009+ (the first time Malaysia participated in this assessment) were also discouraging, with Malaysia ranking in the bottom third of 74 participating countries, below the international and OECD average (Exhibit 3). Almost 60% of the 15-year-old Malaysian students who participated in PISA failed to meet the minimum proficiency level in Mathematics, while 44% and 43% did not meet the minimum proficiency levels in Reading and Science respectively. A difference of 38 points on the PISA scale is equivalent to one year of schooling (a comparison of scores shows that 15-year-olds in Singapore, South Korea, Hong Kong and Shanghai are performing as though they have had three or more years of schooling than 15-year-olds in Malaysia) (p E-4).

In TIMSS 2011, Malaysian students' performance fell below the international average with 38% having failed to meet the minimum proficiency levels in science, while in PISA 2009, 43% of the students who participated did not demonstrate the higher order thinking skills, like application and reasoning, expected of 15-year-olds.

1.3 DIDACTIC TEACHING, DISENGAGED STUDENTS AND DECLINING SCIENTIFIC LITERACY

How did this decline in performance and competencies come about? Researchers have long identified a major cause to be the problem of “disengaged students” (Howard, 2017). Students become disengaged in deeper learning largely due to the way science is taught in the classroom, that is, in a very abstract and didactic way (Lee & Nurzatulshima, 2014). Often times, students were not able to see the meaning of the science concepts taught in this way. Such teaching gave little opportunity for active participation, self-expression, and critique of ideas presented in class. In addition to didactic teaching, the lack of authentic contexts, resources or materials for science learning also contributed to non-learning and student disengagement (Cakmakci, 2017; Hbstoveckey & Stubna, 2015; Norafizah, 2018). Subsequently, it appears that

the first aspect to examine about the issue at hand is how teachers teach. In Malaysia, the obsession with centralized national examinations and standardized testing has produced much negative washback. It has driven teachers to teach to the test in order to help students do well on tests and examinations (Hampton-Thompson & Bennet, 2011). Hence teachers' choice of teaching methods grows out of the need to equip students with the skills to survive in an examination-oriented system rather than to develop deep content understanding and competencies. The pressure to produce students that do well in examinations has diminished teachers' ability to employ meaningful instructional methods. They, therefore, resort to teaching-to-the-test methods like rote learning, drill and practice, spoon-feeding, and question spotting. These methods and strategies are known to be incapable of developing higher order learning abilities that involve knowledge application and reasoning, the very skills tested in PISA and TIMSS. Documents of OECD analyses (OECD, 2019) have indicated how Malaysian students lacked these skills and competencies in not only Science, but also Mathematics and Reading with scores that are still way below OECD average.

The development of a holistic, coordinated and integrated intervention program is, therefore, crucial to help address these issues of didactic science teaching and to improve science performance and indirectly its science literacy in international benchmark tests among Malaysian students. Such a program would help students to discover concepts through inquiry, an instructional approach proven effective in promoting higher-order abilities in students (Annaf, Amah, Baah & Assem, 2018; National Science Education Standards, 2003; Sever & Guven, 2014; Skas, 2017). The program should then augment the learning further with *contextualized instruction* so students can see how the concepts just discovered relate to and operate in the natural