EFFECTIVENESS OF USING AN OPEN-SOURCE DIGITAL TECHNOLOGY FOR PRACTICAL WORK IN SENIOR SECONDARY PHYSICS CURRICULUM

by

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Statement of Originality

I, WONG, Shek Nin Rocco, hereby declare that I am the sole author of the thesis and the material presented in this thesis is my original work except those indicated in the acknowledgement. I further declare that I have followed the University's policies and regulations on Academic Honesty, Copyright and Plagiarism in writing the thesis and no material in this thesis has been submitted for a degree in this or other universities.

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Abstract

Effectiveness of using an open-source digital technology for practical work in senior secondary physics curriculum

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Abstract

The aim of this research study is to investigate and evaluate the effectiveness of innovative use of an open-source digital technology, Arduino, which is an information and communications technology (ICT) tool for practical work in physics in the senior secondary curriculum. The study also seeks to ascertain factors affecting the effective use of the technology in students' learning of physics with a view to informing possible extensive use of the Arduino technology in senior secondary science education and its application to Science, Technology, Engineering, and Mathematics (STEM) education. The importance of harnessing ICT in education is well recognized in the education arena. Educators have viewed ICT as an enabling tool for higher levels of analysis to take place in science teaching and learning. However, the use of technology does not guarantee meaningful and effective learning. What is crucial is the transformative, appropriate use of ICT to enhance students' learning. In this regard, proper integration of ICT into the curriculum, or even across disciplines in the context of STEM education, for meaningful study is an area of concern. While ICT integration has been advocated for many years in the senior secondary physics curriculum in Hong Kong, there remains a gap in its holistic integration into the curriculum. This study demonstrates successful development of seven Arduino-based experiments and an entire set of courseware that covers a wide range of experiments in the topic of “mechanics” in the senior secondary physics curriculum. Design-based research (DBR) methodology is adopted in the development, which is characterized by rounds of systematic iteration, feedback gathering, and modification. The final outputs are encouraging for performing the series of experiments in “mechanics”. The study bridges the gap between theoretical framework and practical application in an authentic setting, and it informs of the suitability of DBR in developing ICT tools for integration into the curriculum. The Arduino-based experiments were introduced to F.4 and some F.6 students of the author’s school. Surveys and interviews from the students, their physics teachers, the laboratory technician, and the technical assistant were conducted. Highly positive results were revealed. The experiments were then further tried out by a group of local students and teachers who joined the STEM Olympiad 2016, organized by the Education University of Hong Kong and the Singaporean Master Teachers, who participated in the Outstanding-Educator-in-Residence (OEIR) Programme held in July 2016 in Singapore. Views gathered shed light on the concern and factors affecting the effective use of the Arduino technology in physics learning. It was revealed that, with the right technology, suitable teaching strategy and scaffolding, enhanced teacher efficacy, sufficient technical support, allocation of lesson time, and school resources, ICT can appropriately be integrated into the curriculum to enhance the effectiveness of students’ learning of physics.

Keywords: ICT, Design-based Research (DBR), Open-source, Arduino-based physics Experiments, STEM

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List of Abbreviations

ACOLA	The Australian Council of Learned Academies
ALLEA	ALL European Academies
AST	The Academy of Singapore Teachers
CATEX	Abbreviation for the categories in coding the views of participants in the Study, which stands for “Challenges”, “Aurdino Technology”, “Teaching and Learning”, “Conduct of the Experiments” and “Comparisons with the Traditional Experiments”
CDC	Curriculum Development Council
CEES	Centre for Education in Environmental Sustainability
CPDD	Curriculum Planning Development Division (of Singapore)
DAT	Design and Technology
DBR	Design-based Research
EdB	Education Bureau
EdUHK	The Education University of Hong Kong
EMB	Education and Manpower Bureau
FCI	Force Concept Inventory
HKDSE	Hong Kong Diploma of Secondary Education
HKEAA	The Hong Kong Examinations and Assessment Authority
HKIEd	Hong Kong Institute of Education
HKSAR	Hong Kong Special Administrative Region
HOD	Head of Department
ICT	Information and Communication Technology
IDE	Integrated Development Environment
IEA	Evaluation of Educational Achievement
IL	Information Literacy
IS	Integrated Science
IT	Information Technology
MIT	Department of Mathematics and Information Technology
MOE	Ministry of Education
NCREL	North Regional Education Laboratory
NIE	National Institute of Education

NSS	New Senior Secondary (Curriculum)
OECD	Organization for Economic Co-operation and Development
OEIR	Outstanding-Educator-in-Residence (Programme)
OTA	The office of Technology Assessment
PBL	Problem-based Learning
PCK	Pedagogical Content Knowledge
RCL	Remotely Controlled Laboratory
SBA	School-based Assessment
SEN	Special Education Needs
SES	(Department of) Science and Environmental Studies
SITES	Second International Information Technology in Education Study
STEM	Science, Technology, Engineering and Mathematics
STS	Science, Technology and Society
TEL	Technology-enhanced Learning
TIPS II	Integrated Process Skill Test II
UNESCO	United Nations Educational, Scientific and Cultural Organization

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CHAPTER 1

INTRODUCTION

Since two to three decades ago, the reform in science education has been calling for teachers and educators to integrate technology into science and mathematics curriculum and instruction (Pedersen & Yerrick, 2000). Educators highly appraise the potential of enhanced learning with information and communication technologies (ICT; Salomon, Perkins, & Globerson, 1991; Bork, 1992; Collins, Hawkins, & Frederiksen 1993/1994; Lockhard, Abrams, & Many, 1994; Jenkins, 2000). Ofsted (2004) asserted that ICT in science teaching and learning enabled 'a higher level of analysis to take place than would otherwise be the case'. With the advent of technology at affordable prices, open-source digital technology provides opportunities for the development of myriads of innovative ICT tools for science education. In recent years, the term 'STEM', which stands for science, technology, engineering, and mathematics, aroused serious attention in the science educational field. Learning in the STEM fields was linked to improved critical reasoning and logical thinking (Sadler & Zeidler, 2004), which are required for problem solving and sound decision making. In the United States, the Obama Administration articulated a clear priority for STEM education (U.S. Department of Education, 2015). The development of STEM education gathered momentum not only in the United States but globally. The Hong Kong government first set forth the direction to bring STEM education more explicitly into existing science, technology, and mathematics curricula and learning activities in the 2015 Policy Address (Hong Kong Special Administrative Government, 2015), which was further supported in the 2016 and 2017 Policy Addresses. This research study examines the effectiveness of innovative use of open-source digital technology in science education and looks into the factors that affect its effective use.

1.1 Context of This Study

1.1.1 Teaching and Learning of Science under the New Senior Secondary Curriculum in Hong Kong

The current study looks into the effectiveness of innovative use of ICT in the study of physics, which is an elective subject under the New Senior Secondary (NSS) academic structure in Hong Kong. The NSS academic structure was the result of education reform launched in Hong Kong beginning in 2007. The Education Commission, set up in 1984 to advise the government on the education system (Education Commission, 1984), formulated a blueprint for the development of education in the 21st century that was student focused and that called for reform in the education system. Premised on the direction set forth by the Education Commission, the Hong Kong government in 2005 announced the introduction of an NSS academic structure, offering three years instead of a ‘2+2’–year programme of senior secondary education. The new structure was rolled out progressively from the 2009/10 school year onwards, starting from Secondary 4 students. Under this structure, students are required to take four core subjects (Chinese, English, mathematics, and liberal studies) in their senior secondary study, and they are allowed to take two or three elective subjects from a range of 24 subjects (physics being one of these elective subjects). At the time that the research study started – that is, in the 2015/16 school year – the NSS curriculum had been fully implemented for five years.

1.1.2 Information Technology in Education Strategy as Advocated by the Hong Kong Government

The 21st century marks an era where knowledge construction and information exchange are executed at a global scale in an unprecedentedly swift manner. To stay competitive and to foster lifelong learning capabilities, there is a need to harness ICT in education. This has been well recognized in developed economies, and most have implemented initiatives on employing ICT in education.

In Hong Kong, the government has issued four directional documents on information technology (IT; interchangeable with the term ICT, as defined in the 'Final Report on Phase (II) Study on Evaluating the Effectiveness of the "Empowering Learning and Teaching with Information Technology" Strategy (2004/2007)' commissioned by the Education and Manpower Bureau [EMB; 2007]). These four documents on IT in education, which spanned the period from 1998 to 2015 (EMB 1998, 2004; Education Bureau (EDB) 2008, 2014), guide the use of IT to facilitate learning and teaching in the 21st century. The Fourth Strategy on Information Technology in Education, announced in late 2015, aims to strengthen students' self-directed learning, problem solving, collaboration, and computational thinking competency and to enhance their creativity and innovation, as well as to nurture the students to become ethical users of IT for pursuing lifelong learning and whole-person development through leveraging technology and the capacity of IT (EDB, 2015). Given the persistent efforts of the government in support of IT in education, this research study is relevant in integrating the use of ICT in the physics curriculum to enhance the effectiveness of the learning and teaching of the subject.

1.1.3 Implementation of Science, Technology, Engineering, and Mathematics Education in Hong Kong

STEM education has been at the forefront of current discussions in STEM education (Aydeniz & Hodge, 2015). In Hong Kong, the government formally placed this topic on the public agenda in the 2015 Policy Address, which announced that

> The EDB (Education Bureau) will renew and enrich the curricula and learning activities of Science, Technology and Mathematics, and enhance

> the training of teachers, thereby allowing primary and secondary students to fully unleash their potential in innovation.

The government further pledged to step up efforts to promote STEM in the 2016 Policy Address. In November 2015, the Curriculum Development Council (CDC) issued the consultation document on STEM education entitled *Promotion of STEM Education – Unleashing Potential in Innovation* to solicit views and comments from various stakeholders in the education and other sectors of the community on the recommendation and proposed strategies for the promotion of STEM education among schools in Hong Kong (CDC, 2015). STEM education was promoted in primary and secondary schools in a progressive manner in the 2016/17 school year. In December 2016, the EDB issued a further report in relation to the consultation documents with the aim to chart the way forward in promoting STEM education (EDB, 2016). In December 2017, the Innovation and Technology Bureau issued the 'Hong Kong Smart City Blueprint', which further confirmed the determination of the government to nurture young talents by organizing intensive training programmes on STEM for curriculum leaders to enhance their capacity in holistic planning and implementation of the updated curricula and STEM-related activities. The goal is to have more students selecting STEM for their senior secondary/postsecondary education and professional careers, have a local supply of data scientists and other technology practitioners in need, and have more successful entrepreneurs in their new ventures (Innovation and Technology Bureau, 2017). It is in this context that the research study is conducted.

1.2 Background of This Study

1.2.1 Application of Information and Communication Technology (ICT) in Science Education

For the past three decades, developed countries have placed great emphasis on the application of ICT in education. Since the mid-1980s, Australian schools have expended considerable resources to set up computer and associated technologies, and school principals and teachers have been equipped with notebook computers. The aim was to encourage principals and teachers to integrate the use of ICT into the classroom and administrative practices of the schools. American schools have similarly provided nearly ubiquitous access to computers and the Internet, and computer use has become widespread. Means, Penuel, and Padilla (2001) have criticized leading-edge ICT for pushing down education by expanding where and when learning can take place. This raises questions about best teaching practices. Contemporary ICT has become so closely connected to daily life that the innovative application of the technology in the learning and teaching of science has become an area of scholastic research. In 2001, a project was conducted in 28 countries under the coordination of the International Association for the Evaluation of Educational Achievement (IEA), called the Second International Information Technology in Education Study (SITES; IEA, 2002). Its Module 2 studied innovative pedagogical practices that use ICT. In an in-depth case study of 11 countries across five continents participating in SITES Module 2, Anderson (2002) concluded that the innovative practices under investigation can be implemented in a much larger segment of schools than those with ‘innovative technology’, and leading-edge innovations do not necessarily lead to widespread adoptions, especially with such a rapidly evolving resource as ICT. He reiterated the following quote from a case study in England: ‘The clear message …. is not the importance of ICTs in their own right, but the benefits to be gained when confident teachers are willing to explore new opportunities for changing their classroom practices by using ICT.’ (p.386)

1.2.2 Trend of Integrating ICT in Authentic Science Education

The Office of Technology Assessment (OTA; 1995) of the United States Congress has cautioned that educational technologies used in classroom settings, such as computers, are not self-implementing and that successful implementation hinges on teachers' decisions made in classrooms. There saw a need for teachers to use the technology in learning and teaching in the classroom. However, a survey study in the United States carried out by Pedersen and Yerrick (2000) revealed that science educators lacked support in the area of education about the use of technologies, though the students of science teacher education faculty indicated a desire to know more about new technologies. The researchers indicated that a gap existed in teacher education programmes to impart beliefs and corresponding practices regarding technological integration effectively. In another study, by Ng and Gunstone (2003), among Australian teachers, it was similarly revealed that most teachers were positive about the potential of the introduction of technologies in the classroom, but the use was infrequent. The study showed that the state of computer-based technologies in science teaching at secondary schools in Australia was patchy across and within schools, with obstacles ranging from access to resources, time constraints, and IT literacy to class management issues. Nevertheless, successful ICT-supported practices were found in other places (Hennessy et al., 2007). Such success relied on teachers exploiting dynamic visual presentations through using the technology as a powerful, manipulatable object of joint reference – to stimulate discussion and hypothesis generation as they described and reformulated the shared experience for students (Mercer, 1995). Teachers integrated technology carefully with other practical activities so as to support sequential knowledge building, consolidation, and application (Hennessy et al., 2007). Educators continued to explore the integration of ICT into the learning and teaching of science beyond the confines of time and space, enabling learning to be more interactive, self-directed, and internalized.

1.2.3 The Significance and Implication of STEM Education

The significance of STEM education can be appreciated from the extent of the discussion of the subject worldwide, including the fact that politicians, national education committees, and industry have linked the quality of STEM education in K–16 to continued scientific leadership and economic progress across many developing and developed countries (ALLEA Working Group Science Education, 2012; Rocard et al., 2007; Dufaux, 2012; Fortus, Mualem, & Nahum, 2009; Jones, 2013; National Research Council, 2012; Norwegian Ministry of Education and Research, 2012; Organisation for Economic Co-operation and Development [OECD], 2007; Sjoberg, 2002). The European Commission has been focused on STEM policy since the 1990s, and the Commission, when expressing concern about declines in participation in STEM fields, indicated the strategic importance of innovation and technology in science and technology for the maintenance of economic growth (European Commission, 2008, p. 16). The United Nations Educational, Scientific, and Cultural Organization (UNESCO; 2010, p. 27) affirmed that excellence in STEM played an important role in promoting long-term economic growth and in building a base for a science-knowledge society. Given the focus on STEM education across nations, the Australian Council of Learned Academics (ACOLA) carried out a project on international comparison of STEM education so as to draw out possible lessons and ideas for STEM policy and strategy in Australia (2013). In 2017, the Hong Kong Government issued the Hong Kong Smart City Blueprint, which posited the importance of STEM education for youngsters as related to the vision of embracing innovation and technology to build a world-famed ‘Smart Hong Kong’ characterized by a strong economy and high quality of living.

While all the above attempted to relate the importance of STEM with an overall economic agenda, some scholars have provided a more global outlook on STEM to promote national cooperation for improved results. Johnson (2013) advocated that solving the 21st-century issues of sustainability would require strong STEM education of students in all nations and international cooperation. Marrero, Gunning, and Germain-Williams (2014) advocated the thread of examining how STEM education may be developed to be accessible and appropriate for all learners worldwide. Viewed from this perspective, STEM is something not only for the elite but for all in the community to make sound decisions, grounded on critical reasoning and logical thinking, for oneself, for one's own family, and for the community.

1.2.4 Use of Innovative Open-Source Digital Technology for Science Education

With STEM education bearing such significance, efforts in promoting STEM education globally nevertheless lacked clear focus until recently, around 2005 in the United States, around 2014 in Singapore, and only around 2016 in Hong Kong. Insofar as the Hong Kong context is concerned, STEM education is still in an infancy stage. There is a lack of proven exemplary STEM courseware or projects that could be shared among and applied across schools to cater to the learning needs of local students aptly. Most secondary schools implemented STEM programmes only at the junior secondary level, so as not to interrupt the NSS curriculum, and the programmes were often isolated class activities. Science teachers were baffled as to how a STEM programme could effectively be integrated into the NSS curriculum, first because most teachers were only specialized in their own fields, without extensive knowledge of other fields in STEM to achieve integration, and second because teachers simply did not have the time and resources to develop integrated STEM programmes for students at the NSS level. A gap therefore exists between the high-level goal as set by the government and the actual implementation in schools.

To bridge this gap, the EDB of the HKSAR Government has provided financial resources to primary schools and secondary schools since 2016/17 and 2017/18, respectively, to acquire hardware or services to implement STEM programmes. However, given the tight teaching schedule, schools that lacked profound knowledge or deep interest in STEM were inclined to acquire packages of STEM learning activities that might not suit the interests and needs of the students and that might not aptly fit into the curriculum, especially at the NSS level. The purpose of promoting STEM education holistically was thus defeated. Hence, there remains a need to develop STEM programmes that can genuinely be practiced across disciplines and integrated into the curriculum.

Open-source digital technology offers an economical and accessible means for the development of education courseware for interactive and self-directed learning and teaching of science, as copyright issues are not a concern and the software can be modified to fit individual use. Arduino is an open-source digital technology that has high potential to be used in science education (Arduino, 2014). Its easy-to-operate hardware and wide range of free Arduino software or libraries offer great opportunity for wide applicability in senior secondary science education. The Arduino boards may be interfaced to different sensors for carrying out investigative studies – such as force sensors, commonly used in physics; heartbeat sensors in biology; or pH sensors in chemistry. The proposed research focuses on the innovative use of Arduino as an exemplary platform for the effective learning of physics integrated with digital technology at the senior secondary level.

1.3 Aims and Research Questions

The main aim of this research study is to investigate and evaluate the effectiveness of innovative use of an open-source digital technology for practical work in science education to achieve technology-enhanced learning (TEL) and strengthen the self-directed learning of physics in the senior secondary curriculum. The knowledge, skills, and attitudes acquired by students through the use of the open-source digital technology in physics, as well as the implementation problems, will be critically evaluated with a view to ascertaining the feasibility and the effectiveness of the innovation to facilitate students' science learning.

Specifically, the two research questions that guided this study are:

1. How can the open-source hardware and software be appropriately employed to develop courseware for the effective learning and teaching of physics at the senior secondary level?
2. What are the crucial factors underlying the effective use of the open-source digital technology in students' learning of physics?

Special focus will be given to what innovative or non-traditional experiments can be developed by using the Arduino technology for physics, both in the classroom setting and out of school, and the necessary conditions required for the use of Arduino to enhance the learning and teaching of physics, as well as its further extension into other realms of STEM education.

1.4 Methods of This Study

This study was conducted under a design-based research framework that provided a systematic but flexible methodology to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings (Wang & Hannafin, 2005, p. 6). The first part of the study involved the development of open-source hardware and software on the Arduino platform for use in physics experiments under the New Senior Secondary Curriculum. Prototypes were tried out in the pilot study among Secondary 6 students of the 2014/15 cohort who had already experienced performing the experiments with conventional methods. Feedback from these students was then fed into the system for further refinement of the initial courseware. A total of seven physics experiments were developed with the use of Arduino. These were tested by teachers and a technical assistant, and their views on how to improve the courseware were taken on board. The Arduino-based setup and the course materials were repeatedly fine-tuned before they were rolled out for students' use. Throughout the process, the researchers and the practitioners were actively engaged in social discourse to enhance the design and implementation of the programme.

The second part of the study, the Main Study, focused on analysing the feedback from students and teachers on the introduction of this innovative tool in the learning and teaching of physics.

After conducting the entire series of experiments, teachers and students participating in the Main Study were requested to complete a survey form with some open-ended questions. This was supplemented by interviews with selected teachers and all students involved in the study to probe deeply into their perception of this ICT tool. Qualitative analysis of the feedback gathered from teachers and students was carried out, which offered insight on how and under what circumstances the Arduino-based setup could best be used in the learning and teaching of physics.

Beyond school, the Arduino-based experiments were also introduced to senior secondary students and teachers who joined the STEM Olympiad, and their views were gathered by way of survey forms. The experiments were introduced to and personally experienced by Singaporean teachers who participated in the Workshop on Innovative Science Education in the Outstanding-Educator-in-Residence (OEIR) Programme 2016 in Singapore. Their feedback was also collected through a survey.

The data gathered formed the basis for evaluating the effect of use of Arduino on students' science learning so as to answer the two research questions raised in this study.

1.5 Significance of This Study

Integration of ICT into learning and teaching was advocated as early as the late 1990s in Hong Kong, but the adoption of TEL in the senior secondary science curriculum was limited – in particular, the use of open-source hardware and software. Integration of open-source technology into the curriculum should not be viewed simply as the application of technological tools that support factual learning and memorization, but it should be understood as a learning technology that gives students tools to engage in meaningful science learning. Songer (2007) differentiated digital tools, such as scientific data on the web, from cognitive tools, which are tailored specifically to meet the needs and learning goals of science learners. In this study, the author aims to bridge the gap in applying open-source digital technology in the NSS physics curriculum and to ascertain whether this digital technology can enhance students' learning.

A design-based research (DBR) methodology is adopted in this study to develop the open-source digital technology for integration into the physics curriculum. Open-source digital technology, as a tool for TEL, offers a multitude of opportunities for performing not only guided science experiments but also student-centred, self-designed, innovative, and interactive experiments that allow meaningful collection of data for analysis. The TEL environment can support the gradual development of higher-order thinking, such as critical thinking and problem-solving skills (Kyza, Erduran, & Tiberghien, 2009), which are 21st-century learning skills. This research study, therefore, bears significance in that if design-based research methodology proves successful in integrating open-source digital technology into the physics curriculum, it opens up new grounds for adopting this methodology in integrating open-source digital technology into other science curricula. The investigative element that is embedded in open-source digital technology provides students considerable space to hypothesize, to perform real-time experiments, and to verify their convictions. Ready access to the platform by all also helps to encourage collaborative learning, which is considered a key element in science education nowadays. This research study also attempts to gather findings to confirm and to evaluate whether the open-source digital technology – or, to be specific, the Arduino technology – can contribute towards the teaching and learning of physics among senior secondary students. Positive results of the research would reinforce the effectiveness of this learning technology as a cognitive tool that is conducive to inquiry learning. The research unveils considerable opportunities for the multi-pronged development of open-source digital technology for enhancing the learning of a whole range of science subjects, including integrated science, physics, chemistry, and biology. The findings thus bear great significance, and the study's success can offer a good base for others to continue research into the use of open-source hardware and software for students' learning.

Moreover, the Hong Kong Government has placed great emphasis on the promotion of STEM education in recent years. A major challenge in STEM education is the integration of each STEM discipline to provide students with cross-disciplinary experiences that will enhance academic achievement and thus create a pipeline for future scientists and engineers (Asghar, Ellington, Rice, Johnson, & Prime, 2012). Open-source hardware and software provide an enabling ground for performing integrated STEM learning activities. The research can shed light on future directions in the integration of ICT into school plans, curriculum planning, and the teaching and learning process in formal and informal contexts and in fostering cross-fertilization in STEM education. Finally, the research also informs the important factors that contribute to the effective use of open-source digital technology for the learning and teaching of physics. Policymakers and school leaders who have the mission to promote the use of ICT in science education and STEM education can draw reference from these research findings when planning their schools' science curriculum.

1.6 Outline of This Thesis

The study aims to investigate and evaluate the effectiveness of use of an open-source digital technology for practical work in physics to achieve diversified teaching and learning as well as to motivate the self-directed learning of science among senior secondary students in Hong Kong under the NSS curriculum. The research included two arms: first, the development of an array of innovative Arduino-based experiments of relevance for integration into the physics curriculum at the senior secondary level; second, the implementation of the Arduino-based physics experiments in classrooms or a teachers' professional development workshop to gauge whether this innovative ICT tool was conducive to enhancing the learning and teaching of physics among students, and the contributing factors leading to effective implementation.

The thesis is organized in eight chapters. Chapter 1 provides an overview of the study. Chapter 2 reviews the related literature. Chapter 3 describes the methodology in the system design and development. Chapter 4 focuses on the adoption of the DBR approach in developing and modifying the experimental setups through successive iterations to maximize the potential use of the Arduino-based platform in physics experiments. Chapter 5 provides a summary of the data collected and the coding system developed to facilitate discussions. Chapter 6 presents the results and analysis in the context of school-based implementation, and Chapter 7 presents the results and analysis of data gathered beyond the author's school, as well as a comparison of the results with those collected in the author's school. Finally, Chapter 8 draws the conclusion and discusses implications for further researches.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This research was grounded on the conviction that the use of ICT could enhance the effectiveness of the teaching and learning of science. The focus of the study was on the use of open-source digital technology, an ICT tool, in the learning and teaching of physics under the NSS curriculum, which was introduced beginning in 2009 in Hong Kong. The conceptual framework of the application of ICT in science education, and in particular the NSS science education curriculum in Hong Kong, was examined. The extent and effectiveness of ICT in enhancing the learning and teaching of science was looked into. This was then followed by a review of the importance of authentic science education for students, which supported the argument for the use of ICT in science education.

With STEM education recently drawing considerable attention in the education arena, the correlation and relevance of ICT in STEM education was discussed. As this research study examined student-centred learning in the TEL environment, the framework for assessing the effectiveness of TEL was covered, as well as the use of design-based research as a methodology for the research and design of a TEL environment, which was the methodology deployed in the study. The last part of the literature review covered the synergy that could be achieved through learning science on an open-source digital technology platform and the implications as well as the potentials in using open-source digital technology in science and STEM education.

2.2 Application of ICT in Science Education

The 21st century marks an era where knowledge construction and information exchange are executed at a global scale in an unprecedentedly swift manner. Technological advancements and the proliferation of ICT devices have affected behaviour and ways of living in modern-day society, including the learning and teaching of students. Mindful of the impact of ICT and the need to enhance students' information literacy to help them stay competitive and pursue lifelong learning, an educational paradigm change took place over the decades, from the paradigm of teaching to the paradigm of interaction and eventually to the paradigm of learning (Petkunas, 2007).

2.2.1 Conceptual Framework of the Application of ICT in Science Education

UNESCO (2002) has defined ICT as the combination of 'informatics technology' with other related technology, specifically communication technology. The various kinds of ICT products available and having relevance to education, such as teleconferencing, email, audio conferencing, television lessons, radio broadcasts, interactive radio counselling, interactive voice response systems, audiocassettes, and CDROMs, have been used in education for different purposes in the 21st century (Sharma, 2003; Sanyal, 2001; Bhattacharya & Sharma, 2007). The use of the World Wide Web for the acquisition of new skills and knowledge has become an integral part of students' self-directed learning. The advent of open-source learning platforms, the growing market for robots for educational purposes, remote control learning, and more have further opened up new realms in the integration of ICT into the science education curriculum.

The Institute for Prospective Technological Studies of the European Commission's Joint Research Centre (2008) related the importance of ICT in education with lifelong learning, a key focus of education in the 21st century, as follows:

> Lifelong learning strategies need to answer to the growing need for advanced digital competence for all jobs and for all learners. Learning digital skills not only needs to be addressed as a separate subject but also embedded within teaching in all subjects. Building digital competence by embedding and learning ICT should start as early as possible, i.e. in primary education, by learning to use digital tools critically, confidently and creatively, with attention paid to security, safety and privacy. Teachers need to be equipped with the digital competence themselves, in order to support this process.

The above statements set the framework for the development of ICT in education in the European Commission. The challenge was to embed ICT in the learning and teaching of all subjects and to equip teachers with the competence to support this process.

Apart from the European Commission, the application of ICT in education was also widely discussed elsewhere. Literature has showed that educators have been trying out an array of ICT devices to enhance the effectiveness of students' learning, both inside and beyond schools globally. Petre and Price (2004) and Robinson (2005) conducted trials of robotics competitions, and activities among teachers and students revealed positive perceptions of the educational value. In order to solve problems in robotics, children were motivated to learn subjects in programming and engineering that they previously considered difficult and inaccessible (Petre & Price, 2004). Williams, Ma, Prejean, and Ford (2007), in a robotics summer camp organized for students of K–12 classrooms in the United States, revealed that the camp enhanced students' physics content knowledge, though improvement to skills in conducting scientific inquiry was not evident.

Hennessy et al. (2007), in their study on pedagogical approaches for technology-integrated science teaching, concluded that there was a shift away from the educational legacy of 'exemplary scientific practice' within the school curriculum, as characterized by real experiments (Gooding, 1990), towards a more 'naturalistic philosophy' – that people learn by interactive intervention within a concrete world (Giere, 2002) where tools such as simulation and animation may play a bigger role. Technologies proved to help as tools to support the processes of both empirical and thought experiments, since scientific reasoning is the common underlying goal, and the role of the teacher – in selecting appropriate resources, sequencing and structuring learning activities, adapting to particular learners' needs, and guiding students' experimentation, generation of hypotheses and predictions, and critical reflection on outcomes – proves pivotal in moving students towards knowing the physical world as a scientist (Hennessy et al., 2007). All these studies point to the potential of enhancing science education with the use of ICT.

In Hong Kong, integration of ICT into learning and teaching was advocated as early as the late 1990s. In 1998, the Hong Kong Government issued the first strategy document for IT in education, 'Information Technology for Learning in a New Era: Five-Year Strategy 1998/99 to 2002/03', which focused on providing the necessary IT infrastructure in schools, getting teachers prepared for the challenge, fostering students' capability to link up with the network world of knowledge and information, and developing the appropriate skills, knowledge, and attitudes in learners to ensure lifelong learning (CDC, 2000; EMB, 1998). In tandem, the first important official publication that attempted to weave science, technology, and the society together in the Hong Kong school curriculum was released by the CDC in 1999. CDC's view on science education reform, as depicted in this publication in the context of a Science, Technology and Society (STS) curriculum, was:

(i) to enhance students' scientific thinking and strengthen their investigative and problem-solving skills

(ii) to better the coordination of fundamental science and technology courses at junior secondary level with a view to promoting scientific and technology literacy

(iii) to develop among senior secondary students a solid foundation in science and technology for empowering them to cope with a dynamically changing environment and to make informed judgements in a technological society.

In 2000, a set of IT learning targets, highlighting the use of IT and information, was also developed. Parallel to the education and curriculum reforms in Hong Kong, information literacy (IL) was defined, which served as a framework for teachers to frame learning and teaching activities pertaining to four key tasks (CDC, 2001): reading to learn, project learning, IT for interactive learning, and moral and civic education.

In 2004, a second strategy on IT in education was issued, advocating the empowerment of learners and teachers with IT and enhancing leadership to integrate IT into school plans, curricula, and the teaching and learning process (EMB, 2004). In this policy document, the former EMB asserted that the CDC had embedded IT into the curriculum guides and that interactive learning was a key task with a set of generic IT skills. The third strategy, issued in 2008, further focused on successful integration of IT into learning and teaching (EDB, 2008). On this premise, schools are encouraged to explore the wide integration of IT in learning science and other subjects and to draw up and implement development plans for school-based IT in education and for integrating IT into learning and teaching activities. Alongside this strategy, the EDB developed a depository of educational software on teaching and learning and set up an interactive platform for exchange on ‘Good Practices on IT in Education’. The curriculum guide set forth the direction on the use of IT in the NSS curriculum. The extent of integration of IT into the curriculum was school based, and this was allowed to vary from school to school, having regard to the policy, objectives, and readiness of the school in the implementation. In May 2014, the government released the consultation document 'Fourth Strategy on Information Technology in Education' and conducted a two-month public consultation. The goal was to unleash the power of all students to master the skills for learning to learn and to excel through realizing the potential of IT in enhancing interactive learning and teaching experiences (EDB, 2014). The notions of providing quality e-learning resources to cater to curriculum development, making good use of e-learning and teaching strategies, enhancing professional training for principals and teachers, and communicating with parents were advocated (EDB, 2014). With the government's determination to develop e-learning, there is a case for research on how open-source digital technology, as a type of IT tool, could be used to enhance students' self-directed, lifelong learning and whole-person development.

2.2.2 The Effectiveness of ICT in Enhancing the Teaching and Learning of Science

The educational concepts of lifelong learning and learning to learn were key elements in the educational reform of the 21st century. ICTs were conducive to enhancing self-directed, lifelong learning and to enriching students' learning and teaching experience. Ng and Gunstone (2003) pointed out a quite broad acceptance that computer and multimedia technologies had an important role to play in the delivery of curriculum in schools. Many educators advocated the potential of enhanced learning with these technologies (Salomon et al., 1991; Bork, 1992; Hawkins & Collins, 1993; Lockhard et al., 1994; Jenkins, 2000).

More and more educators are developing ICT tools for enhancing the acquisition of content knowledge and inquiry skills and for the integration of ICT into the science curriculum. The purpose of developing educational technology thus became a way to achieve intended results through inquiry learning. If the goal were to promote inquiry through data collection and analysis of real-world problems (Berger et al., 1994; Collins, 1991; Greenberg et al., 1998;

Roth, 1995; Thornton, 1987; Thornton & Sokoloff, 1990) or to establish discourse communities in which students and professionals together constructed knowledge (Bereiter & Scardamalia, 1991, 1994; Linn, 1986; McLaughlin & Talbert, 1990), there existed few superior tools than the evolving educational technology of the day. Many educators viewed the impact of IT as significant in assisting higher-order cognitive processes, such as information processing, problem solving, and analytical or critical thinking (Wilson, 1995; Edwards, 1995; Liu, Macmillan, & Timmons, 1998; Pedretti, Mayer-Smith, & Woodrow, 1998; MacGregor & Lou, 2004).

The working paper entitled 'A Review of the Impact of ICT on Learning' (European Commission, 2006) brought together evidence on the impact of ICT on education and training in Europe. The Joint Research Centre of the European Commission reviewed 20 studies and/or reports that provided empirical accounts of the significance of ICT for learning and showed that educational achievements were positively influenced by ICT. The OECD (European Commission, 2006), investigating student performance at the secondary level, provided evidence of the impact of ICT on concrete school achievements. The analysis of headmasters', teachers', pupils', and pupils' parents' perceptions of the impact of ICT on learning showed a positive impact and beneficial consequences. ICT was seen positively by teachers as a valuable tool for tailoring learning, with beneficial effects on both academically strong and academically weak pupils. The view was that integrating ICT literacy would be crucial, as it meant harnessing technology to perform learning skills, and that literacy must include the use of ICT to access, manage, integrate, evaluate, create, and communicate information in order to develop information and communication skills (21st Century Skills Partnership).

Given the worldwide trend in the use of ICT in education, local academics also launched various research projects to gauge the effectiveness of its use in the local context. So, Hung, and Kong (2001) developed a digital video database and analysed how it assisted teachers in using IT for teaching general studies. Cheng and Li (2002) implemented innovative science teaching methods with the use of IT in general studies in primary levels (including data logger experiments, web technologies in science projects, and use of IT in science assessment) and found that the innovations benefited students' science learning. So and Leung (2005) tested the use of multimedia resources in the teaching of general studies and revealed that this inspired students and increased their learning effectiveness. Yuen (2005) engaged primary students in an interschool asynchronous online threaded discourse through a computer-mediated communication platform and also revealed positive results in broadening the basis for learning and teaching science. Law, Yuen, and Chow (2003), in a study of the pedagogical innovation and use of ICT in Hong Kong, concluded that innovative learning activities involving ICT empowered students. In the Phase (I) Study on Evaluating the Effectiveness of the 'Empowering Learning and Teaching with Technology' Strategy (2004/2007) conducted in selected schools in Hong Kong, it was found that teachers and students of the primary and secondary school sectors in the study perceived that IT had positive impact on learning, enhancing students' self-learning and interest in learning subject content as well as enhancing information-processing ability (Hong Kong Institute of Education (HKIEd), 2007).

The Hong Kong Government also expressed support for the use of ICT in education. The EDB of the Hong Kong Government has been playing a key role in advocating the deployment of IT in education in the school environment for the last two decades. In the Fourth Strategy on IT in Education, formally launched in the 2015/16 school year, the EDB set the goal to strengthen students' self-directed learning, problem solving, collaboration, and computational thinking competency; enhance their creativity, innovation, and even entrepreneurship; and nurture the students to become ethical users of IT for pursuing lifelong learning and whole-person development, through leveraging technology and the capacity of IT in IT-rich school environments, with schools' professional leadership and capacity, as well as support from community partnerships (EDB, 2015). The government is unequivocally positive on this subject and has adopted a holistic approach under which six actions are formulated: (i) enhancing the IT infrastructure of schools and re-engineering the operation mode; (ii) enhancing the quality of e-learning resources; (iii) renewing curriculum and transforming pedagogical and assessment practices; (iv) building professional leadership and capacity, as well as communities of practice; (v) involving parents, stakeholders, and the community; and (vi) sustaining the coherent development of IT in education.

While there was evidently wide acceptance of integration of IT in education, the implementation was not always without problems. Research studies revealed that in some cases, computers and network technologies were often underutilized and poorly integrated into core science education activities. This was evidenced in a study conducted by Songer (2007) among K–16 students in the United States. Ng and Gunstone's (2003) research into the attitudes of Australian secondary science teachers in the use of science and computer-based technologies in schools revealed that teachers' use of ICT in the classroom was infrequent, though teachers were generally positive about the potential of ICT in the classroom. A range of obstacles preventing the use of ICT were identified in this research, including the availability of computer resources, limited budget to purchase computer-based resources, lack of suitable software, lack of skills and time for teachers to acquire the knowledge, and classroom management issues. Anderson (2002) also cited a concern about the integration of ICT into the curriculum, that the content of the field was changing rapidly, and, partly because of that, there was little consensus among educators about how ICT should be integrated into schools and their curricula. In an in-depth case study of innovative, ICT-supported pedagogical practices in 11 countries, Anderson (2002) further raised the issue of school-level conditions influencing how effectively educational ICT was implemented. Among the conditions examined were formal staff development practices, ongoing support for teachers' ICT use, school-wide decision-making practices and policies related to ICT, and individual teachers' pedagogical beliefs and instructional practices, as well as the professional community. Anderson (2002), in the in-depth study, also brought up the concept of sustainable implementation, which was found to be associated with commitment to a learning community and personal investments by teachers and staff in ICT-supported innovation. For teachers to be effective in helping students achieve an understanding of technology, teachers must be confident in their own use of computers as instructional tools (Greenberg et al., 1998; Troutman, 1991), and students must recognize their teachers' confidence and general acceptance of technology in the learning process (Bradshaw, 1997; Zammit, 1992; McLaughlin & Talbert, 1990). Teaching constructively via technology required teachers to possess knowledge of computer capabilities and skills and to think broadly across all content areas and about the many areas of available technological resources (Greenberg et al., 1998). Teachers need to consider issues of content and technological integration from pedagogical and content perspectives. Pedersen and Yerrick (2000), in their study on the use of technology by science teacher education faculty within classrooms and the desire of science education faculty to learn about integrating technology to prepare future science teachers in the United States, found out that science teacher educators indicated a high commitment to the use of computer technologies, but their current knowledge was moderate. A discrepancy existed between interest in and proficiency with technology. Bork (1991) argued that teachers coming out of schools of education had almost zero acquaintance with computers because very few schools of education anywhere in the world were in a position to deal with this question adequately. The U.S. OTA (1995) reported that only about one-third of all K–12 teachers had had even 10 hours of computer training. Hollingsworth (2005), in a comparative study of integration of ICT in education in Hong Kong and Sweden, pointed out that the vision and leadership for IT in education were put in the lap of school principals without taking into account the other stakeholders. Students and teachers were found not ready to take on their new roles, and the system was also not ready to change from being examination driven to student empowered. So (2002c) also revealed similar findings when she investigated teachers' feelings towards the use of IT in teaching. Teachers believed that they were ill prepared for the integration of IT into the classroom. All these findings converged to the argument that teacher education programmes bear a large part of the responsibility to prepare teachers to use technology in line with current science education visions (Pedersen & Yerrick, 2000). It was only when teachers had gained confidence in the integration of IT in classroom learning and teaching that the effectiveness of ICT could be realized.

An Australian study identified similar issues that stood in the way of science teachers using computer-based technology in their teaching: among others, the lack of skills and knowledge of appropriate applications that use computer-based technologies; the lack of suitable software programs; and the lack of time to investigate, learn, and plan computer-based science activities (Ng & Gunstone, 2003).

Locally, in the Phase (I) Study on Evaluating the Effectiveness of the 'Empowering Learning and Teaching with Technology' Strategy (2004/2007), it was observed that the current pedagogical practice was still more related to expository teaching with simple technology. The project team pointed out that it took time for teachers to become familiar with the technology and to incorporate IT into the pedagogical design in line with instructional objectives (HKIEd, 2007). More guidance and opportunities for project-based learning, especially for secondary school students, was seen as necessary to attract students' interest in self-learning as well as to create opportunities for their use of higher-order thinking skills in the learning tasks (HKIEd, 2007).

Premised on this, the current research attempted to address the questions raised by Anderson and other educators with a view to demonstrating the positive impact of the use of innovative ICT tools in the learning and teaching of physics. The future challenges were to use ICT to revolutionize teaching processes at school, to equip teachers with a full understanding and complete mastery of ICTs as pedagogical tools, and to get those who have not yet used e-learning services on board.

2.2.3 Relevance and Significance of ICT in Authentic Science Education

Access to practical work is an essential part of learning science, as performing experiments and reflecting on them help students construct knowledge in science (Colwell, Scanlon, & Cooper, 2002; Thomsen, Scheel, & Morgner, 2005). In 1982, Hoffstein and Lunetta acknowledged the importance of laboratory work as playing a central and distinctive role in science education at that time. Twenty years later, Hoffstein and Lunetta (2003) reaffirmed that laboratory experiences can help students develop ideas about the nature of a scientific community and the nature of science, asserting that 'there also continue to be important reasons to believe that school laboratory activities have special potential as a media for learning that can promote important science learning outcomes for students'. Other academics stress the importance of practical work as introducing students to full participation in the sociocultural practices of a community (Lave & Wegner, 1991) and consider it an integral part of school science education, with a three-fold purpose (Braund & Driver, 2005; Colwell et al., 2002; Scanlon, Morris, Di Paolo, & Cooper, 2002) – namely, first, to deepen students' conceptual knowledge by linking science theories with the real world; second, to develop students' procedural understanding of science topics with the use of instruments, equipment, and techniques in scientific investigation; and third, to establish favorable attitudes among students towards science learning.

Conventional cookbook-type practical work, nevertheless, fails to attract or stimulate students to understand their field of study. Laboratory-based work simply requires students to follow the work procedures in the manual to collect data, plot graphs, and perform data analysis in a well-controlled manner. Such practical work can no longer sustain the interest of students in the pursuit of science, as the laboratory problems are far from related to their daily lives. As Peffer (2015) put it, simple inquiry activities were recipe-like and straightforward, they generally did not require the student to engage in problem solving or critical thinking, and they provided poor models of authentic science inquiry. As a result, students left school without the ability to reason scientifically.

More and more educators, therefore, argue for the doing of science in an authentic environment, as the real world of science is not typically represented in the classroom (Chinn & Malhorta, 2002; Roth, 1995; Ryder, Leach, & Driver, 1999). In an authentic environment, students are presented with real-life problems that are closely related to their day-to-day lives. The relevance and the need to acquire additional knowledge to solve the problems they face with sparks off immediate interest among students to solve the problems. Students can be actively engaged in constructing meaningful knowledge on their own. Chinn and Malhotra (2002) concluded from their study about epistemologically authentic inquiry in schools that textbook inquiry tasks assume an epistemology that is entirely at odds with the epistemology of real science. Students are not encouraged to think about alternative interpretations of the data they generated, and they draw obvious inquiry conclusions from simple experiments and simple observations. Braund and Reiss (2006) further argued that laboratory-based school science teaching needs to be complemented by out-of-school science learning that draws on the actual world (e.g., through field trips), the presented world (e.g., in science centres, botanic gardens, zoos, and science museums), and the virtual worlds that are increasingly available through information technologies. It was observed that the educational experiences of students at home or in the informal sector in science were often in stark contrast to those they acquired from formal schooling. There is, therefore, a valid claim to design and develop suitable science curricula and teaching strategies to extend the learning of science outside the classroom into the community. Bao, Kim, Raplinger, Han, and Koenig (2013) recognized the cognitive conflicts of students in inquiry-based learning and the possible anxiety that would be generated. With suitable instrumentation, students' anxiety could be addressed and their conceptual changes motivated.

With the advent of ICT, novel didactic technologies can be adopted for performing science experiments that are able to overcome the constraints posed by working in a real laboratory (Colwell, Scanlon, & Cooper, 2001). Such technologies include, but are not limited to, videotaping or use of a CD for a recorded experiment, a simulation of virtual laboratory or a remote laboratory. These technologies make it possible for a whole range of out-of-school practical work to be performed – for example, experiments to conduct research into the interrelationship between tides and weather, the correlation of humidity with plant growth, or the detection of pressure change inside a water rocket. Integrating these authentic scientific activities through adoption of ICT into the curriculum enriches the learning experience of students, opens up the realms of science-technology-society to the students, and brings new inspiration to students that they can hardly gain through standard, instructional experiments in school laboratories. This not only expands the horizons of students' encounters with the real world but also develops their inquiry learning ability, sharpens their problem-solving skills, and motivates them to learn to learn and do science on their own.

In a nutshell, the out-of-school context learning of science unveils a new dimension of linkages between science and society, enhances the scientific literacy of the society, and stimulates learners to conduct research into different domains of science for the advancement of the technological world.

2.3 Significance of STEM Education and Its Relation with ICT

2.3.1 Conceptual Framework of STEM Education

As mentioned earlier, the term STEM is an acronym for science, technology, engineering, and mathematics. This term is nothing novel. Gonzalex and Kuenzi (2012) pointed out that, while many observers cited the launch of the Soviet Union's Sputnik satellite in the 1950s as a key turning point for STEM education policy in the United States, federal interest in scientific and technological literacy writ large was longstanding and dated to at least the first Congress, that is, the 1780s. In the 1990s, the U.S. National Science Foundation (NSF) used the term 'SMET' to describe the field. By the turn of the century, it was renamed STEM. Yet, as recently as 2003, relatively few knew what the term meant (Sanders, 2009). Muddled definitions of STEM in school settings and varying ideas about what good STEM education looked like were leading to confusion and disagreement (Marrero et al., 2014). More recent concerns about scientific and technological literacy in the United States have focused on the relationship between STEM education and national prosperity and power (Gonzalex & Kuenzi, 2012).

Dugger (2010) argued that there are a number of ways that STEM can be taught in schools today. One way is to teach the four subjects individually. Another way is to teach with more emphasis going to one or two of the four disciplines. The third way is to integrate one of the disciplines into the other three – for example, integrating engineering into science, technology, and mathematics. The fourth is to infuse all four disciplines into one another and teach them as an integrated subject matter.

Bybee (2010) remarked that, for most, STEM education meant only science and mathematics, without giving appropriate place for technology and engineering. He advocated that a true STEM education should increase students' understanding of how things work and improve their use of technologies, and that STEM education should introduce more engineering during precollege education, which was directly involved in problem solving and innovation. He supported STEM curricula to incorporate group activities, laboratory investigations, and projects to afford the opportunity for students to develop essential 21st-century skills and prepare them to become citizens who were better able to make decisions. He saw a need for a bold new federal strategy for improving education that included the creation of high-quality, integrated instruction and materials, as well as the placement of problems associated with grand challenges of society at the centre of study.

STEM disciplines are, nevertheless, not well integrated in schools. Worldwide educational systems have typically been discipline specific, and students take singularly focused content courses with little interdisciplinary work (Marrero et al., 2014). Sanders (2009) noticed that NSF had used the term 'STEM' simply to refer to the four separate and distinct fields as science, technology, engineering, and/or mathematics, and, for a century, the four disciplines had defended their sovereign territories. He pointed out that many believed this was no longer serving America as well as it should or might. In 2007, Virginia Polytechnic Institute and State University (Virginia Tech) launched an integrative STEM education programme with the notion that it included approaches to explore teaching and learning between/among any two or more of the STEM subject areas and/or between a STEM subject and one or more other school subjects (Sanders, 2009). The integrated approach resonated with the Benchmarks for Science Literacy (American Association for the Advancement of Science (AAAS), 1993) statement that ‘The basic point is that the ideas and practice of science, mathematics and technology are so closely intertwined that we do not see how education in any one of them can be undertaken well in isolation from the others.’ In essence, the conceptual framework of STEM education is not a framework of four disconnected disciplines. It should be grounded on the integration of science, technology, engineering, and mathematics and support cross-disciplinary learning so as to provide students with authentic learning experiences, sustain their interest in STEM education, empower them to solve non-routine problems, and foster their creativity and systems thinking to compete in the modern economy. As Lantz (2009) put it, STEM education removes the traditional barriers erected between the four disciplines by integrating them into one cohesive teaching and learning paradigm helping students make connections between school, community, work, and the global world. The advantage of integrating STEM education into all content areas at all grade levels has been described as providing students with informal practice in creatively solving problems long before they need to decide on a course of study for college (Meyrick, 2011).

With STEM education being closely related to meeting a nation’s economic needs, supporting its technological advancement, and maintaining its competitiveness, the importance of developing STEM education and raising the number of STEM graduates to meet future needs has prompted concern among educators and policymakers in this decade. The 2009 National Assessment of Education Progress, released in January 2011, indicated that U.S. students were struggling in science, with less than half considered proficient and just a tiny fraction showing advanced skills that could lead to careers in science and technology. Facing the challenge, U.S. President Barack Obama saw the need to reinvigorate innovation through STEM education initiatives (Prabhu, 2009). President Obama further articulated as a priority for STEM education that American students must ‘move from the middle to the top of the pack in science and math’ (U.S. Department of Education, 2015). The Observatory on Borderless Higher Education (2013) published an article titled ‘The Global Race for STEM Skills’ in its January 2013 report that illustrated a shortage of STEM graduates in the United States and Europe. Keonig, Schen, Edwards, and Bao (2012) described the retention of majors in science, technology, engineering, and mathematics as a national problem that continues to be the focus of bridging and first-year experience programmes. Accenture Institute for High Performance (also called ‘the Accenture’; 2011) compared the percentages of STEM degree holders with the total number of degree holders in 2011 and revealed that the percentage was highest in China (41%), followed by India (26%), the United Kingdom (22%), Japan (18%), Brazil (14%), and the United States (13%). Based on this research, the Accenture defined the problem of shortage of STEM talent as a location mismatch issue and advocated a talent supply mapping on a global scale (2013). No matter how the problem is viewed, to stay ahead in rising to future challenges, the need for STEM talent is unquestionable.

Implementation of STEM education in Hong Kong is still in an infancy stage. Given the experience of other countries, the Hong Kong Government recognized the need for an integrative approach to develop STEM skills. The EDB of the Hong Kong Government provided guiding principles for promoting STEM education, that a holistic approach in school education, with different strategies focusing on strengthening students’ ability to integrate and apply knowledge and skills from different disciplines, should be adopted so as to unleash their potential in innovation (EDB, 2015). Specifically, the curricula of the Science, Technology, and Mathematics Education Key Learning Areas would be renewed, highlighting the importance of strengthening students' integration and application of knowledge and skills across disciplines. The Education Bureau also took actions to enrich learning activities for students to promote the culture of cross-disciplinary learning of science, technology, and mathematics. However, what has been done so far in Hong Kong is merely a start, and the term 'STEM' has been widely discussed among primary and secondary teachers and school heads only since the government announced the allocation of additional funding to schools to promote STEM education. Lots is left to be done to deepen the understanding of teachers and school heads of what the STEM framework refers to and to get teachers prepared to integrate the curriculum and adopt new modes of teaching practices to encourage cross-disciplinary teaching and learning of science, technology, engineering, and mathematics.

2.3.2 Relevance of ICT in STEM Education

STEM education and initiatives are the creation of a discipline based on the integration of other disciplinary knowledge into a new whole (Lantz, 2009), in which technology and engineering play a key role. These disciplines are closely related to the use of ICT. ICT is connected to the innovative application of technology in the learning and teaching of science, in which computer-based technologies, such as the use of computers and the Internet, play an important part. A common theme that transverses STEM-related curricula, initiatives, and organizations is that they implement the power of the World Wide Web and computer-related technologies to share information and supplement instruction geared towards infusing aspects of STEM into the curriculum (Asunda, 2011). The 21st-century skills advocate students to acquire science and mathematics skills, creativity, fluency in information and communication technologies, and the ability to solve complex problems (Business–Higher Education Forum, 2005). At this forum, the importance of STEM and of ICT was put in the same context for discussion. The relevance of ICT to STEM education is evident. In fact, in Malaysia, the use of ICT as a teaching tool and learning has been the main focus of research articles pertaining to STEM education (Jayarajah, Saat, & Rauf, 2014).

To succeed in economies that are rapidly embracing STEM-related careers, individuals are required to develop the skills necessary to secure meaningful employment (Asunda, 2011). With the notion to advocate the use of information and communication technology to encourage self-directed, lifelong learning, ICT also shares the same goal in support of STEM literacy. However, the mere use of technology, such as putting iPads and laptops in front of students, does not in itself help encourage innovation, if the technology itself does not offer opportunities for students to explore and appreciate the intertwining relationships among the fields to understand the real world. There is thus a challenge for teachers at all levels of the academy to seek ways to be responsive and to accommodate in their teaching the changing needs of the workforce and students (Asunda, 2011). Dugger (2010) was of the view that it was imperative that teachers become STEM technically literate as well as aware of various teaching models.

The Partnership for 21st Century Skills (2009) argues that all 21st-century initiatives must focus on both core academic subject mastery and 21st-century skills outcomes. In providing recommendations for the implementation of 21st-century initiatives, both the Partnership and North Central Regional Education Laboratory (NCREL) strongly suggest, among other things, developing teacher professional development programmes and workshops that focus specifically on 21st-century skills instruction, investing in ICT, providing professional development opportunities for both ICT staff and teachers, and integrating 21st-century skills into both student and teacher standards. The professional development of teachers in ICT and

STEM education remains a challenge in the years ahead.

2.3.3 Implementation of STEM Education in Classrooms

STEM education emphasizes creativity and exploration in the learning process to understand real-world problems that span across different disciplines. This means that classroom learning should be shifted from textbook-based to project-based, and pedagogy should be shifted from teacher-centred to student-centred. Yarker and Park (2012) argued for a need to teach science in a more enriching and interesting manner, one that is interdisciplinary in nature, to keep curiosity alive. However, in situations of daily life, fewer students in Western countries are choosing to study science in upper secondary school and at university level, as many have found science difficult, dull, and not relevant to their needs or interests (Miller, 2006). Retaining students' interest in science is important, not least because of the need for an adequate number of students to select science in their secondary years (Cleaves, 2005; Lindahl, 2003) in order to pursue science-related careers. It is therefore important to design curriculum and pedagogical practices for implementing STEM education in the classroom.

Many of the learning experiences advocated in STEM education are congruent with the underlying principles of problem-based learning (PBL); hence, PBL has promise for serving as an organizing framework for STEM initiatives (Asghar et al., 2012). PBL, in essence, tries to mirror the processes used by scientists to solve real-life problems (Crawford, 2000; Colliver, 2000) through the active construction of knowledge and the development of social and communication skills (Goodnough & Cashion, 2006; Lieux, 1996) and understandings (Barnes & Barnes, 2005; Frykholm & Glasson, 2005; Loepp, 1999; Moseley & Utley, 2006; Sage & Torp, 1997; Venville, Rennie, & Wallace, 2004). PBL in STEM advances interdisciplinary learning by breaking down the siloed nature of secondary science instruction (Asghar et al., 2012).

Integrating STEM education through project-based learning has been put forth as another way to implement STEM education in the classroom. The most effective project-based learning programmes are those that contain themes with a high potential for student interest, authentic problem solving, and rich, standards-based content in STEM (Satchwell & Loepp, 2002). The project-based approach to STEM is grounded on the constructivist theory (Fortus, Krajcikb, Dershimerb, Marx, & Mamlok-Naamand, 2005), which is shown to improve student achievement in higher-level cognitive tasks, such as scientific processes and mathematic problem solving (Satchwell & Loepp, 2002). Schunk (2004) explained that constructivism is not a theory but an epistemology that explains the nature of learning and how individuals construct what they learn and understand. Brown (1998) viewed constructivism as a learning approach that argues well with contextual learning. As project-based or problem-based learning is squarely contextual based, and the adoption of STEM skills across disciplines to solve problems is a key element in PBL, the STEM-PBL approach offers a perfect combination to link students' experience and learning.

The effectiveness of implementing STEM education through PBL or project-based learning in classrooms, nevertheless, very much hinges on teachers' self-efficacy. The STEM-PBL approach demands a transformation in the teacher's role from a transmitter of knowledge to that of a facilitator of knowledge to help students to identify and use relevant sources of knowledge to solve real-world problems. There must be substantive changes in the way science and mathematics curricula, pedagogy, and assessment systems are conceptualized, organized, and implemented (Asghar, Ellington, Rice, Johnson, & Prime, 2012). The training of teachers in discipline-specific ways is not conducive to the implementation of STEM education, which may limit teachers' ability to embrace an expanded view of mathematics and science learning. To support STEM education in the classroom, interdisciplinary collaborations, lesson planning, and new ways of assessing student learning in STEM are necessary. Teachers need specific school-based coaching and mentoring in various STEM content areas as well as instructional and assessment techniques (Asghar et al., 2012).

In Hong Kong, PBL is not a compulsory learning programme or experience in primary or secondary education. While the NSS curriculum introduced beginning in 2009 aims to align with the international trend of higher education development to broaden students' scope of learning and to enable students to have a more in-depth learning experience in preparation for lifelong learning, there is no explicit requirement that PBL should be incorporated into the learning and teaching process. Insofar as science education under the NSS curriculum is concerned, the subjects of physics, biology, chemistry, and integrated science are grouped under this Key Learning Area. For physics, the latest curriculum framework under the NSS Academic Structure, as elaborated in the Physics Curriculum and Assessment Guide (2007, updated in November 2015), embodies the key knowledge, skills, values, and attitudes that students are to develop at the senior secondary level. To facilitate the integration of knowledge and skills into learning, students are required to conduct investigative studies to solve authentic problems. As regards the assessment of students' performance, the Hong Kong Examinations and Assessment Authority (HKEAA) lays down the requirement that 80% of the assessment be made by way of a public written examination and 20% be a school-based assessment conducted by teachers on students' performance in a wide range of skills involved in practical work throughout S5 and S6. Of the 20%, 8% is related to investigative study where students are orginally expected to design and conduct an investigative study. Yet, before this was rolled out in 2014, the assessment framework had already been modified. Under the 2014 Hong Kong

Diploma of Secondary Education (HKDSE) – Physics Assessment Framework, which states that students might be required to design and conduct an investigative study with a view to solving an authentic problem, or an experiment with a detailed report. Therefore, to fulfil this 8% of the programme, students may simply choose to conduct a cookbook-type experiment with a detailed report. In a survey conducted by Yeung, Lee, and Lam (2012) among Hong Kong teachers teaching the NSS science education curriculum, it was revealed that experiments and scientific inquiry activities were adopted as the most and second most popular pedagogies. However, the deductive approach instead of the inductive approach would be used because most teachers still rely on cookbook-type experimental worksheets for instructing students to perform experiments. In addition, the key element of inquiry learning in the study of physics, which may best be assessed in investigative study, was not given proper attention, especially when the framework was later revised to allow students to present a detailed report in place of designing and conducting an investigative study. This departs largely from the notion of PBL.

Hence, in this study, a key objective is to test whether and how innovative tools can effectively be used to help students learn topics in physics through a PBL approach under the NSS curriculum.

2.4 Technology-Enhanced Learning

2.4.1 Conceptualizing TEL

The term 'TEL' refers to the application of ICT to teaching and learning (Kirkwood & Price, 2014). TEL seeks to improve students' learning through the integration of technology into teaching. It is not only about the use of technology to enhance learning but also an essential aspect of developing and integrating new technologies for the purpose of enhancing the effectiveness of science education and shaping the curriculum. Kyza, Erduran, and Tiberghien

(2009) viewed the role of new technologies in science learning as cognitive tools to engage students in meaningful science learning, and the TEL environment as a learning environment that supports the gradual development of higher-order skills, such as critical thinking and problem solving in inquiry-based learning, alongside the development of domain-based reasoning. They derived a set of basic requirements for TEL environments, namely, adding authenticity to the learning environment, supporting the building of communities of learners, extending learning beyond the science classroom, and empowering teachers to design flexible and customizable environments for learning.

Insofar as TEL tools are concerned, educational technologies have been evolving over the years in line with the rapid development of ICT. Technologies such as the World Wide Web, simulation, the use of mobile devices, online learning, computer-supported collaborative learning, and so forth have been deployed as tools to enhance effectiveness in teaching and learning. For the past decade or so, LabView, virtual instruments, data loggers, remote control technologies, and so forth have also been applied in the teaching and learning of science, especially in the laboratory context. Educators have proved the effectiveness of TEL in science education through computer-mediated or data logger–based experiments (Deaney, Hennessy, & Ruthven, 2006). However, science learning in the school laboratory with TEL tools was not widely accepted even in the early 2000s. What was more commonly found in practice was that technology was used to replicate or supplement traditional activities (Blin & Munro, 2008; Eynon, 2008). Hofstein and Lunetta (2003), when examining the scholarship on laboratories in science education that emerged in the 20 years between 1982 and 2002 – though they firmly approved of the effectiveness of incorporating inquiry-empowering technologies, including computer technologies, in science education – did point out serious discrepancies between what is recommended for teaching in the laboratory-classroom and what is actually occurring in many classrooms. They summarized factors that inhibit learning in school science laboratories as follows: Use of ‘cookbook’ lists of tasks fail to engage students in thinking about the larger purpose of investigations; assessment of students’ practical knowledge and abilities tends to be seriously neglected; teachers and school administrators are not well informed about best professional practices, and thus a potential mismatch occurs between teachers’ rhetoric and practice, which likely influences students’ perception and behaviours in laboratory work; and the incorporation of inquiry-type activities in school science is inhibited by limitations in resources and the lack of sufficient time for teachers to become informed and to develop curricula.

For the effective adoption of TEL, there is a need to focus not only on changes in the means of teaching and learning but also the transformation in how teachers teach and how learners learn.

2.4.2 Framework for Assessing the Effectiveness of TEL

TEL environments are technology-based learning and instructional systems through which students acquire skills or knowledge, usually with the help of teachers or facilitators, learning support tools, and technological resources (Aleven, Stahl, Schworm, Fischer, & Wallace, 2003; Land, 2000; Shapiro & Roskos, 1995). In TEL environments, learning is student centred. Whether or not TEL tools are conducive to improving the construction of knowledge, collaboration and meaningful learning among students are of prime importance. Mor and Winters (2007) were of the view that the learner or user in a TEL environment is the main focus of design approaches, as the learner is the target user of the TEL tools developed for achieving learning goals. Hence, the effectiveness of the teaching and learning of science among students should be given equal, if not more, emphasis relative to the development of the open-source courseware or the use of the technology itself.

The development of frameworks for assessing the effectiveness of TEL has flourished since the 1990s. Theoretical frameworks such as those developed on the premise of constructivist epistemology have been put forth. Among the systems, Wang and Hannafin (2005) indicated that DBR has considerable potential as a methodology suitable to both research and design of TEL environments. What they advocate is a DBR that provides a systematic but flexible methodology to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings (Wang & Hannafin, 2005, p. 6).

2.4.3 Design-based Research (DBR) as a Methodology for Research and Design of TEL Environments

DBR was brought up for discussion initially by Brown (1992) and Collins (1992) for understanding the synergistic relationships among researching, designing, and engineering. It evolved near the beginning of the 21st century as a practical research methodology that could effectively bridge the chasm between research and practice in formal education (Anderson & Shattuck, 2014). The theoretical framework of DBR was grounded on the conviction that learning, cognition, knowing, and context are irreducibly co-constituted and cannot be treated as isolated entities or processes (Barab & Squire, 2004). The framework focuses on the integration of technology with the real world in education and the examination of learning in a naturalistic context, where technology is seen as a process rather than a subject. DBR works with a mixed-method approach in research to improve the objectivity, validity, and applicability of ongoing research (Anderson & Shattuck, 2012; Wang & Hannafin, 2005, p. 10) with the intent to produce new theories, artefacts, and practices that account for and potentially impact learning and teaching in naturalistic settings. Cobb, diSessa, Lehrer, and Schauble

(2003) described the design context of DBR as being ‘subject to test and revision, and the successive iterations that result play a role similar to that of systematic variation in experiment’ (p. 9). DBR takes place in real-life settings, where a multiple of variables (Collins, 1992, 1999) will interact that may affect the outcome, and the research is characterized by the complexity, fragility, and messiness of the design in practice. Participants are involved in the design so as to provide feedbacks into the system for subsequent refining and modification. Hence, unlike formative evaluation, DBR in learning science is a constant impulse towards connecting design interventions with existing theory. A critical component of DBR is thus the notion that the design is meant not just to meet local needs but also to advance a theoretical agenda – to uncover, explore, and confirm theoretical relationships (Barab & Squire, 2004). It generates evidence-based claims about learning that not only address local issues and but also provide information for establishing, enriching, or demonstrating the viability of theories. As a result, the relevance of the design in science learning is readily revealed, and how theoretical claims about teaching and learning can be transformed into effective learning in educational settings becomes evident.

The DBR framework forms the major backbone in this research study, starting from the identification of existing problems in the teaching and learning of science, moving to the development of solutions with the aid of technology and continuous testing and adjustment of the proposed solution in an authentic environment, and concluding with actual production of a TEL tool – namely the open-source tool in this research – for the purpose of improving effectiveness in science education. With constant feedback made available from real data collected from investigative activities via the open-source digital technology, problems can continuously be re-defined and solutions refined to achieve meaningful and positive science learning.

2.4.4 Challenges in Adopting DBR as the Research Framework

One of the major challenges of adopting DBR is the fact that the findings are difficult to replicate in a real-life cultural context. This thus necessitates the sharing of the designed artefact, as well as a rich description of the context, the guiding and emerging theory, the design features of the intervention, and the impact of the features on participation and learning (Barab & Squire, 2004). Another challenge of DBR arises from the dual role of the researchers – as designers and researchers – as a result of which the credibility and trustworthiness of their assertions might be at stake. Cobb and colleagues (1999), nevertheless, argued that effective instructional models are developed through interventions by researchers, and it is through subsequent refining and testing that effective models are developed and deployed in other contexts. Hence, Barab and Squire (2004) are of the view that the goal for DBR is not to 'sterilize' the naturalistic contexts but to develop flexibly adaptive theories that remain useful when applied to new local contexts.

In the current research, open-source technology, namely Arduino, is developed for flexible use by students in scientific investigations in a real-world environment so that students can collaborate and make use of the tool for their chosen inquiry-based learning. The open-source tool is highly programmable, such that learners can collect different kinds of data to help support the hypotheses they set. Where the data fail to support the hypotheses, learners try to identify problems, propose solutions, and design approaches to implement the solutions so as to gather appropriate data or refine the hypotheses. This iterative cycle continues in the course of the use of open-source tools, and through the digital technology, meaningful discourse can be enhanced and solutions to problems more readily worked out through concerted efforts and collective wisdom. The DBR framework is therefore a highly relevant framework for this study.

In the NSS curriculum of Hong Kong, a number of activities or student projects for scientific investigation that use the Arduino platform can be developed for senior secondary students who take physics or integrated science as an elective subject, to conduct scientific investigation. Most of the investigative studies can be related to real-life problems so that students can immerse themselves hands-on and 'minds-on' in the study. Data collected from the Arduino platform, which can be connected to an array of sensors, can automatically be uploaded to a web server through wifi, mobile phone, Bluetooth, personal computers, and so forth for the generation of meaningful results and data analysis. Real-time or close to real-time data collection, even for data collected from experiments conducted in remote sites, allows instant sharing among students, which encourages collaborative learning and social discourse. In addition, the microprocessing unit (MPU) of Arduino or the connecting computer can take instant feedback and intervene in the experimental procedures – for example, driving a robotic arm, regulating the pressure in a reaction inside a container, or maintaining constant temperature in a vessel – to gather data that are difficult to collect in traditional experimental settings.

2.4.5 Open-source Digital Technology as TEL in Science Education

The availability of open-source software has enhanced teaching, impacting the way educators instruct at all levels of education (Asunda, 2011). Open-source software is also called 'free software', 'libre software', 'free/open-source software', and 'free/libre/open-source software' (Couros, 2006, p.10). With the development and increase in use of open-source digital technology, the scene in science education has changed progressively. Before the turn of the century, for experiments that required labour-intensive manual measurement, platforms for a control laboratory were expensive, as the equipment in use was specialized and designed for specific purposes. Given the limited size of the customer base, producers had little incentive to produce robust equipment or bug-free products to cater to customers' needs (Hopkins & Kibbe, 2014). Very often, users were locked into a particular manufacturer's system due to the high cost of the monitoring equipment, making it cost-prohibitive for a researcher to switch to a different vendor for other equipment that enabled connections to other input instruments (Fisher & Gould, 2012). This greatly constrained the extent to which researchers could perform authentic experiments and collect crucial, sufficiently representative data.

However, the advent of inexpensive open-source controller hardware has revolutionized the situation, as it is possible to obtain good control-hardware capability at relatively low cost (Hopkins & Kibbe, 2014). Open-source software gives educators more options than ever before. Open-source software can be developed to support customization that may adapt to student responses and to provide simulations and engaging visual lessons, as well as projects that can help students comprehend why they need to learn certain key concepts (Asunda, 2011). Advances in technology have also brought about the development of a variety of low-cost, new sensing, monitoring, and control capabilities for conducting experiments. Popular open-source digital technologies with different processing capabilities include Arduino, Raspberry Pi, pcDuino, and UDOO. These platforms can be minute in size and therefore can be readily portable as mobile devices for remote control in performing science experiments. Examples of such include mobile phones and tablets connected to sensors that remotely control the sensor to monitor an experiment and send out a signal to record scientific phenomena. Through such devices, students can perform real-time experiments that are conducted outside the classroom or that extend beyond the laboratory session. Cortez and colleagues (2004) carried out a five-week experience in a high school physics class in Chile with a mobile computer-supported collaborative learning system and gathered statistically significant results showing that the environment created by combining the teacher's instruction with the mobile system was highly motivating, promoted collaboration among students, and enabled the students to construct new knowledge based on previous knowledge provided by the teacher.

With open-source digital technology gaining popularity today, there exists a library of hardware and software for teachers to use, and the resistance to the use of the technology should be reduced. Nevertheless, customization is often necessary. Without prior knowledge and skills in mastering this new technology, teachers may hesitate to apply the new technology in science education, especially in highly compressed senior secondary study such as the NSS curriculum in Hong Kong. This research will focus on one open-source digital technology – namely, Arduino – to examine whether the technology is favorable in practice to enhancing the teaching and learning experience in physics, thereby reducing teachers' burden.

Arduino is an open-source digital technology that has high potential to be used in science education (Arduino, 2014). Its easy-to-operate hardware and wide range of free Arduino software offer great opportunities for its wide applicability in senior secondary science education in Hong Kong. This research is related to the innovative use of Arduino as the platform for learning science at the senior secondary level. With analog and digital input/output (I/O) pins, Arduino can communicate with the physical world through sensors and peripherals. This offers practical solutions for performing a whole range of science experiments that could hardly be done in the past, either because of technical constraints/complexity or because of the time and costs involved. Arduino offers tangible means for students to explore and understand science concepts through hands-on personal interaction and experience rather than merely by way of textbook knowledge. The Arduino open-source digital technology also allows simultaneous conduct of science experiments at different locations, so that students can collaborate proactively to perform the same science experiment – against the same or a different set of parameters, to capture any spatial differences, trends, and patterns – to produce meaningful results across geographical boundaries, by means of instant sharing through the Internet. The Arduino courseware is thus developed to illustrate the innovative use of and the effectiveness of adopting the open-source digital technology in achieving diversified teaching and learning, strengthening students' self-directed learning, and enriching the supply of quality e-learning resources to cater to curriculum development.

Fisher and Gould (2012) have illustrated the use of Arduino as a low-cost alternative for scientific research, presenting an open-source Arduino project that 'consists of a programmable microcontroller development platform, expansion capability through addon boards and a programming development environment for creating custom microcontroller software. All circuit-board and electronic component specifications as well as the programming software are open-source and freely available for anyone to use or modify.' The open-source microcontroller-based platform, together with a wide array of open-source software and sensors interfacing directly with the microcontrollers, thus allows researchers enormous opportunities to explore.

As of late, the Arduino hardware is generally presented in the form of an open-source circuit board with a microprocessor and input/output pins for sensing, communication, and controlling physical devices (LEDs, servo motors, stepper motors, relays, etc.). It is driven by open-source software that is similar to the language C++. The Arduino integrated development environment (IDE) allows users to write, compile, and upload code to individual Arduino platforms for stand-alone use as prototypes or in projects. The hardware usually comes with programming libraries that contain routines to drive the hardware, and the source code can be modified.

Programming libraries allow users to take on new devices and sensors for use in projects without the need to develop subroutines. The IDE, libraries, and sample code can be accessed via the Arduino project website. This helps users tremendously minimize their programming efforts and readily incorporate advanced features into their applications. The easy-to-use and open-source features of Arduino therefore open up a channel for users to write their own programs to accomplish some specific tasks and let users freely develop their ideas into real practices.

As depicted above, the Arduino fits the theoretical framework of TEL well, in that it offers the potential for teachers to customize the tools for application in a whole range of investigative studies in an authentic environment beyond the classroom, and it facilitates discourse and collaborative learning within the student community that are conducive to higher-order thinking and problem solving in science process skills.

Open-source digital technology has therefore been attracting educators' attention as a means for teaching and learning – first, because of the myriads of educational activities that can be conducted out-of-school through the use of affordable open-source tools; second, because of the online threaded discourse it can permit among students across the boundaries; third, because of the interactive activities that can be conducted to deepen understanding and knowledge as well as concept construction; and fourth, for the opportunities it offers for students' self-directed learning, anytime and anywhere. The rise of the Internet and computer resources has catalysed the application of open-source software. Individuals are granted the right and freedom to access the computer code for individual use. Given the easy accessibility, programmability, and modification, the collective efforts and expertise of developers around the world have been drawn together to promote the growth of the open-source world.

CHAPTER 3

METHODOLOGY

Chapter 2 set out the role of ICT in education which has been increasingly recognized worldwide and the positive learning outcomes through ICT integration (Law et al., 2003) was evidenced. However, over the years, the development of ICT for integration into the curriculum is limited and a gap exists in its full-fledged integration that supports life-long learning of students. In a study commissioned by the Education Bureau of the HKSAR Government to evaluate the effectiveness of the 'Empowering Learning and Teaching with IT Strategy (2004/2007)', it was revealed that the use of ICT was still focused on traditional practices and less in 'lifelong practices' and 'connectedness practices' (Education Bureau, 2007). Law & Plomp (2003) cited a need for teachers to develop knowledge and skills to use ICT in meaningful ways to reform pedagogical practices. With STEM receiving considerable attention in the education sector in recent years, the Education Bureau set forth the Government's policy in promoting STEM education in 2016. Educational activities for students to promote the culture of cross-disciplinary learning of Science, Technology and Mathematics were advocated. From the perspective of development of ICT in education, the promotion of STEM education resonated with the integration of ICT into the curriculum.

With the advent of the open-source digital technology, this opens up immense opportunity to make use of this economical platform for development of ICT tools for learning and teaching of Science as well as the subjects of Technology, Engineering and Mathematics. It is against this setting that the current research is initiated and the result aims to inform further development of the ICT integration into the STEM curriculum.

3.1 Research Questions

In this study, the author develops open-source hardware and software using the Arduino-technology and examines the effectiveness of using this open-source digital technologyfor practical work in the New Senior Secondary (NSS) Science education. The study is guided by two research questions as follows –

1. How can the open-source hardware and software be appropriately employed to develop courseware for the effective learning and teaching of physics at senior secondary level?
2. What are the crucial factors underlying the effective use of the open-source digital technology in students' learning of physics?

In respect of the first question, special focus is given to what innovative or non-traditional experiments can be developed using the Arduino for leaning and teaching of physics both in the classroom and out-of-classroom, as well as further extension of Arduino into other realms of STEM education. As for the second research question, the following aspects will be examined –

(i) the school's existing practice on the use of ICT in the learning and teaching of science.
(ii) teachers' competence and confidence in adopting ICT in their teaching practices.
(iii) students' readiness and receptivity for using open-source digital technology in self-directed learning of science.

3.2 Conceptual Framework

This study is proceeded with along two strands, namely the development strand and the research strand. The development strand is basically related to the hardware component of the study. These include the adoption of the design-based research approach for development of the ICT tools, the sourcing, testing and actual production of the TEL tool using the Arduino technology for performing a series of physics experiments under the NSS curriculum and the design of the worksheets and related courseware. The research strand largely deals with the software of the study including the framing of the research questions, the selection of a mixed mode for the research, the choice of research tools, the conduction of the intervention, the design of the survey and interview questions, the data collection and analysis etc.

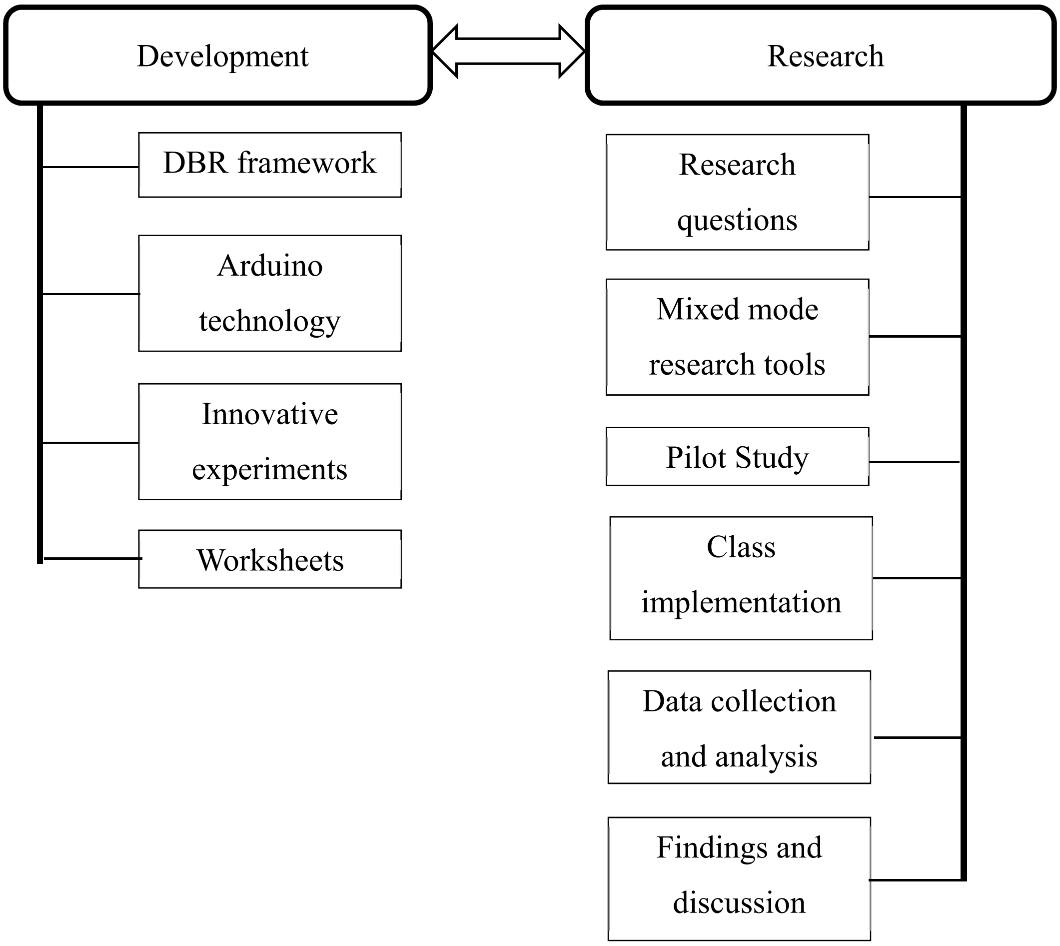


Figure 3.1 Two strands of the Study

The development strand and the research strand are interconnected in the sense that the decision on one part affects the design and approach on the other part. For example, how the research questions are framed determine what ICT tools should be sourced and developed; how the Aduino-based experiments work affect the research method to be adopted; the feedback from the pilot study guides the design of the innovative experiments; the need to feature the scientific investigation components governs the design of the worksheets. An attempt to illustrate the linkage between the development and research strands is diagrammatically set out in figure 3.1.

3.3 Research Design

Evaluation of the study particularly on the effectiveness of the use of open-source digital technology in science education, is done using the mixed methodology research as suggested by Libarkin and Kurdziel (2002) that makes reference to a combination of qualitative and quantitative data collected including surveyed questions and interviews. The mixed-mode research in this study therefore features the collection of both quantitative and qualitative data from the participants. Specifically, pre-tests and post-tests were conducted on an intervention group and a control group to gauge whether there is significant change in students' science efficacy. In addition, survey forms were gathered from all participants and audio-taped interviews were conducted with selected participants in this study. This methodology is adopted so as to gain a comprehensive understanding on how the Arduino-based experiments impact on the learning of physics among the students and how this TEL tool facilitates teachers to shift the learning and teaching of physics to a student-centered environment with a view to fostering scientific investigation and higher-order thinking of students.

Specifically, in this research, the Main Study comprised Phase I and Phase II in which data collected was analysed quantitatively and qualitatively. Phase I referred teachers and students involved in the intervention. Specially, it covered the Intervention Programme for a group of F.4 students of the 2015/16 cohort in the author's school who took physics in their NSS study. Students from both the English and the Chinese streams were recruited for the research. Data from 30 students of this group were expected to be collected for quantitative and qualitative analysis. These students were guided by teachers to use the Arduino-based setup to conduct seven experiments on the topic of “mechanics”. Pre-tests and post-tests were conducted on these students to gauge their knowledge gain on the topic of “mechanics” after the intervention. Their performance in the pre-tests and post-tests were compared with a control group of F.4 students of the 2014/15 cohort in the author’s school to ascertain whether there were significant differences with the intervention. Data from 30 students were also expected from the control group. The intervention group was further invited to complete a survey form and an interview. Feedbacks from another group of F.6 students of the 2015/16 cohort were collected to obtain a balanced view from this third group who had tried out some of the experiments both using the traditional method and the Arduino setup. Survey from the teachers, the technical assistant and the laboratory technicians participating in the Evaluation Phase of DBR were also collected. Four teachers and the technical assistant who guided the students in the Arduino-based experiments were interviewed after the completion of the Intervention Programme.

Phase II was an extension of the Intervention Programme which was carried out outside the School. Arduino-based experiments were introduced to them and they were offered the chance to personally conduct the experiments on their own. Data were collected mainly from two groups of participants by way of the survey form. The first group was local students and teachers who joined the STEM Olympiad 2016 organized by the Education University of Hong Kong and the second group was Singaporean Master Teachers who participated in the Outstanding-Educator-in-Residence (OEIR) Programme held in July 2016 in Singapore.

In gist, both quantitative and qualitative were collected in Phase I and Phase II of the Main Study. Quantitative data were from the survey while qualitative data included written comments from surveys and audio-taped interviews of various participants. The qualitative data is seen to supplement the quantitative research in filling up the gaps in providing in-depth information on the participants. It adds weight and rigor to the research finding, enables researchers to identify intangible factors and helps understand the complex reality of a given situation (Mack, Hilden, Waterson, Moore, Turner, Grier, Weeks & Wolfe, 2005). It provides descriptive meanings to numbers, and adds precisions to stories and pictures displayed on the scene with the use of open-source digital technology in science education. Quantitative and qualitative data gathered formed the basis for answering the two research questions in this study. Figure 3.2 is a schematic diagram on the development, implementation and evaluation process of this study.

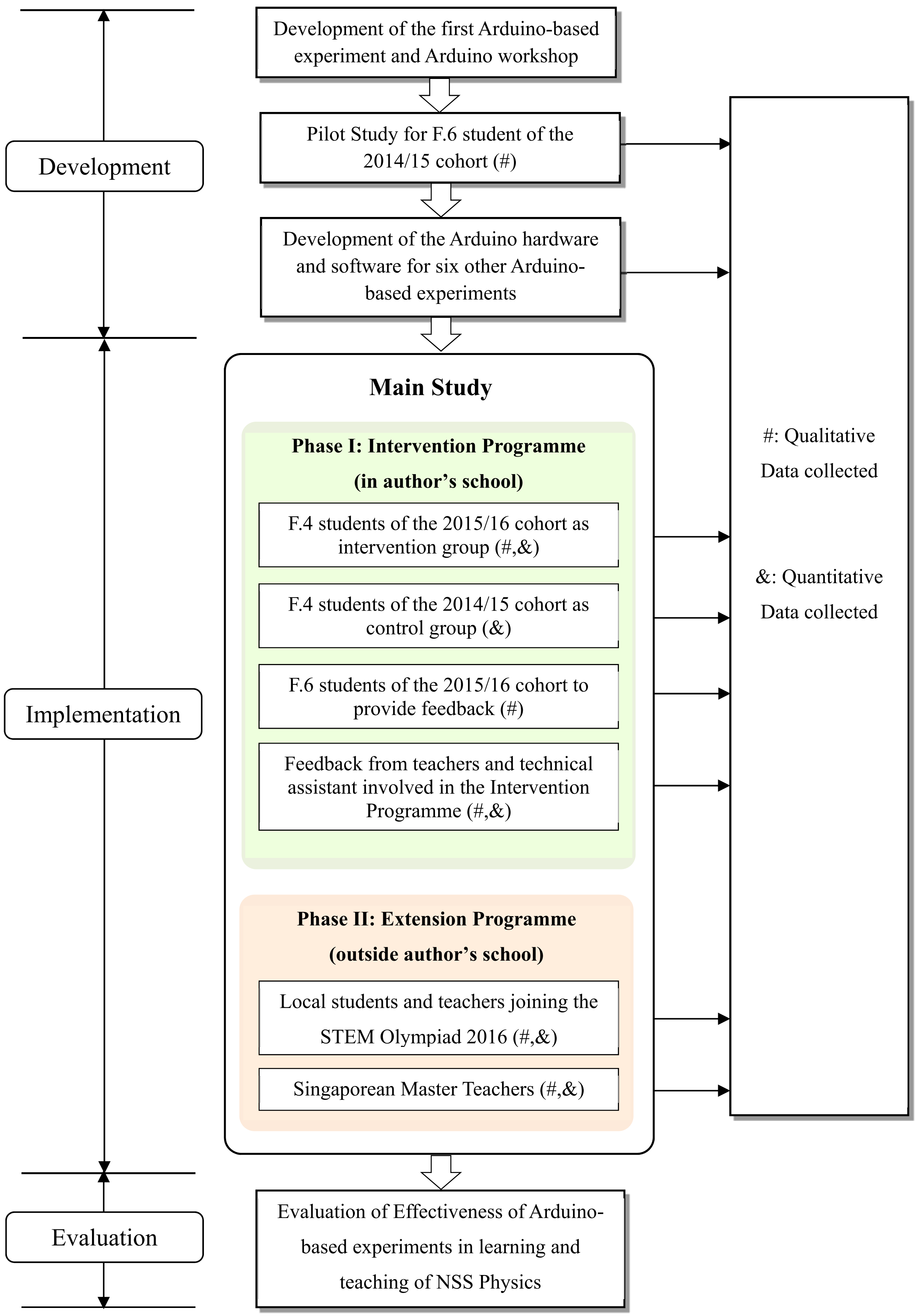


Figure 3.2: Schematic diagram on the implementation and evaluation process of the study

3.4 Research Tools

A number of instruments were deployed for data collection in the Main Study. Given the various target groups, instruments employed and the depth of information gathered through the instrument varied. These instruments were discussed below.

3.4.1 Integrated Process Skill Test (TIPS II)

The Integrated Process Skill test (TIPS II, Appendix E1) was an instrument developed by Joseph C. Burns, James R. Okey and Kevin C. Wise (1982). TIPS II was a validated and reliable instrument for measuring process skills achievement for middle and high school students. 14 out of 36 items in TIPS II were set out in Appendix E1. The 14 questions were selected on the basis that similar types of questions were minimized to shorten the test for easier administration by teachers and to avoid students of the author's school to lose interest in completing.

3.4.2 Force Concept Inventory (FCI) Test

The Force Concept Inventory (FCI) was designed to assess students' understanding of the Newtonian concepts of force. It was developed by Hestenes, Halloun, Wells, and Swackhamer (1985) and was revised by Ibrahim Halloun, Richard Hake, and Eugene Mosca in August 1995. Out of the 30 questions in the FCI question bank, available in English, Chinese and other language versions (Appendix E2), 12 multiple choice questions were selected for the pre-test and pro-test of this research. Han, Bao, Chen, Cai, Pi, Zhou, Tu, & Koenig (2015) when using FCI pointed out that two half-length tests can be a viable option for score-based assessment that need to measure short-term gains where using identical pre- and post-test questions, that shorter tests provide the benefit of being quicker to administer and overcoming the test retest effects, and that if a test is too long, instructors may be reluctant to administer the test. Taking this into account and considering that the Intervention Programme in this research study lasted for half year in the author's school, instead of two different half-length tests, identical half-length pre-test and post-test were conducted. Only 12 questions were selected for this study and the questions were selected on the basis that they were commensurate with the academic attainment of the students in the author's school, such as the topic (projectile) not yet covered was not selected, simpler questions which were commensurate with relatively lower academic standard of students were taken.

3.4.3 Survey

After conduction of the whole series of seven experiments, teachers and students of the author's school participating in the Main Study were requested to complete a survey with multiple choice and some open-ended questions. This was supplemented by interviews with selected teachers and all students involved in the Intervention Programme to probe in-depth into their perception of this ICT tool, to find answers to the two research questions.

3.4.3.1 Survey Form I

Based on the well-known qualitative research methods (Wiersma, 2005; Kubiszyn & Borich, 2000), the survey form for students of the intervention group of the author's school (Appendix B1, Survey Form I) was designed having regard to the fact that the students had gone through the seven Arduino-based experiments. The survey was in the form of a questionnaire which was divided into four sections. Sections A, B and C were multiple choice questions. Questions related to "the prior learning experiences with relevant IT skills", "their attitudes and views on the Arduino-based science experiments" and "Evaluation of experience after applying Arduino technology in various science activities" were set in these sections. A 5-point Likert scale was adopted to collect students' response, with the options of "1", "2", "3", "4" and "5" to stand for "strongly disagree", "disagree", "neutral", "agree" and "strongly agree". Section D involved short, open-ended questions which aimed to collect free-text "written opinions". Views were sought from an experienced science educator regarding the design of the questionnaire and comments were incorporated before it was deployed for use.

3.4.3.2 Survey Form II

Another survey form (Appendix B2: Survey Form II) which was an abridged version of Survey Form I was used to collect views from –

(i) Teachers in the author's school;

(ii) Students and Teachers in the STEM Olympiad 2016; and

(iii) Singaporean teachers in the OEIR Programme 2016.

The form was shortened because the participants, especially those in the STEM Olympiad and OEIR Programme, had limited exposure and/or hands-on experience in the Arduino-based experiments. It would be disproportionate to require them to go through the whole length of the questionnaires as in Survey Form I. Only essential elements were included, but key features of the Survey Form I were retained. Specifically, the survey was divided into two sections with multiple choice questions in Section A and open-ended questions in Section B to ascertain whether knowledge, skills and attitude could be enhanced by applying Arduino technology in learning and teaching of physics. In particular, participants were requested to rate the use of Arduino technology in science learning and to give views on the merits and anticipated difficulties in putting the Arduino technology to practical use in learning and teaching of science.

3.4.4 Interviews

Apart from using the Survey Forms to collect quantitative data, interviews were conducted using the well-known qualitative research methods (Wiersma, 2005; Kubiszyn & Borich, 2000).

The interviews aimed to gather views and feedback from students of the intervention group, F.6 students of the 2015/16 cohort, teachers and the technical assistant of the author's school that could not be directly observed. It also offered a platform that permitted participants to describe detailed personal information (Creswell, 2017, p218). Structured interview was conducted and audio-taped for all sessions. The interview was conducted in the author's school, a familiar setting for all interviewees. The author was the one who conducted all the interviews. As such a high degree of consistency was ensured. The interview questions were not provided to the interviewees beforehand so that their genuine, instinctive response could be captured. Before the commencement of the interview, the author gave a brief introduction to the interviewees so that the interviewees knew exactly what the interviews were for. All interviewees were encouraged to express their views freely and they fully understood that their comments would not have any bearings on their performance ratings or their work in the School.

For the purpose of conducting a fruitful structured interview, a list of interview questions was worked out as based on the procedure outlined by Patton (2002) and kept on an interview form. The design of the interview form for F.6 students of the 2015/16 cohort (Appendix C1) was relatively simple and straight forward. Interview for this group of students was carried out in March 2016 when the F.4 intervention group was mid-way through the Intervention Programme. This group of students had been taught the whole physics syllabus and ready to sit for the HKDSE Examination by the time the interview was done. As such they were interviewed before the intervention group. The questions put to them were focused on comparing the traditional experiments with the Arduino-based experiments and the effectiveness of the use of Excel for data treatment.

The interviews for the students in the intervention group, teachers and technical assistant were conducted after the intervention group had finished the seven Arduino-based experiments. The design of the interview form for students of the intervention group (Appendix C2) was also simple and straight forward but the design of the interview form for teachers and technical assistant (Appendix C3) was relatively complicated to probe deeper into how they view the Arduino technology. Some questions in the interview were common to all while some were specific to the teachers who had conducted the interventions and some were only for the technical assistant.

3.5 Pilot Study

3.5.1 Objectives

The development of the seven Arduino-based experiments on the topic of "mechanics" in physics was scheduled to be finished at the fourth quarter of 2015. Before proceeding to the full development of seven experiments, a Pilot Study was conducted with a group of 21 F.6 students in the 2014/15 cohort. It aimed to identify the receptiveness of students to the Arduino-based experiments, to assess the feasibility of using Arduino in science education, to probe any defects in the hardware and software design, to look for any misconception and to make improvements. Feedbacks collected helped consolidate the direction for future development of other Arduino-based experiments as well as the approaches in conducting the research.

3.5.2 Set up of the Development Team

A Development Team was set up in the 2^{nd} quarter of 2014 for developing the hardware and software for the study. The prototype of the Arduino device was first produced for application in the "circular motion" experiment. The team also generated the codes for driving the hardware, tested the functionality of the prototype and examined the worksheets prepared for the students. The Development Team consisted of the author, an experienced laboratory technician and a technical assistant who had relevant experience and profound knowledge in electronics and computer programming.

3.5.3 Implementation of the Pilot Study

The Arduino-based experiment developed on the topic of “Circular motion” was a common, traditional experiment in the HKDSE syllabus. However, results from the experiment were rarely reliable and the procedures in data collection were tedious and repetitive. The Arduino-based experiment, if successfully run, could give students a completely different experience in performing the experiment. It was on this basis that this experiment was chosen as the first experiment to be tried out in the Pilot Study. With the question in mind as to whether some fundamental knowledge on Arduino would be beneficial to students in the implementation of the Arduino-based experiments, an Arduino workshop was developed in parallel for the students. The workshop aimed at giving students prior, basic knowledge and hands-on experience with the use of Arduino. The workshop included a brief introduction of the Arduino hardware architecture, basic knowledge on some electronic components and sensors, the techniques of modifying and uploading simple programs to operate input/output devices such as LED, buzzer, variable resistor, and temperature sensors, etc.

The Development Team conducted the Pilot Study at the 2nd quarter of 2015. Eleven and ten students from the Chinese and English streams respectively voluntarily participated in the Pilot Study. All students were F.6 students who had completely gone through the NSS physics curriculum and had conducted the traditional experiment on circular motion. Conventionally, this was an experiment involving considerable time to perform and a long report for the experiment was required in the school-based assessment (SBA) of the HKDSE.

In the Pilot Study, the Arduino workshop and the Arduino-based experiment on circular motion were carried out in two consecutive weeks, each lasted for 50 minutes. A ten-minutes briefing was conducted in each session. As only four sets of apparatus were available, 21 students were divided into four groups, with about five students in each group to try out the device and perform the experiment. Worksheets were distributed among students to record their findings and they were requested to complete the worksheets within the lesson at their best effort. Class observations, exchange with students during their conduction of the experiment and post-experiment discussion among Development Team members were conducted. Field notes were taken by the author. Feedbacks collected were carefully adopted for future development of other Arduino-based experiments. Specifically, feedback from the students in the Pilot Study helped confirm the feasibility of the use of Arduino for conducting experiment on "mechanics" among students. How the feedbacks helped the further planning and development of the research were discussed in Chapter 4.

3.6 Population and Data collection

Purposeful samplings, in which individuals and site to learn and understand were selected according to whether they were "information rich" (Patton, 2002), was adopted in this study. Different groups of participants were selected in different phases of the study and different tools were used to collect data and gather feedback from different perspectives. These are discussed in ensuing paragraphs.

3.6.1 Phase I: Intervention Programme within author's school

The target group in Phase I were NSS students and teachers of the School in which the author taught and conducted the study. The School was one of the few technical schools in Hong Kong. Only boys were admitted and their academic achievement and the socioeconomic status were relatively lower than the average of Hong Kong. The School put emphasis on the overall development of the students with particular focus on the practical and hands-on skills of the students. The School's policy on science education, workshop facilities, teachers' competency, resources allocation, students' learning aptitude and their readiness on hands-on learning favored the introduction of new technology into the science education curriculum. This feature is further discussed in Section 4.3 in Chapter 4.

The rationale for selecting NSS students and teachers in the author's school for the study was related to the background of the School and the students. Anderson (2002) has pointed out that leading-edge innovations do not necessarily lead to widespread adoptions, but the benefits that are to be gained are when confident teachers are willing to explore new opportunities for changing their classroom practices by using ICT. In this study, all participating teachers were ready to use the Arduino device in their practical lessons. Students were adept at carrying out hands-on experiments on their own. These offered a favorable environment for the research on the effectiveness of the use of the Arduino technology in the teaching and learning of NSS physics, without the need to consider the possibility that any failure could be due to the lack of self-efficacy of students and teachers in mastering hands-on experiment and ICT devices, rather than the ineffectiveness of the ICT devices in the teaching and learning of physics.

For the NSS curriculum in the School, apart from four core subjects that students must take, namely Chinese, English, mathematics and liberal studies, students could choose two more elective modules in their study such as physics, chemistry, biology, design and technology, physical education and visual arts, etc. In this study, the intervention group is the group of students who has chosen physics as an elective subject in their NSS study.

3.6.1.1 Intervention group: F.4 students of the 2015/16 cohort

The research entered into the Main Study in 2015. It was expected that there should be over 30 students taking physics in the NSS syllabus. These students came from two classes, one class with English as the medium of instruction and the other class with Chinese as the medium of instruction. They all participated in this study voluntarily. At the time of intervention, they have gone through the topics of thermal physics and optics in the physics syllabus and have conducted a series of laboratory sessions on the related topics. As such, they have mastered a certain degree of skills in carrying out physics experiments and were familiar with the safety regulations in the laboratory.

Before the Intervention Programme, students of the intervention group were requested to sit for the pre-tests of TIPS II and the FCI Test (as further elaborated in Section 3.4.1 and 3.4.2 in Chapter 3) to assess their integrated process skills and knowledge in the topic of mechanics of the students, respectively. They were then tasked to conduct the seven Arduino-based experiments in groups of two or three students in order of the teaching schedule when the topic was covered or about to be covered. Students conducting the experiments in groups rather than individually provided them the opportunity to actively share their ideas and exchange thoughts about the ongoing tasks (Shieh & Chang, 2014). As Koenig et al. (2012) argued, possibility of cooperative learning in a small class setting under the guidance of a caring instructor is just as important in helping students transition from high school to college. The design of the Intervention Programme was designed with these taken into consideration. After the series of experiments, students were invited to conduct the post-test to assess again their integrated process skills and knowledge in mechanics. Finally, all students who had participated in the Intervention Programme were invited to complete a survey (Survey Form I, Appendix B1) and attend an interview. The interviews were conducted in groups of two to three students. Each interview lasted for about an hour and was audio-taped.

3.6.1.2 Control group: F.4 students of the 2014/15 cohort

The pre-test and post-test results of the intervention group on FCI and TIPS II were compared with those of the control group which had not been subject to intervention but had sat for the pre-test and pro-test before and after carrying out the experiments using the traditional method. This enabled a parallel, objective comparison of the effect of the intervention on the students vis-à-vis the traditional method on the students. As the population of students choosing physics as an elective subject in the NSS syllabus dropped drastically in recent years, it was impossible to have enough sample size of the intervention group and the control group in the same year. As a compromise, the control group was taken from a group of F.4 students studying physics of the 2014/15 cohort (i.e. the previous cohort). The control group also went through the same physics syllabus and had finished relevant experiments on the topic "mechanics" using the conventional methods. The control group also voluntarily took part in the study and completed the pre-test and post-test. A t-test was carried out to compare the results of the intervention group with those of the control group to see if there was significant difference after the intervention or after the traditional experiments in the science self-efficacy of the two groups of students. The result is further discussed in Chapter 6.

3.6.1.3 Feedbacks from a group of F.6 students of the 2015/16 cohort

In parallel, six F.6 students of the 2015/16 cohort were invited to give feedbacks on the use of Arduino in performing the experiments versus the traditional method. This group of students had finished the whole HKDSE physics syllabus and had carried out all traditional experiments on the topic of "mechanics" at the time they were invited to participate in the study. The six students were invited on the basis that three of them were selected from the English class, and three from the Chinese class. In each class, students from the segment of low, medium and high academic achievements were randomly selected for the study to ensure equal representation at different levels. They all participated in the study voluntarily. For this study, they first attended a workshop in which a brief introduction of Arduino and demonstrations on two selected Arduino-based experiments (Experiment 3 on Newton's second Law and Experiment 6 on circular motion) were shown to them.

The six students were then divided into two groups (Chinese group and English group) to conduct the two Arduino-based experiments on their own, with worksheets in hand. Immediately after the workshop, they were invited to an audio-taped interview. The workshop and the interview each lasted for about an hour. They were asked to compare the effectiveness of learning the topics between the Arduino-based experiments and the traditional methods. Their views carried weight as they were the only group in the Main Phase who had performed the experiment, with both the traditional method and the innovative method using the Arduino technology.

3.6.1.4 Feedback from the Teachers and Technical Assistant

Three physics teachers, the head of the science key learning area, and the technical assistant who assisted in the development of the Arduino hardware and software throughout, were individually invited to an interview to collect their views on the research questions. All of them (refer to Section 4.7.2 for a brief introduction of their background) had taken part in the Evaluation Phase in the DBR. Two of the physics teachers, Teacher D and Teacher E were responsible for conducting the English class and Chinese class respectively in the Intervention Programme. The interview lasted for half an hour and was audio-taped. Structured questions were posed to them to understand their attitude and interest in the use of the Arduino technology for the teaching. Reference was also made to classify answers in the survey forms. The author might respond to the answers of the interviewees to have an in-depth probe into the response, reasoning and perception of the interviews.

3.6.2 Phase II: Target groups outside School

In Phase II of the Main Study, the target groups were students and teachers outside the School. The Arduino-based experiments were introduced to local senior secondary students and teachers who joined the STEM Olympiad 2016 and the Singaporean teachers who participated in the Master Classes of the Outstanding-Educator-in-Residence (OEIR) Programme 2016 in Singapore. Their views were gathered by survey (Survey Form II, Appendix B2)

3.6.2.1 STEM Olympiad 2016

Relevance of inviting students and teachers participating in the STEM Olympiad 2016 to join the study was premised on the fact that STEM Olympiad was an event jointly organized by the Department of Science and Environmental Studies (SES), Department of Mathematics and Information Technology (MIT) and Centre for Education in Environmental Sustainability (CEES) of the Education University of Hong Kong (EdUHK) in July 2016. The event aims at nurturing individuals not only in the STEM subject knowledge but also integrated skills and problem-solving techniques for innovative ways of dealing with contemporary environmental issues. About 700 F.5 and F.6 students from around 100 local secondary schools participated in this event. Participants were expected to have a keen interest in STEM education and were eager to take part in innovative STEM activities. Viewed from this perspective, they should be a relevant target group for this study. In this research, students and teachers participating in STEM Olympiad 2016 were invited, on a voluntary basis to join a hands-on workshop on the use of Arduino technology in the learning and teaching of physics. Two separate workshops, each lasted for 45 minutes, were organized for students and teachers respectively. Given the limited time, not all seven experiments were demonstrated to these target groups. Only four Arduino-based Experiments (Experiments 1B, 2, 3 and 6) were selected for a twenty-minute demonstration. Experiment 1B was chosen as the first one to start with as it was a simple investigative experiment. Experiment 2, which was the first experiment to work with Excel to manipulate data collected from the Arduino device, was the second one selected. Experiment 3 (Newton's 2^{nd} Law) and Experiment 6 (Centripetal force) which could fully exhibit the advantages of the Arduino technology over traditional methods in performing the experiments were also selected. Eight sets of experiments (two sets for each experiment) were setup for their hands-on experience. Participants were given twenty minutes to carry out four experiments. After that, five minutes were given to the participants to complete a survey form (Survey Forms II), which was the key data collected form this participating group for subsequent analysis.

3.6.2.2 Outstanding-Educator-in-Residence (OEIR) Programme

As a further extension, the effectiveness of the Arduino devices in the learning and teaching of physics in education institutional settings in Singapore was tested. Singapore is a country which attaches great importance to nurturing students on the scientific front. In the Programme for International Student Assessment (PISA) held in 2012 and 2015, performance of the Singaporean students in the science subject was at the top echelon and was ranked first in 2015. The table below shown the mean scores in the science subject of 15-year-olds in the top ten countries/economies.

Country/Economy	Mean Score in Science in PISA 2012	Country/Economy	Mean Score in Science in PISA 2015
Shanghai-China	580	Singapore	556
Hong Kong-China	555	Japan	538
Singapore	551	Estonia	534
Japan	547	Chinese Taipei	532
Finland	545	Finland	531
Estonia	541	Macao (China)	529
Korea	538	Canada	528
Vietnam	528	Vietnam	525
Poland	526	3.7 Hong Kong (China)	523
Liechtenstein	525	Beijing-Shanghai-Jiangsu-Guangdong (China)	518
Canada	525		

Table 3.1: Mean scores in the science subject of 15-year-olds in the top ten countries/economies in PISA

To test the Arduino technology in this country where science education has been a key development area was envisaged to obtain considerable useful data for drawing inferences. In July 2016, the author was invited by the Academy of Singapore Teachers (AST) and Ministry of Education (MOE), Singapore to participate in an Outstanding-Educator-in-Residence (OEIR) Programme, as a guest speaker. Apart from holding professional conversations to support the teaching and learning of physics with master teachers, officers form AST, National Institute of Education (NIE) and Curriculum Planning Development Division (CPDD) of Singapore, the author conducted four Master Classes and one Head of Department (HOD) dialogue for middle managers and teachers of Singapore. Each Master class lasted for three hours, in which one hour was allocated to an experimental session on four selected Arduino-based experiments in physics. 131 Singaporean teachers participated in the four Master classes held over two weeks. In the one-hour workshop conducted in the OEIR Programme, four Arduino-based experiments (Experiments 1B, 2, 3 and 6) same as that in the STEM Olympiad 2016 were chosen. The participants were given a 25-minute demonstration, a 30-minute hands-on session and a 5-

minute survey session. Their feedbacks on the use of Arduino in the learning and teaching of physics were collected using survey form (Survey Form II), which was basically the same set of survey form used in the STEM Olympiad 2016.

3.7 Data Analysis

In this study, different forms of data were collected. Depending on the data source and data format, different methods were adopted in the data analysis. Details are set out below.

3.7.1 Class observation

In many observational situations, it is advantageous to shift or change roles in the observation. A changing observational role is one when researchers adapt their role to the situation (Creswell, 2017, p215). In the Pilot Study, the author adopted a changing observational role. At times the author played the role of a non-participant, conscious of the importance not to interfere or impede the exploration process of the students. At other times when more in-depth understanding of the students' circumstances was required, the author became a participant actively interacting with the students. Having known the students for years already, the author did not need any ice-breaking session to make the students at ease in performing the experiment themselves. The author closely observed the entire process had discourse with students during the practical lesson, where necessary, to gather their instant feedback and summarized the class observations in the Pilot Study in the form of field notes. The feedback was fed into the Development Phase in the DBR. They were instrumental to the further development of the Arduino-based experiments and the courseware.

3.7.2 Pre-test and post-test

The scores of the pre-test and post-test for the intervention group and the control group were collected and marked. The answers to the tests, that is the test on FCI and TIPS II, illustrated the knowledge that students constructed on these concepts. The answers for individual questions in the pre-test and post-test were input into an Excel table. Macros written in the Excel template compared the inputs with the key answers and calculated the scores for individual items and the total scores of the two tests. The results of the pre-test and post-test were fitted into a t-test to understand the significance of the intervention.

3.7.3 Quantitative Analysis of MC questions in the Survey Forms

Apart from understanding the effect of the intervention on the knowledge building of students, a Survey Form served to gauge the attitudes, views and evaluation of experience of the students with the use of the Arduino technology in the seven Arduino-based "mechanics" experiments. The answers for individual questions in the Survey Form were input into an Excel table. Macros written in the Excel template generated statistics on the basis of the options the participants had entered. Excel would calculate the average score for individual items. The options that stood for "strongly disagree", "disagree", "neutral", "agree" and "strongly agree" were numerically coded with, an average score of "3" representing "neutral" position while scores higher than 3 representing "agree" or "strongly agree" positions. Bar charts were used to present the distribution of choices, which gave a quick overview of the opinions of the participants.

3.7.4 Qualitative Analysis of transcriptions of interviews and written comments in the Survey Forms

Qualitative analysis of the text-based feedback gathered from teachers and students through the Survey Forms, and interviews in respect of certain participants in the author's school as set out in Section 3.4.3 and 3.4.4 above was carried out. The analysis aimed to find out how and under what circumstances the Arduino-based setup could best be used in learning and teaching of physics. Qualitative analysis was carried out by coding the data collected and categorizing them purposely.

Transcriptions of the audio-taped interviews were not word by word, but only the main ideas were recorded. The data collected from the interviews were broadly grouped into five categories: first, the effect of Arduino technology on the learning and teaching of physics; second, how the Arduino technology facilitated the conduction of experiment; third, how favorable the Arduino technology was for the use in physics experiments; fourth, how the Arduino technology compared with the traditional method which referred to the experimental setup and methodology commonly used by secondary schools in Hong Kong for conducting experiments in the topic of "mechanics"; and fifth, what challenges were envisaged with the use of Arduino technology. To code the data, the author conducted a preliminary analysis by reading through the interview records to obtain a general sense of the data (Creswell, 2017, p261). Participants' utterances or text segments were broken into simple statements (or threads) for coding. The coded threads under the five categories were then used to develop themes that presented a broader abstraction than codes. Details of the coding system are further elaborated in Section 5.5 in Chapter 5.

3.8 Validity of Data

Validity of the data collected in this study is closely related to the factors discussed below. In order to improve the validity, specific strategies to tackle problems such as a limited sample size, the language barrier of the students etc. were adopted in the study in the light of potential challenges.

3.8.1 Sample size

Sample size was a determining factor in the validity of data (Wiersam, 2005; Creswell, 2017, p.146). The continuous declining birth rate in Hong Kong over the decades had a great impact on the population of students in the author's school. Moreover, with the introduction of the NSS curriculum, the number of students taking physics as an option in the NSS study was dropped even more dramatically, from almost 200 students in each form before the NSS curriculum was introduced in Hong Kong to less than 20 in each form at the year when the Intervention Programme launched. Therefore, the validity of the data in comparing the pre-tests and pro-tests of the two groups of F.4 students of the 2014/15 and 2015/16 cohorts in the Main Study might become an issue. Given this possible situation, the research design includes collection of qualitative data from participating students to probe in-depth into and understand the impact of the intervention on them.

3.8.2 Language Barrier

The students participated in the Intervention Programme had to sit for the pre-test and post-test for the FCI and TIPS II tests respectively. FCI was officially available in many languages including Chinese and it was not necessary to make any translation for the students. However, Chinese version of TIPS II was not available. The author therefore specially arranged translation of the test into Chinese, which was certified by two experts from local universities, one specializing in education and the other specializing in translation before the test was passed to students for carrying out the pre-test and post-test.

In the School where the author conducted the intervention, students of junior classes (i.e. F.1 to F.3) attended lessons in science subjects with Chinese as the media of instruction. When students were promoted to F.4, they were split into the English and Chinese streams, with majority going to the Chinese stream. As Chinese remained the most familiar language for students of both streams, to avoid any inconsistencies of results due to the use of languages, only Chinese version of the worksheets were prepared in the Intervention Programme and Pilot Study for both streams of students. Apart from worksheets, Chinese was used as a medium of instruction for all students in the Intervention Programme, including in the pre-test, post-test and interviews.

The Survey form used in the author's school was bilingually written. Students were free to give written answers in Chinese or English. For the interviews held for the School's teachers and technical assistant, the participants replied the author's questions verbally in Cantonese (a dialect of Chinese). As the author is a native Cantonese speaker as well as a fluent English speaker, there is no problem in understanding or transcribing the written comments and contents of the interviews into English.

For the worksheets used in the OEIR Programme, as the official language in Singapore is English, four worksheets of the Arduino-based experiments were translated into English, again with the help of two experts mentioned in this Section to certify the translation. The survey form (Survey Form II) for the Singaporean teachers was also written in English.

3.8.3 Other considerations in data validity

Other factors that would affect the validity of the data collected in the research were also taken into consideration. This included the Hawthorne effect, the role of the author in class observation, and the close working relationship of the author's colleagues who participated in the study. These factors are further discussed in Chapter 7.

3.9 Ethical Issues

In this study, the author was previously the physics teacher of some of the students in the author's school. The teachers of the School participating in this study were close working partners of the author. Against this setting, particular concern was placed on the ethical issue to ensure that none of the participants felt they were compelled to join the study. The author, as an EdD candidate, submitted application for ethical review from the Human Research Ethical Committee of HKIEd (renamed EdUHK in 2016) and had obtained formal approval before the collection of data form the target population.

3.9.1 Consent form for students and teachers

At the outset of the study, it was made clear to all students and teachers participating in the research that the participation was solely on a voluntary basis. Those who agreed to join the study were invited to sign a consent form, indicating that that they agreed on the purpose of the data collected from them. The two consent forms used for (i) local students and teachers and (ii) the Singaporean teachers was documented in Appendices 19A and 19B. The author ensured that all participants fully understood the purpose of the study, the full protection of their personal privacy in the course of the study and their benefits and rights while participating in this study.

3.9.2 Author's students

The F.6 students participated in the Pilot Study were further reassured that the results of the two laboratory sessions would not affect their final grade or scores in their School-based Assessment or internal examination. Their feedback was solely for research purpose, and their honest reflection of their experience with the Arduino-based experiments was valued. For the F.4 students of the intervention group who participated in the seven Arduino-based experiments, they were informed that the scores of the seven laboratory sessions would be counted as their course work marks, which constituted part of their final grades in physics in the School's internal examination. It was a fair arrangement as laboratory work was always counted in the examination, only that in this case, the traditional experiments were replaced by the Arduino-based experiments. Whether or not the students joined the pre-test and post-test and subsequent interviews were entirely voluntary. In addition, the results of the seven Arduino-based experiments would not affect their scores in the School-based Assessment, which contributed their final grade in the HKDSE examination. In this way, students' possible fear of any negative consequence for not joining the research was alleviated.

3.9.3 Identities of the participants

The participants in the research involved different stakeholders. In the author's school, science teachers, laboratory technicians, technical assistants and three groups of students had participated in different phases of the study. Outside the author's school, teachers and students from other schools in the STEM Olympiad 2016 Programme and the Singaporean teachers in the OEIR Programme 2016 had been involved.

In Phase I of the Main Study, to ensure that the students treat the study seriously, students in the author's school were required to put their real names on the pre-test, post-test and the survey form. However, their identities were masked in the interview records, data coding, and the final presentation of the Thesis to protect their personal data.

In the interview records, teachers were coded with letters like "Teacher A" and "Teacher B" while students in the author's school were coded sequentially with their "Form" in front, e.g. "F4S7" to mean the seventh student in the F.4 student group. Some of the students were repeaters and some were students with "Special Education Needs (SEN)", suffering from Autism, Dyslexia, etc. Their identities were hidden as a measure to protect them. For the survey in the STEM Olympiad 2016 Programme and the OEIR Programme 2016, the survey form is anonymous.

CHAPTER 4

DESIGN-BASED RESEARCH

4.1 Design-based Research

This research is pursued under the design-based research framework in which the author, who acted as a researcher, managed the research processes in collaboration with participants at difficult phases, mainly the technical assistant, experienced science and physics science teachers, laboratory technicians and senior secondary school students, designed and implemented interventions systematically to refine and improve initial designs, and ultimately sought to advance both pragmatic and theoretical aims affecting practice (Wang & Hannafin, 2005). DBR is a research that manifests both scientific and educational values through the active involvement of researcher in learning and teaching procedures and through "scientific processes of discovery, exploration, confirmation, and dissemination" (Kelly, 2003, p.3). Throughout the process, the researcher assumes the functions of both the designer and researcher, drawing on procedures and methods from both fields (Wang & Hannafin, 2005). As far as this research is concerned, I accordingly play the role of the designer and researcher in developing a series of experiments on the topic of mechanics using Arduino.

DBR is grounded in real-world contexts where participants interact socially with one another, and within design settings rather than in laboratory settings isolated from everyday practice (Brown & Campione, 1996; Collins, 1999). Premised on this, the series of experiments developed in this research emphasized an authentic setting, and it was expected that the results of the experiments could be affected by a multitude of factors pertaining to the actual circumstances. In addition, DBR stresses the collaboration among participants and researchers (Cobb, Confrey, diSessa, Lehrer & Schauble, 2003), as direct theory application without practitioner interaction is often not feasible because of dynamic and complex relationships between theory and practice (Schwartz, Lin, Brophy & Bransford, 1999; van den Akker, 1999). This crucial element was manifested through the development process as further discussed in this chapter. DBR is also characterized by an iterative cycle of design, enactment or implementation, analysis, and design (DBRC, 2003). Cycles of refinement, testing and adjustment to develop effective model for deployment marked a key feature in this research.

From a DBR perspective, research should refine both theory and practice (Collins, Joseph & Bielaczyc, 2004). In addition to asking whether a theory works, researches further question how well the theory works; that is, whether a given theory is better (i.e. more effective in achieving the design goals, cost efficient, and appealing to stakeholders) than known alternatives to attaining a desired outcome, and how research might refine the theory (Reigeluth & Frick, 1999). Anchoring on this perspective, DBR is closely related to the two research questions in this study, namely to test how open-source hardware and software can be used in developing innovative experiments for the learning and teaching of physics; and to review the effective use of the open-source digital technology in the learning and teaching of physics.

4.2 Arduino Technology

Arduino is an open-source electronics platform that operates with easy-to-use hardware and software. Open-source software means that the copyright holder provides the rights to study, change, and distribute the software to anyone and for any purpose. Arduino boards are equipped with sets of digital and analog input/output pins that may be interfaced to various sensors, expansion boards (shields) and other circuits for carrying out an array of meaningful investigations. Arduino is designed as an easy tool for fast prototyping, aims at novices without background in electronics and programming to create devices that interact with their environment using sensors and actuators.

Arduino offers multiple advantages over other system in science education. Open-source Arduino software relieves users the concern about copyright issues. Cross-platform capability (i.e. runs on different operating systems), low cost and abundant supply of hardware, sensors and peripherals, programmability in automated data collection and high portability make Arduino very suitable for building flexible scientific instruments to study science principles. Pedagogically, Arduino opens up an array of opportunities to cater for self-directed learning, namely in the data, collection aspect, higher order thinking, authentic scientific investigation and student-centered learning and exploration

4.2.1 Automated data collection

A major advantage with the use of Arduino was to relieve students from tedious and repetitive data collection procedures. With the use of Arduino, the procedures of data collection were made simple, fast and easy manipulation of data could easily be done with an Excel template. The fundamentals of the experiment were revisited that it should not stress on teaching and drilling students' practice to take data, which only reduced students' interest in performing experiments, but more on reasoning, interpretation of the data from the graphs and searching for what further investigations could be made. This is in line with the notion of DBR that it provides an alternative approach that emphasizes direct, scalable and concurrent development improvements in research, theory and practice (Wang & Hannafin, 2005).

4.2.2 Time saving for higher order thinking

Students were motivated to ask questions of "what if" regarding changes to some parameters or make their own hypothesis. They could spare time to repeat the experiment with some modifications in the settings, and could observe how the changes would make differences. They could also systematically change the parameters to understand the impact and construct their conceptual knowledge. Students no longer need to spend time and focus on following procedures without actually comprehending why and what they are doing. They could have higher-order discourse and collaboration to test their hypothesis. Excel was introduced from the bouncing ball experiment (Experiment 3 as coded in Section 4.6.3) onwards to facilitate students in plotting graphs and deriving relations. Data stored in the SD card could be transferred to the Excel template simply by the "cut and paste" function and the macros embedded in Excel would generate all necessary graphs (e.g. displacement-time and velocity-time graphs). Students could zoom in and print out an area of a graph simply by clicking the pull-down menu for more in-depth study. Some graphs could be fitted with a best straight line and some important physics parameter (like gravitational acceleration, friction, mass etc.) could easily be retrieved from the values of the x, y-intercepts and the slope of the straight line shown on the screen. As students practiced these experiments progressively, they became more familiar with the skills in data collection and data manipulation and more and more time could be saved for performing tasks that involved higher-order thinking. In this way, DBR can "help create and extend knowledge about developing, enacting and sustaining innovative learning environments." (DBRC, 2003, p.5)

4.2.3 High adaptability for authentic scientific investigations

Merits in the use of Arduino also lied in its enormous potential to generate variations. For some Arduino-based experiments developed, with little modifications in hardware or programming, the Arduino devices could easily be converted into some other applications or could be brought outside of classroom to perform outdoor science activities or investigations. In this way, learning and teaching of physics was extended outside the classroom into the real-world settings e.g. ultrasonic sensor used in the bouncing ball experiment (Experiment 2 as coded in

Section 4.6.3) and collision experiment (Experiment 5 also as coded in Section 4.6.6) could be conducted at playgrounds or at the sea to gather meaningful data like the sea water level, or the height of a human body, or the motion of an athlete in a race, etc. This is consistent with the DBR framework which advocated the importance of real-world contexts research when participants interact socially with one another and within design setting rather than in laboratory settings isolated from everyday practice. (Brown & Campione, 1996; Collins, 1999).

4.2.4 Enhancing accessibility to students

Cost has always been a consideration in the use of ICT for teaching and learning physics. When comparing Arduino with other digital devices which had been widely used such as the data logger, it was revealed that the price for a commercial data logger with sensors and software was far more expensive than the Arduino. An Arduino system only costed about US$10 to US$20 whereas a data logging system could cost four to five times higher (Yeung, Cheang & Fok, 2015). In doing the data manipulation, students could use the free licensed Open Office instead of the Microsoft Office. Such setup was most advantageous to schools when budget was a concern. Nowadays, many schools were facing a tight budget on purchasing ICT hardware and software and very often could only afford to purchase one to two sets of data loggers for the purpose of demonstration of experiment. Low-cost Arduino devices offered a great advantage over the conventional data logger. Some of the Arduino-based experiments designed could directly replace expensive data logger and students could be divided into small groups to perform the experiments on their own, thereby enhancing their personal accessibility and experience in carrying out the experiments. The effectiveness of Arduino was comparable to that of conventional data logger.

4.2.5 High programmability for flexible applications

Programmability was also an advantage of Arduino over conventional data logger. As Yeung, Cheang & Fok (2015) had pointed out, existing commercial datalogging systems are not only quite expensive but are also installed with their own proprietary software that restricts the teachers' and students' full or creative utilization of the systems. On the contrary, Arduino offers great flexibility in its application. Special program could be written and embedded into the Arduino mother board to perform some real-time data processing. For example, in the collision experiment (Experiment 5), program could be embedded into the Arduino mother board to perform real-time noise filtering to filter off random errors in the data collected.

4.2.6 Flexible combination of components for scientific investigation

The appeal of Arduino in the learning and teaching of physics also lied in the possible combinations of sensors that it could be connected to and applied in testing a whole range of concepts in physics, or even in some other science subjects. e.g. verifying Pressure Law with the temperature and pressure sensors, monitoring the rate of production of carbon dioxide in a plant using carbon dioxide sensor. These varied combinations of sensors for scientific investigation leave much room for students in exploring science by themselves, which is conducive to the constructivist made of learning whereby students are responsible for their learning.

4.2.7 High portability of Arduino device

The petite size of the device was another advantage of Arduino in science data collection. Some versions of Arduino boards, like Arduino-nano or Arduino beetle, had the size of a finger or a stamp so that the Arduino device could be made portable or even wearable. The whole set-up together with the sensors, modules and battery, could be mounted onto a moving trolley or carried on human body for direct measurement of motion. In the Newton's 2nd Law experiment

(Experiment 3), the whole Arduino device was carried by a moving trolley. In the circular motion experiment (Experiment 6 as coded in Section 4.6.7), an Arduino board together with the motion sensors, SD card module and battery were mounted onto the end of a swinging ruler to record centripetal acceleration and angular velocity in a circular motion. Such motions could never have been captured with such great details in conventional experiments. The high portability of Arduino device, with its low cost, enticed students to acquire the device for carrying out experiments outside of the classroom in real world. The resulting principles using Arduino under a DBR framework were perceived as having greater validity than those developed in laboratory settings, (Greeno, Collins and Resnick, 1996) and as better informing long-term and systemic issues in education (Bell, Hoadley, and Linn, 2004). The Arduino-based platform had immense opportunity for development under DBR.

4.3 Considerations in designing the Arduino-based experiments

Before the development of the seven Arduino-based experiments, the rationales for selecting Arduino technology in the teaching and learning of physics and the direction as to how the technology could be integrated into the syllabus were critically considered.

4.3.1 Integration of the Arduino technology into the curriculum

A primary consideration was that the experiments to be developed favored teaching and learning of physics and were conducive to promoting STEM education. The experiments must practically be integrated into the Hong Kong NSS physics curriculum and the traditional experiments could be readily replaced by the new technology i.e. the Arduino-based experiments without causing any undue disruption to the current already tight teaching schedule. Teachers who were involved in implementing the program should be supportive and mentally prepared to accept the changes. The experiments were not tailor-made for senior secondary students of a specific school, i.e. the School that the author was teaching, but for senior secondary students of different levels of academic attainment in Hong Kong, on the Mainland or even overseas. As Wang and Hannafin (2005) advocated, as a principle of DBR, researchers need to optimize a local design without decreasing its generalizability because effectiveness is a function of both success in addressing local needs and the applicability of the design principles to the settings. The Arduino-based experiments were developed with particular focus on the generalizability perspective.

4.3.2 Policy of the School in STEM education

A secondary consideration was related to the implementation of this technology at school level. Integration of Arduino-based experiments into the NSS curriculum could create great challenges among teachers and students if not well planned. Effective implementation of the program depended very much on the school policy on the use of ICT in teaching and learning of science and technology. This research was conducted in the author's school which was one of the few technical schools in Hong Kong that owned the largest technical workshop and the best workshop facilities among the schools of Hong Kong. Our School's orientation and positioning in education over decades put great emphasis on the use of ICT in science and technology education. The policy and the focus of the School both favored the introduction of new technology in science education.

Considerable investment has been placed on ICT hardware and software and the School has been taking a leading role in many pioneering projects related to the use of new technology. It was one of the first batch of schools in Hong Kong that introduced the use of data logger into the science curriculum.

4.3.3 The competency and efficacy of teachers

The success in implementing the program hinges much on the competency and efficacy of physics teachers in the School. Arduino is a novel concept for most secondary school teachers, even for teachers in our School. In designing the experiments, the Arduino device was presented to our School's teachers as a simple tool. Teachers were not involved in the design of the hardware architecture and software programming. A former student of the School, who had gone through the Advanced Level physics curriculum and was an expert in the Arduino technology, was recruited to the Development Team as a technical assistant to develop the Arduino hardware and software. The hardware was made as simple as possible. Excel templates for data treatment and self-explanatory worksheets were written for teachers and students. Training was provided for science teachers and technicians to familiarize themselves with the applications of Arduino in science teaching, before they participated in the research and gave feedback at the Evaluation Phase of the Main Study. Teachers participating in this Study were receptive to shift the teaching and learning from teacher-centered to student-centered. That meant that the mindset change was no obstacle in the study. Getting them well equipped for the shift was the focus so that they could be fully competent and confident in conducting the lessons on their own.

4.3.4 Students' readiness

The extent of readiness of students in self-directed learning of Arduino-based experiments affected the effectiveness of the program. The design of the Main Study was such that teacher gave students short briefing before they started to work with their peers on the experiments. Worksheets were made simple and self-explanatory so that even without much guidance form the teachers, capable students would be able to carry out the experiments according to the instructions on their own. To arouse and build up the confidence of students in trying out

Arduino-based experiments, the program was specially designed to start with a simplest one. As soon as confidence was built up, they were given more and more challenging experiments. The scaffolding provided great attention and support to the students at first, but as they began to construct their own knowledge, such support was progressively withdrawn so that students became more and more responsible for their own learning. Following this plan, only a photo sensor was used in the first two experiments (1A and 1B). The Arduino device was made a stand-alone device and there was no need to connect the device to the computer. Data stored in the memory could be scrolled on the LCD screen by pushing buttons on the LCD keypad and the result was instantly displayed on LCD screen. In this experiment, students were requested to make simple calculations to find out the gravitational acceleration and plot the graph manually on graph paper. In other words, some elements of the traditional experiment were retained to contain the scope of change. Calculations were broken down into small steps so as to guide students with special needs to prevent calculation errors. In the later experiments, manipulation of data and graph plotting were done with the aid of Excel.

4.3.5 Choice of topics for the Intervention

In this research, all experiments were confined to the topic of mechanics. This was because, first, professional assessment tools to assess the effectiveness of any intervention device/program on this particular topic were available in the research field. Such tools included, but were not limited to, the Force Concept Inventory (FCI) which was designed to assess student's understanding of the most basic concepts in Newtonian mechanics and the Integrated Process Skills Test (TIPS II) which measured students' Integrated process skills. These assessment tools were conveniently used to assess the effectiveness of intervention on students using Arduino technology in the teaching and learning of mechanics. Second, the teaching and learning of the topic of mechanics particularly favored the use of Arduino, because it was simple and it comprised low-cost sensors such as ultrasonic sensor, force sensor, acceleration sensor, photo-gate that were readily available in the market. These sensors were particularly good at capturing fast and transient events in mechanics experiments.

In the design and development of the seven Arduino-based experiments, the above ideas were borne in mind to maximize the potential use of Arduino which could meet the modern trend of science teaching and learning. All experiments could fittingly be integrated into the Hong Kong NSS physics syllabus.

4.4 Different phases in development of the Arduino based experiments

In this research, seven Arduino-based experiments on the topic of mechanics conducted on an open-source platform together with Excel templates and student worksheets were developed under the DBR framework. The iterative cycle in the DBR was basically divided into three phases, namely the Pilot Study Phase, the Development Phase and the Evaluation Phase.

In the Pilot Study Phase (from 4th quarter of 2014 to 2nd quarter of 2015), a Development Team was formed which included the researcher, a technical assistant and a laboratory technician. An Arduino workshop and an Arduino-based experiment on the topic of "circular motion" were first developed. The Arduino hardware, software and courseware in the Pilot Study was developed through several iterations before putting into trial run. The development and iteration of this experiment (Experiment 1) was further discussed in the Development Phase. Mindful of the importance of collaboration with participants in DBR, 21 F.6 students of the 2104/15 cohort were invited to a trail run in March 2015, during which Arduino workshops were held to give them some background about this open-source platform, and an Arduino-based experiment on circular motion was carried out by the students. Feedbacks were obtained through class observation, discussion with the participating students and the Development Team members. Their opinions were fully taken into account in the design of other experiments in the Development Phase.

In the Development Phase (from 1st to 3rd quarter of 2015), six Arduino-based experiments were developed, all on the topic of mechanics. The development of Arduino hardware, software and courseware together with the various iterations in this phase lasted about a year. The Development Team mainly focused on the design of the Arduino hardware, trying out different type of sensors, writing and debugging the Arduino codes which controlled the input/output devices, testing of the device, and design of the format and macros embedded in the Excel templates for smooth data manipulation and generation of graphs and charts. In parallel, student worksheets were developed. The experimental procedures set out in each worksheet were examined line by line to ensure smooth implementation. The processes were iterated several times to ensure that the hardware, Arduino coding, Excel template and the worksheet worked coherently. After each iteration, areas for modification and refinement were identified and followed through to achieve further improvements.

In the Evaluation Phase (from 3rd quarter of 2015 to 1st quarter of 2016), a Feedback Panel was formed to give comments on the implementation of the seven experiments. The panel consisted of experienced science and physics teachers, laboratory technician and technical assistant. Seven evaluation sessions were organized for the members of the Feedback Panel to try out and examine each of the experiments, in the same way as the experiments were to be carried out by students in the Main Study. The Main Study Phase referred to the stage when the same experiments, after refinement, were adopted for intervention among F.4 students of the 2015/16 cohort. Written and verbal feedbacks immediately after each laboratory lesson were gathered from the Feedback Panel, based on which amendments and refinement were made to each of the worksheets, software and hardware. In this phase, as most of the members of the Feedback Panel were teachers but not Arduino experts, focus was mainly on the teaching and learning effectiveness, as well as aspects of safety precautions, versatility of the courseware to cater for learning diversity and the possibility of achievements of different learning targets and skills. The revised experiments were adopted for use in the Main Study on the target group students (F.4 students in the 2015/16 cohort) starting from the 4th quarter of 2015. The research framework using the DBR process is illustrated in the figure 4.1 below. As illustrated, the designs are evidence-based, that is, they engender tangible changes in TEL environments practice (Wang & Hannafin, 2005).

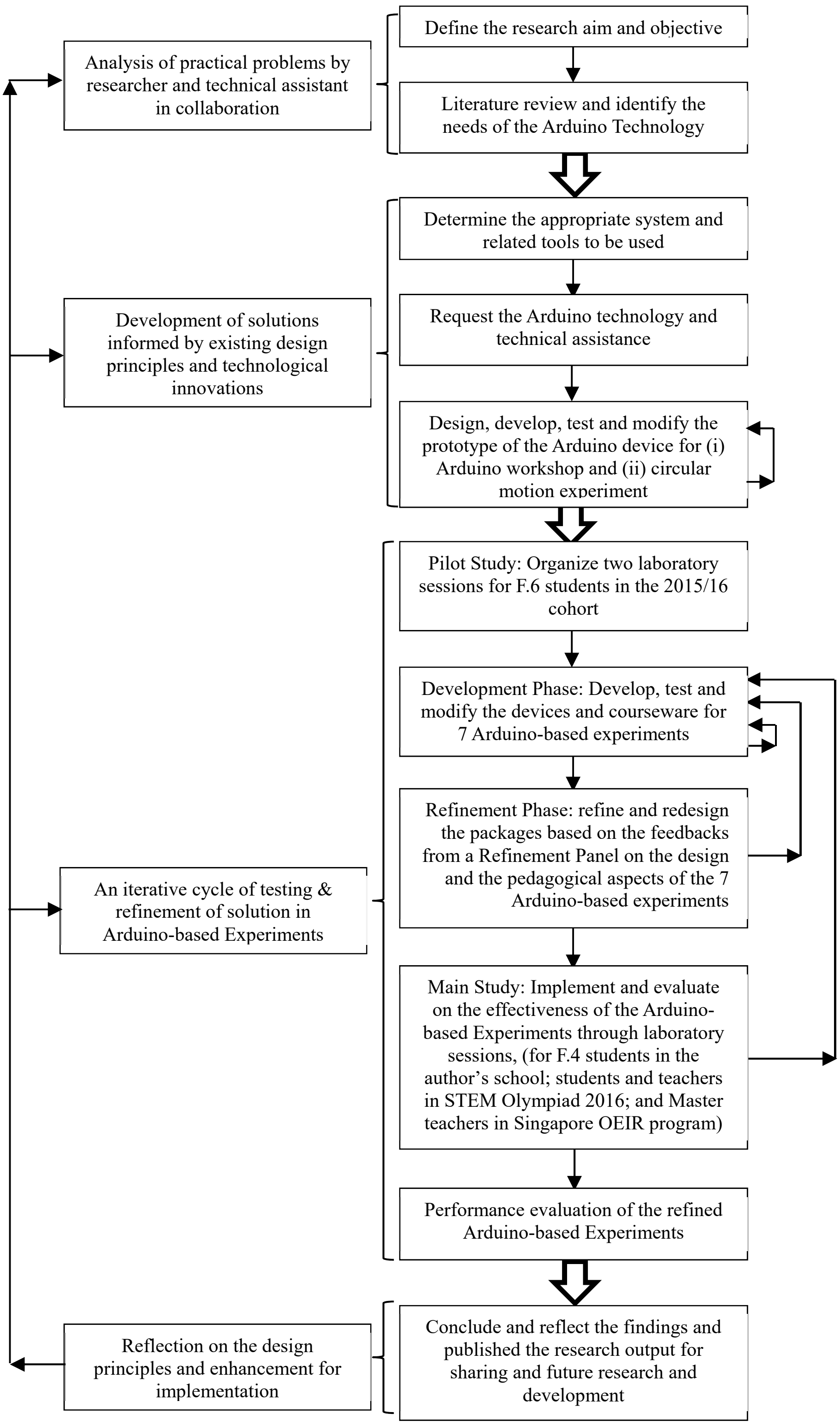


Figure 4.1 Research framework using the DBR process

4.5 Findings in the Pilot Study and its implications

4.5.1 Brief Description of the Pilot Study

The research method of the Pilot Study was covered in Chapter 3. In this chapter, focus was on the findings and implications of the Pilot Study. In the Pilot Study, 21 F.6 students of the 2014/15 cohort were invited to participate in two laboratory sessions, the Arduino workshop and an experiment on circular motion using the Arduino setups. Students participating in these two sessions were informed that the results of the two laboratory sessions would not affect their final grade or scores in their School-based Assessment or internal examination. Their feedback was solely for research propose. Even so, students showed keen interest and self-motivation in conducting the experiments in these two sessions.

Students when trying out the two laboratory sessions at the time had already been taught the whole DSE syllabus in physics. Hence the theory behind the experiment was not new to them. After completing the two sessions, they in general reflected that the instruction in the worksheet was basically self-explanatory and was easy to follow. The graphics and diagrams in the worksheet were clear and could help them understand the contents.

4.5.2 Experience with the Arduino-based Experiment

The Arduino-based experiment on circular motion was the most difficult experiment among the experiments developed. Students were given only a short time to understand the particulars in the workshop, conduct the experiment and complete the reports, but majority of them could finish the experiment in time. This might partly be attributed to the fact that they had already consolidated their understanding of the circular motion through a series of exercises and tests beforehand. However, this could not account entirely for the innovative technology intervention. The students had gone through the traditional experiment and could instantly compare the differences brought about by the Arduino technology. Though encountering the Arduino technology for the first time, they mastered it confidently and many remarked that the Arduino-based experiment should have been introduced to them a year earlier so that they did not have to suffer from getting inaccurate results and going through tedious procedures in the traditional experiment.

Some students were amazed that hundreds of data could be obtained in just only ten seconds with the new device and almost all groups could repeat the experiment several times to obtain a set of "best" data. In the traditional experiment, only three to four sets of data could be collected and two-third of the laboratory session was spent on data collection, leaving not much time for report writing, discussion or collaborative learning.

Students said that in the traditional experiment, it was very difficult to keep the rotational speed and the position of the weight unchanged. It was much easier with Arduino-based experiment as it was not necessary to keep rotational speed constant.

4.5.3 Comments on the use of IT skills

Students in general agreed that SD Card was a reliable and economic means of data storage. They had no problem in transferring data from the Arduino system to an Excel file in a computer. They thought that using SD card was fast, simple and convenient.

Most students had learned about the use of Excel in IT classes in junior forms and so using Excel for data manipulating and graph plotting did not impose problem on this group of students. They found the Excel worked perfectly well with Arduino in handling numerous data in a short time.

4.5.4 Affective Domain of Students

During the conduction of the experiment, keen discourses were observed among students. When they came across difficulties in the experiment, they tended to go through the worksheets again to find out the missing steps on their own or discuss the problems with their peers. Students represented their own ideas and learned from one another so as to resolve problems collaboratively. Teachers seldom needed to give them guidance during the experiment.

Some students were fascinated by the interesting and challenging learning experience to work around with Arduino, to understand its hardware architecture, to use bread board to connect electronic components and sensors to the mother board, to upload or modify simple programs to control some input/output devices. Some other students expressed that even when knowledge of the structure of Arduino, or the operating principle of Arduino and sensors were limited, and they had limited skills in programming, they could still complete the Arduino-based experiment on circular motion without much difficulty. Therefore, in designing the Main Study for a group of F.4 students, the Arduino workshop was entirely taken out from the intervention program.

Moreover, the circular motion experiment was observed to arouse students' curiosity. One group of students asked whether a device could be installed on a motor vehicle to measure the centripetal acceleration such that a warning signal would be issued wherever the speed of the vehicle exceeded the safety speed when turning around the corner. This was how students were inspired by the experiment and attracted to apply the device in an authentic situation to solve real-world problem.

4.5.5 Possible problems and constraints

In the circular motion experiment, the Arduino device was equipped with Bluetooth so that data capture could be activated by an application software installed in a mobile phone. Students however opined that introduction of Bluetooth might cause trouble rather than facilitation. Bluetooth was eventually abandoned in the experiment setup and in the design of the other six experiments. Instead, the Arduino was re-programed to start data capture when a key was pressed. In addition, different “beep” sounds were added to the program to guide students when to speed up or slow down the rotational speed of the device.

The technical assistant, who developed the hardware and software for this program, was impressed by the smooth running of the Pilot Study, except that there was some confusion when students tried to link up their mobile phones with Bluetooth. Installation of applications into mobile phones created some problems as the Wi-Fi of the author’s school was not opened for students and connections between the phones and the Arduino were not very stable. It was because of this unsatisfactory result that the Development Team eventually decided to drop the idea of using Bluetooth. This was a good illustration of outcomes from previously conducted designs that provide explanatory framework (Cobb et al, 2003) for the next cycle of inquiry, which is the Development Phase.

The laboratory technician, who closely kept track of students’ performing the traditional experiment and then the Arduino-based experiment, considered the Arduino platform a very good experience for students. The experiments that the students did for the DSE were often cookbook type experiments. However, in the Arduino-based experiment, students could investigate on their own how the centripetal acceleration was related to the angular velocity. Students could have enough time to investigate how other factors (e.g. length of ruler, mass of the Arduino device) would affect the centripetal acceleration. This opened up a new horizon for students to explore in their future study. As a technician, he was concerned about the likelihood of the hardware or software problems during the laboratory session. This concern was valid which drew the Development Team to review the stability and reliability of the hardware and software.

4.5.6 Improvements and Subsequent Development

Having taking into account the feedback from all participants in the Pilot Study, a checklist was worked out to guide further developments of other experiments which was summarized below:

(i) The Arduino workshop would be removed from the intervention program.

(ii) The hardware design should be simple and trouble-shooting free.

(iii) The idea of data transmission through Bluetooth was abandoned as it complicated the procedures in carrying out the experiment.

(iv) “Beep” sounds produced by the buzzers would be used to guide students to take actions.

(v) SD Card would be widely adopted in other experiments.

(vi) Excel would continuously be used for data treatment in this and other experiments. Macros would be embedded in the template to facilitate data selection and curve fitting.

(vii) The scientific investigation component would be enhanced in the development of other experiments.

(viii) More open-ended questions would be set in the worksheet to trigger students’ thinking and problem solving skills.

4.6 Development Phase

The Development Phase originally started with the development of six experiments as part of the DBR framework. The plan was subsequently revised having regard to teachers’ feedback in the final testing of the Evaluation Phase that Experiment 1 was too lengthy for students to be conducted in one practical lesson. Experiment 1 was therefore split into two experiments, thereby resulting in seven experiments in total. The development of the seven experiments took more than a year to finish which constituted the longest process in the entire research.

The seven Arduino-based experiments were developed with the help of a technical assistant. Leveraging on his proficiency in the technology, the hardware and software for the seven experiments were successfully developed. He also assisted in testing the accuracy and reliability of the device, fine-tuning and calibrating the tools. Where problems were encountered during the development stage, his expertise facilitated instant modifications to the programming or hardware design. This speeded up the development process which was normally reiterated several times to achieve the best results before reaching the final Evaluation Phase.

The thinking and design processes, as well as the improvements and modifications to individual experiments, improve the effectiveness of the Arduino devices in bringing out fruitful inquiry learning. This aspect was further discussed in the ensuing paragraphs.

4.6.1 Experiment 1A: Photo gate experiment

The objective of this experiment was to measure the gravitational acceleration of a free-falling bar. In this experiment, a photo gate was used to detect the time at which a beam of light passing through the slits of a shield was detected by the photo sensors. From the time measured, initial velocity, final velocity and hence gravitational acceleration could all be computed.

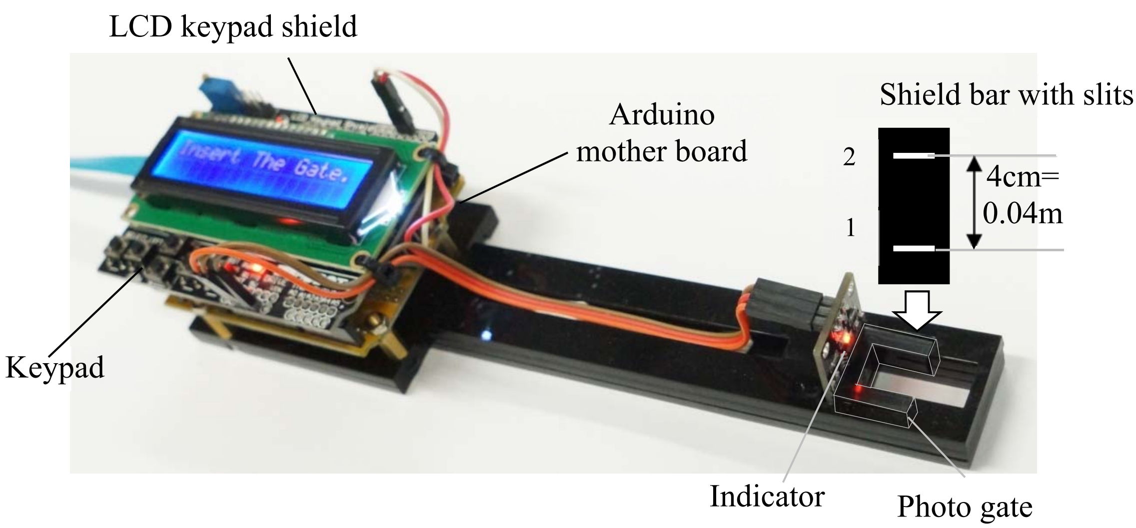


Figure 4.2 Setup of the photo gate experiment

This was the experiment that the students first encountered using the Arduino technology. To lay good foundation as the scaffolding theory suggested, this experiment was deliberately made simple. Arduino with a photo gate was used in the experiment and the data were displayed on an LCD screen. To cater for learning diversity, the time which was originally displayed in μs was reprogramed to *s* to obviate the need for students to make conversion in the units, which was error-prone. The data collection techniques involved in this experiment involved in this experiment included data storage on an SD card, and data transfer to a computer. Manipulating of data with Excel were left to later experiments.

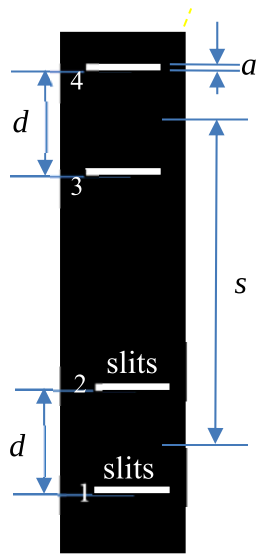


Figure 4.3: Four-slit falling bar

The device was made compact and trouble-shooting free to address the concern of the laboratory technicians. All components were mounted on a rigid frame produced by a piece of laser-cut acrylic so that the whole device was a one-piece design. Safety precautions to prevent the bar from breaking were taken. The width of slit (a), separation of slits (d) and separation of two sets of slits (s) were tested many times to find out the best values so that the experiment would not fail easily. To streamline the process, the Arduino was re-programmed to automatically detect the existence of the bar when it was inserted. Students need not press the "start" button while holding the bar, so that the experiment could be done by one student alone.

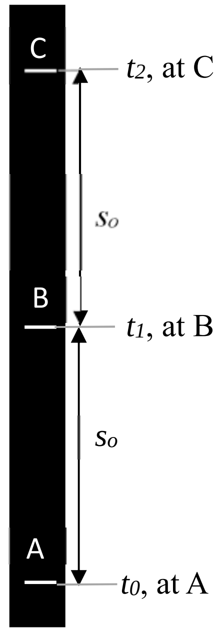


Figure 4.4: Three-slit bar

Further questions were put to students to let them investigate whether the gravitational acceleration could be derived if the number of slits was reduced from four to three. Students were challenged to prove the equation, where t_o, t_1 and t_2 were the times when the slits went through the sensor, and s_o was the separation between the slits.

$$g = \frac{2s_0(2t_1 - t_2 - t_0)}{(t_2 - t_1)(t_1 - t_0)(t_2 - t_o)}$$

4.6.2 Experiment 1B: Photo gate experiment – an investigative study

Experiment 1B was designed to be a scientific investigation which used the same Arduino device as that of Experiment 1A. The average speed between two points could be found from the ratio of displacement between two slits and the difference in time for consecutive light

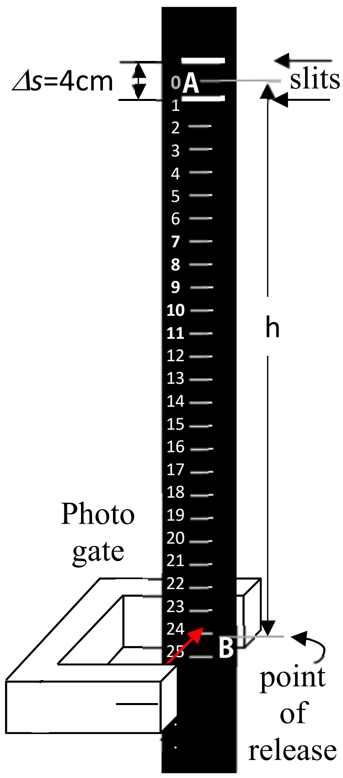


Figure 4.5: Two slit bar

beams to be detected, ($v = \frac{\Delta s}{\Delta t}$). Students were asked to find out the relationship between velocity (v) and the height (h) by plotting suitable graphs, e.g. v against h, v^2 against h. For these simple experiments (Experiments 1A and 1B), which aimed to acquaint students with Arduino technology, students adhere to the traditional methods (hand copying, manual calculations, manual graph plotting, etc…) for data manipulation so that changes were introduced in a progressive manner in the course of the scaffolding. Excel was only introduced in Experiment 2 so that students need not take care of too many new issues at one time.

4.6.3 Experiment 2: Bouncing ball experiment

In this experiment, a basketball was released below an ultrasonic sensor to measure the variation of displacement of the ball with time, and hence work out the gravitational acceleration (g).

Figure 4.6: Setup of the bouncing ball experiment

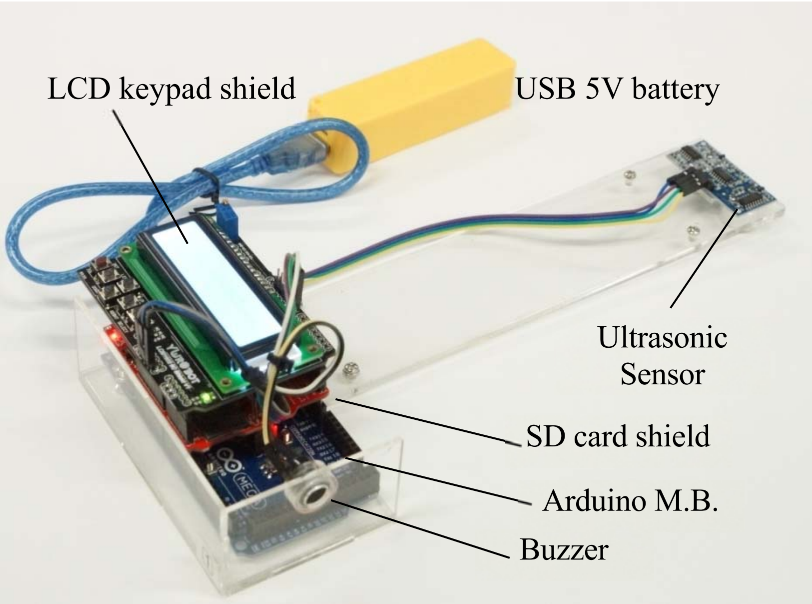
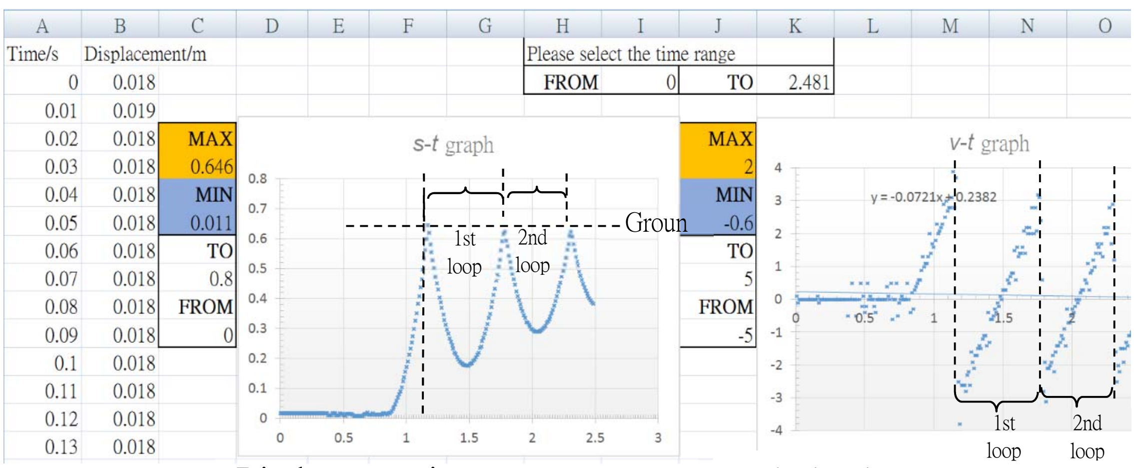


Figure 4.7: Arduino hardware of the bouncing ball experiment

Arduino board with two stackable shields (SD card module shield and an LCD keypad shield) and the ultrasonic sensor were mounted neatly and tidily on a rigid chassis so that the setup was highly compact. The chassis was designed in such a way that the ultrasonic sensor could be orientated in different directions. This added flexibility to the device when the device was reused in future PBL project.

Messages on the LCD screen and the "beep" sounds produced by the buzzer prompted students to take actions or indicate faults occurred during the experiment. Referencing to the experience in conducting Experiments 1A and B and the trial run for this experiment, it was revealed that to increase the data capture rate, data should first be saved in the fast internal memory of the Arduino board, and then transferred to the relatively slow SD card when the capture was finished. To achieve this, the Arduino Uno board was upgraded to Arduino Mega board which had larger internal memory running at a higher speed. Although the device could only store data for about 6 seconds, it was already long enough for many mechanical experiments. The performance of this apparatus was comparable to that of data logger while the price was far lower. This made Arduino far more favorable to data logger.



Displacement-time curve, ***s*-*t*** curve Velocity-time curve, ***v*-*t*** curve

Figure 4.8: Data treatment of the bouncing ball experiment using Excel

This was the first experiment that students used Excel in data manipulation. Students could transfer data to an Excel template which could automatically generate graphs (Displacement-time curve, *s-t* curve and Velocity-time curve, *v-t* curve). A pull-down menu was created in the template to facilitate "zooming-in" of a portion of the graph and fitting of a straight line based on the data collected.

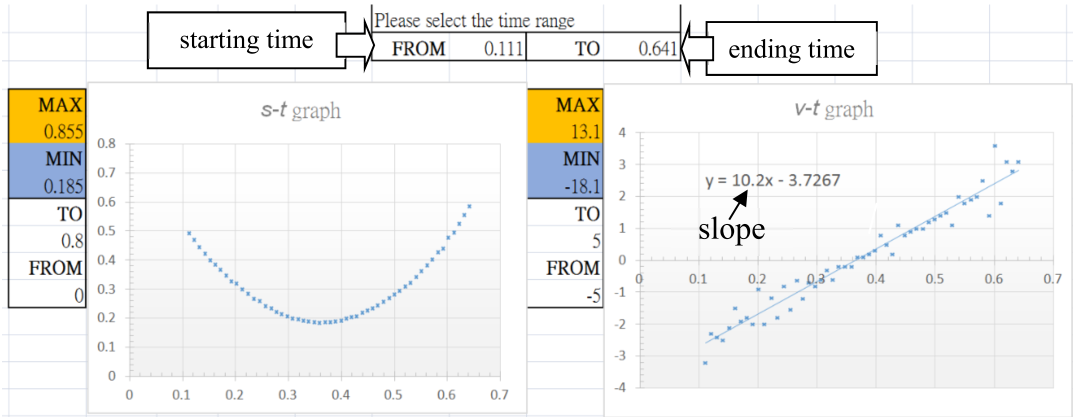


Figure 4.9: Finding the gravitational constant from the slope of the best fit straight line

With this template, students could save time in gathering data and plotting graphs while allowing them the space to do other meaningful scientific investigations and inquiry learning, which was a key 21st century skills. Tedious and repetitive procedures were reduced so that the experiment could be repeated many times to verify results and generate relations speedily. Students could make modifications on the set-up and conduct many "what –if" investigations to understand how the gravitational acceleration (g), the maximum height reached, the change in velocity or kinetic energy after re-bounce, could be affected by various factors, e.g. any change if the basketball was released at a higher height, released with an initial velocity, replaced by a more inflated one, or hit on different surfaces, etc. The students could also explore how the same apparatus could be applied in other settings or environments, e.g. to investigate how an athlete accelerated in a race, how the velocity and momentum changed in a car collision, how fast a rat could run, etc. This was where learning of science outside classroom in an authentic, real world setting came into play. This made the study of science interesting, meaningful and relevant to the students. More open-ended questions were also set in the worksheet to stimulate students' deeper, analytical thinking.

4.6.4 Experiment 3: Newton's 2nd Law

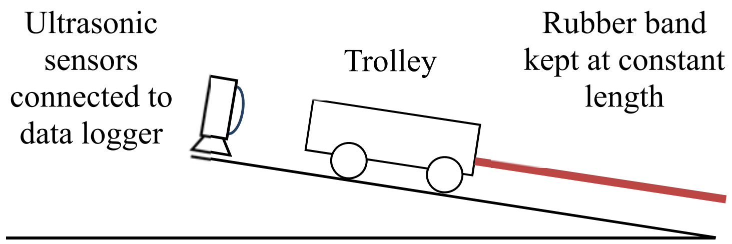


Figure 4.10: A traditional setup of the Newton's 2nd Law experiment

This Arduino-based experiment intended to demonstrate how Arduino device could outperform traditional experiment, in verifying the Newton's 2nd Law. The traditional experiment had already integrated ITC, that is, employed the data logger technology to enhance the performance. The experiment aimed to verify that acceleration of an object was directly proportional to the force. In the traditional experiment, the trolley was pulled on a friction-compensated track with different number (N) of rubber bands that were kept at a fixed length while the trolley was accelerating. Acceleration (a) was measured by a motion sensor connected to the data logger. Only limited data were obtained in this experiment and it was time-consuming. Unreliable results were often obtained which could not provide concrete evidence to prove Newton's 2nd Law.

In the Arduino experiment, the above problems were addressed. With the experience gained in

Experiment 2, the Development Team came to a quick decision to use a faster Arduino Mega board for this experiment to ensure data capture at higher speed. Addition of buzzer and LCD keypad shield facilitated interactions with students. The Arduino device was so compact that it could be fixed on the wooden board and moved together with the board to collect data.

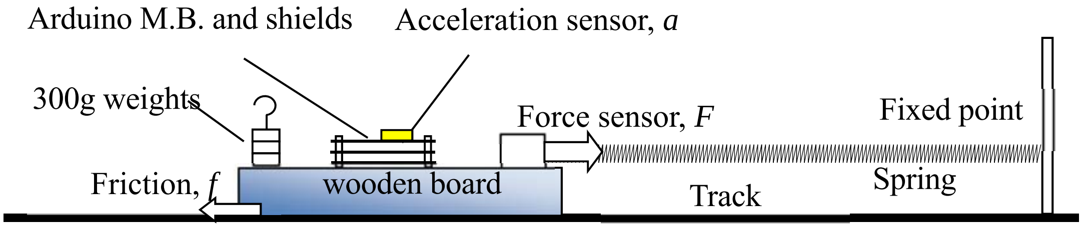


Figure 4.11: Setup of the Newton's 2nd Law experiment with the Arduino device

The Arduino-based experiment setups outperformed the traditional experiment in many ways. First, force and acceleration was directly measured with a force sensor and an acceleration sensor. Second, it was not necessary to keep the length of the spring constant. When the spring was extended and then shrunk in seconds, hundreds of (F,a) coordinates were recorded (as shown in figure 4.13).

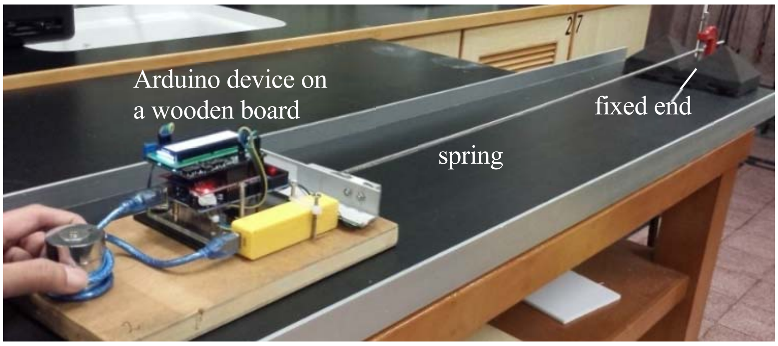
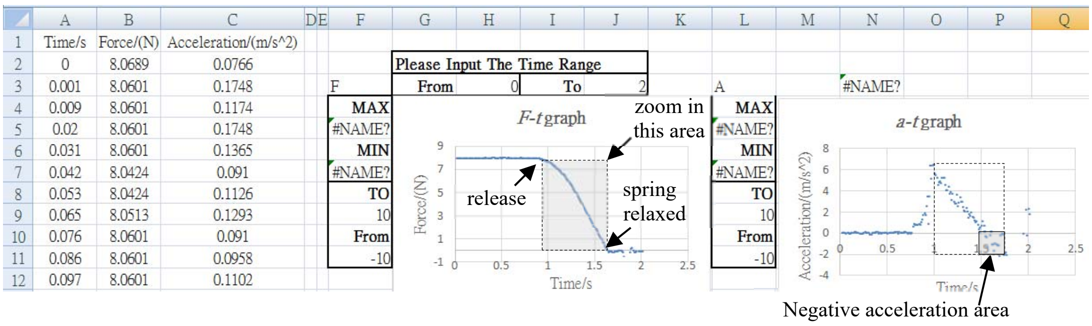


Figure 4.12: Arduino device on a wooden board



	A	B	C
1	Time/s	Force/(N)	Acceleration/(m/s^2)
2	0	8.0689	0.0766
3	0.001	8.0601	0.1748
4	0.009	8.0601	0.1174
5	0.02	8.0601	0.1748
6	0.031	8.0601	0.1365
7	0.042	8.0424	0.091
8	0.053	8.0424	0.1126
9	0.065	8.0513	0.1293
10	0.076	8.0601	0.091
11	0.086	8.0601	0.0958
12	0.097	8.0601	0.1102

Figure 4.13: *F*-*t* and *a*-*t* curves obtained after the release of the trolley

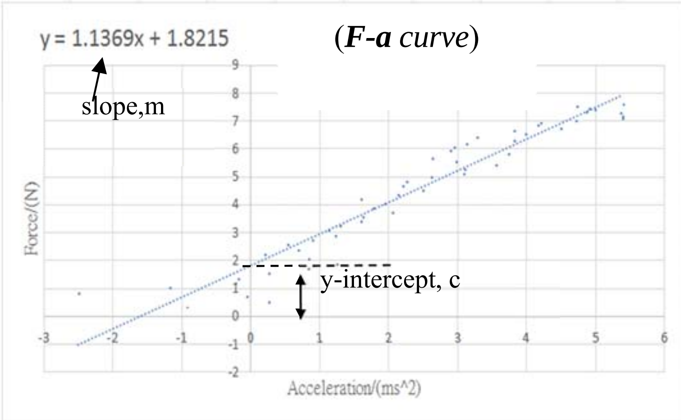


Figure 4.14: Line fitting with Excel

From the slope and y-intercept of the force-acceleration curve (*F*-*a* curve) that were automatically generated by the Excel (figure 4.14), the mass (*m*) of the wooden board (together with the Arduino device) and the magnitude of friction (*f*) could be respectively retrieved. In this experiment, the random nature of friction could be appreciated as the points on the *F*-*a* curve were quite scattered. With hundreds of data, random errors could nevertheless be smoothed out and the best straight line derived. As such, it was not necessary to perform the experiment on a friction-compensated track and the experiment became more authentic.

The experiment could be finished within seconds and the data manipulation was made automatically. Students could spare time for other scientific investigation, interpretation of the data and higher-order thinking. Many open-ended, challenging questions set in the worksheet stimulated students' active participation, e.g. questions about possible causes of errors in this experiment, the physical meaning of the y-intercept and the slope of the *F*-*a* curve, how the setup could be modified to reduce friction, why there existed a "negative acceleration region", etc were raised. Students were expected to repeat the experiment with different settings and observed the effects on the results e.g. the mass of the board was varied, spring with different force constant was used, the initial length of the spring was altered, the friction between the board and the track was changed, etc.

In this experiment, measures were taken to ensure that the trolley run in a straight line and its path was untwisted, data were accurately recorded, and the force on the sensor would not be accidentally over-applied etc. The mass and position of the weights added onto the board, the type of spring used, the scale and linearity of force sensor, calibration of the force sensor and acceleration sensor, zero-setting of the force sensor were repeatedly tested to enhance the reliability of the setup. Problems to be resolved in the process were authentic which the researcher had to face and could share with the participants.

4.6.5 Experiment 4: Acceleration in a lift

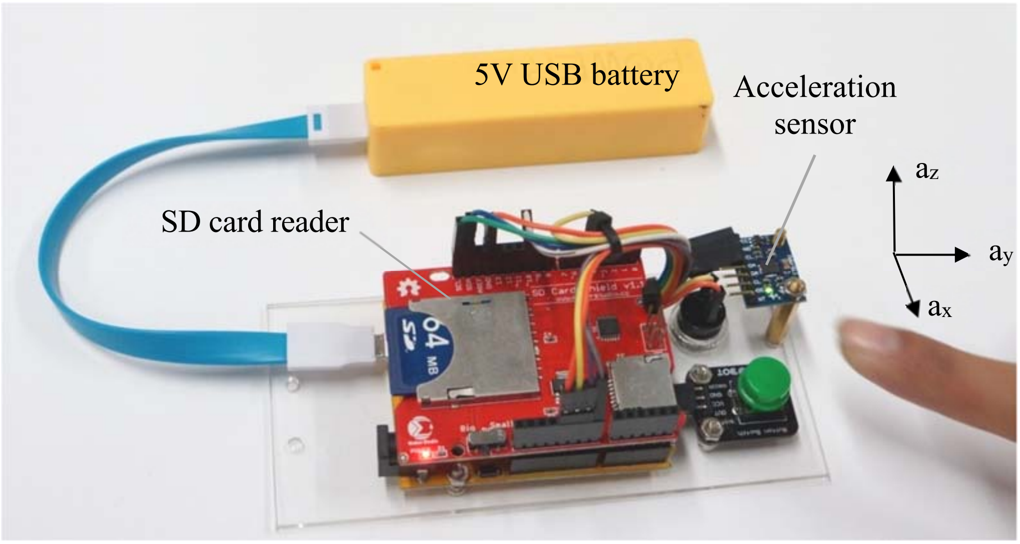


Figure 4.15: Setup of the “aacceleration in a lift” experiment

This was an authentic experiment that students could experience through data collection in a real-world setting – inside a lift. The Arduino board was connected to an acceleration sensor to record vertical acceleration ($\boldsymbol{a_z}$) in a moving lift, and data were saved in an SD card. The change in acceleration reflected the apparent weight of a body inside the lift. Without this authentic experiment, students could not have imagined that the sense of gain or loss in weight when moving with the lift could last for as long as five seconds and there was about 10% change in the apparent weight. DBR enabled the creation of and study of learning conditions that are presumed effective but are not well understood in practice, and the generation of findings often overloaded or obscured when focusing exclusively on the summative effects of an intervention (DBRC, 2003).

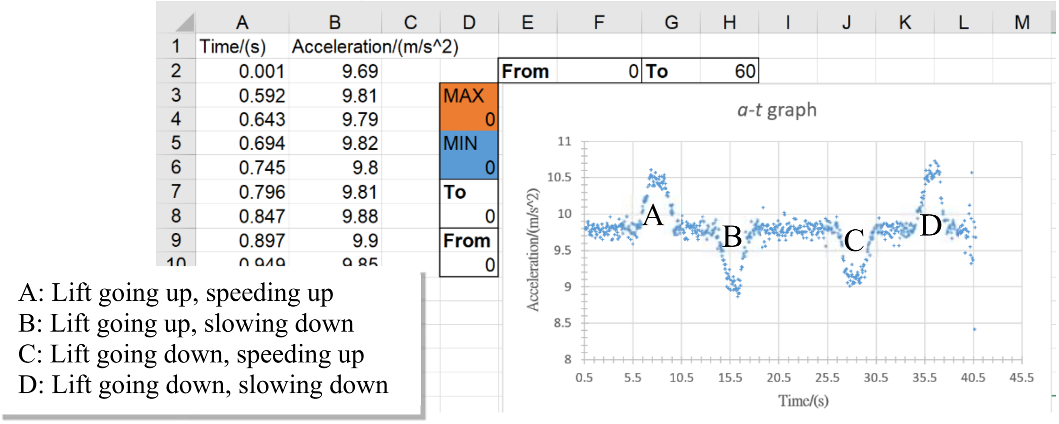


Figure 4.16: Data treatment with Excel on the "acceleration in a lift" experiment

Simplicity, portability and low price made the devices used in this experiment highly affordable. Students could readily purchase the components to construct such device and carried out investigations on their own, like in a bullet lift of a high rise building, in a falling machine in the theme park, when making a bungy jump, or measuring the 3-dimensional accelerations inside a bus. This again is conductive to the problem-based learning, enabling the conduction of scientific inquiry outside classroom or even out of schools.

4.6.6 Experiment 5: Inelastic collision experiment

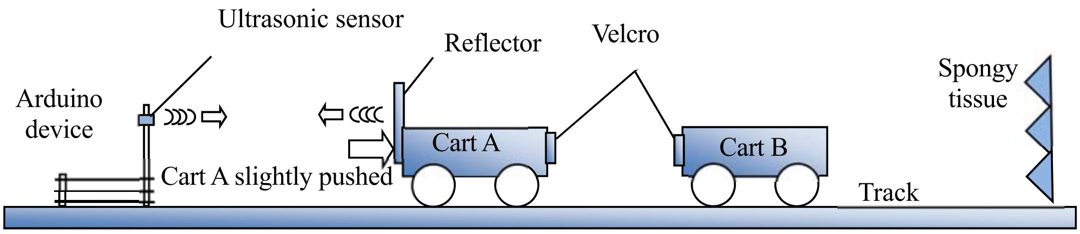


Figure 4.17: Schematic setup of the inelasticd collision experiment

This experiment used the same set up as that in Experiment 2. An ultrasonic sensor was used to monitor the motions of two trolleys undergoing an inelastic collision on a track. This experiment again demonstrated how Arduino was meritorious over conventional data logger. First, data processing could be done real time inside the Arduino or through the Excel table to filter off unwanted noises. Second, the whole set up could be put on the moving trolley as there was no wiring connection with the computer. This greatly enhanced the mobility of the device and opened up lots of opportunities for future development and modifications of the device for other scientific investigations.

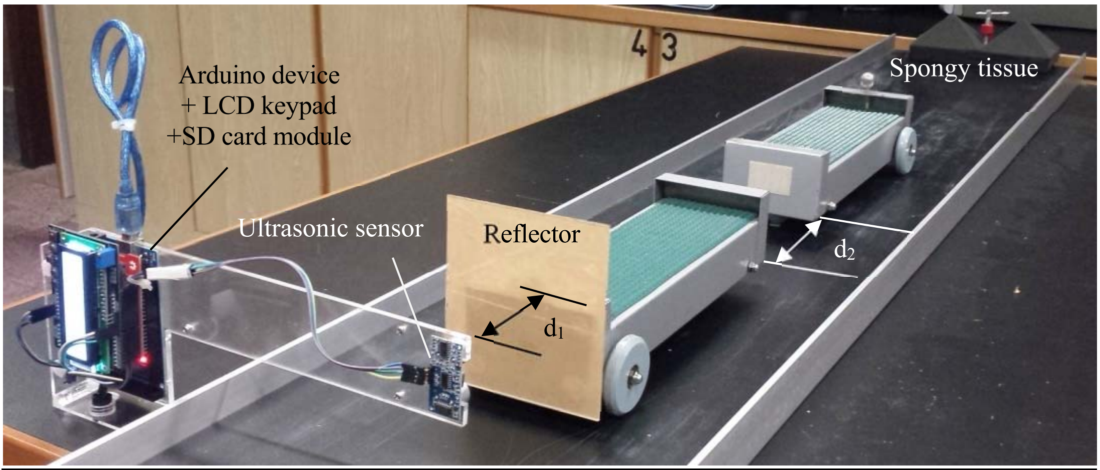
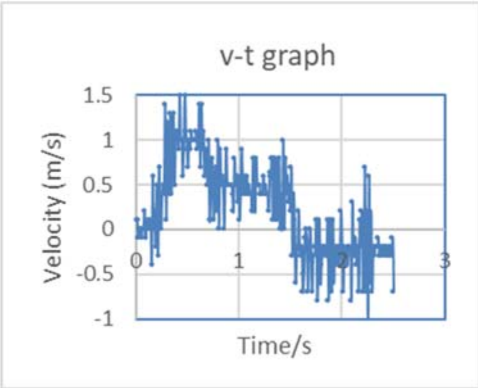


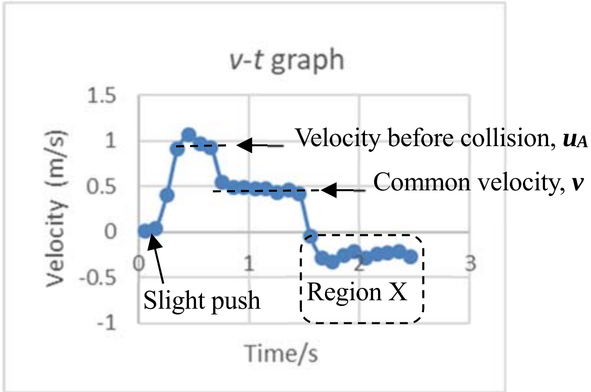
Figure 4.18: Real setup of the inelasticd collision experiment on a track

Initial speed of the trolley, the distance of the reflector from the ultrasonic sensor (d_1) and the separation between two trolleys (d_2) were carefully tested to ensure that the data capture process could be completed within a few seconds and the data collected could be fitted into limited internal memory.

The initial velocity-time graph (*v*-*t* graph) generated by Excel also displayed random errors (noises), as in figure 19 (a). However, the noises could be reduced by embedding some macro in the Excel template to calculate average velocity between ten consecutive points to yield a smooth curve as in figure 19(b). Given the enormous amount of data that could be collected for deriving average velocities, the resultant data in figure 19(b) were representative. This made the results sensible and useful for further analysis.



(a) Raw data without filtering



(b) Taking average of 10 adjacent points

Figure 4.19: *v-t* graphs before and after noise filtering

During the development stage, alternative method to find the velocities before and after collision by computing the velocities from the slopes of the displacement time curve as shown in figure 20 was also explored. After weighing the pros and cons, the Development Team decided to adopt the former method, that is, to derive average velocities from every ten consecutive points, because less technique in Excel was required.

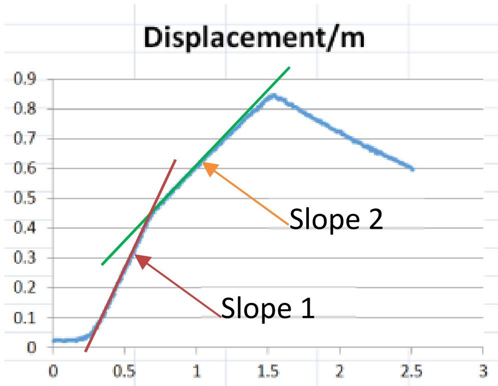


Figure 4.20: Displacement-time (*s-t*) curve

To enrich the inquiry learning element, some hypothetical questions were set in the worksheet to test students' problem solving skill, e.g. students were asked to predict the result if magnets of same polarities were mounted onto the trolley so that they elastically repelled, or to test their understanding as to whether more than one set of Arduino device could be used, to seek for students' innovation on how the Arduino devices could be used to measure velocities of both trolleys. The questions supported peer interactions which was particularly effective in fostering educationally-beneficial distributed practices (Hewitt & Scardamalia, 1998).

4.6.7 Experiment 6: Circular motion – an investigative study

This was the first experiment developed out of the seven experiments and had been put to test in the Pilot Study to gauge feedbacks, which had significant impact and had guided the designs of the other experiments that followed. Traditionally, this experiment was conducted using a piece of nylon string attached to a bob of mass m at one end and a weight of mass M through a hollow glass tube at the other end. The length of the nylon string, as measured from the center of the bob and the upper end of the glass tube, was fixed at length L. The bob was kept rotating in a horizontal plane at a steady speed such that the length L was kept unchanged. The period (T) of rotation was measured and the average angular velocity (ω) of the rotation was then calculated by $\omega = \frac{2\pi}{T}$. The experiment was repeated with different values of L or M and students were asked to verify the relationships among M, ω and L. Data collection in traditional method was very time-consuming and concrete conclusion could not be drawn due to inadequate and inaccurate data. The results suffered from lots of uncertainties, e.g. the difficulty to keep the rotational speed constant and the rotating plane horizontal, irregular friction between the

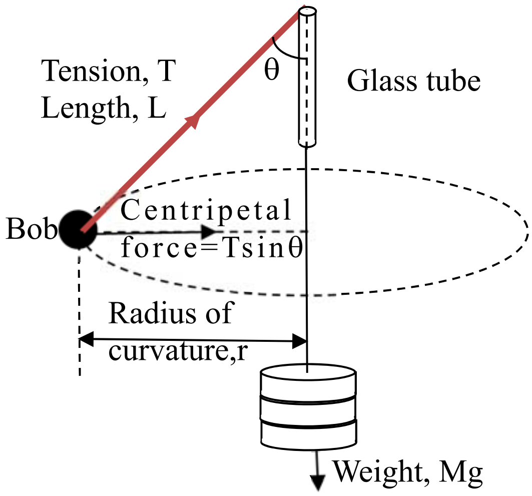


Figure 4.21: Traditional setup of the circular motion experiment

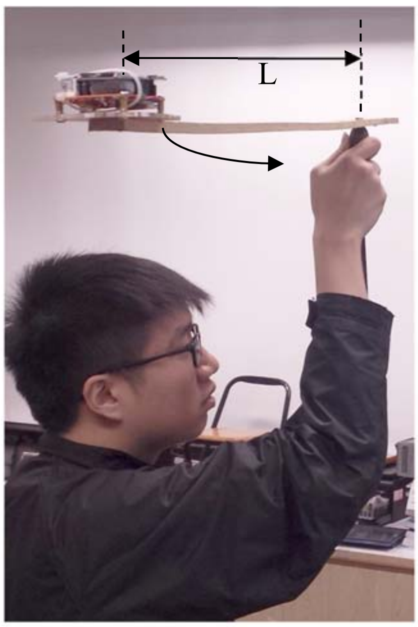


Figure 4.22: Swinging the Arduino device to collect data

upper end of the glass tube and the string.

Arduino could be an innovative solution for this experiment. Investigations were carried out to ascertain the relationship between centripetal acceleration and angular velocity, with the help of Excel. As it was the first Arduino-based experiment developed, a lot of problems came up in the development stage. Aware of the deficiencies, detailed examination of the device was conducted to identify the sources of the problems and to make modifications. The entire process was grounded on relevant research, theory and practice to develop innovations and design (Wang & Hannafin, 2005).

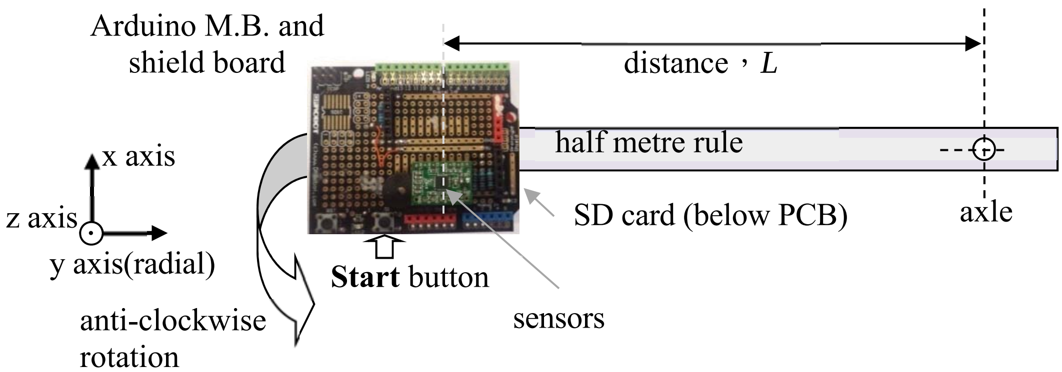


Figure 4.23: Arduino hardware of the circular motion experiment

After many trials, tests and iterations, problems such as calibration of the acceleration sensor and angular velocity sensor, installation of compact power source for the Arduino device, reduction of friction in rotation, keeping the device to rotate in a horizontal plane, application of Bluetooth technology to start data capture, storage of data on an SD card, maximizing data capture rate, etc. were resolved. A prototype Arduino device (consisting of a mother board, an acceleration sensor, an angular velocity sensor, a blue tooth interface and an SD card module) was made and mounted at the end of a rigid half metre rule. Acceleration (a) and angular velocity (ω) were measured simultaneously and data were saved in an SD card. In the prototype, data capture started with a wireless blue tooth signal which was emitted by an application software installed in a mobile phone.

Data saved in the SD card were then transferred to the Excel table. Before the trial run in the Pilot Study, students were asked to verify $M \propto \omega^2$ or $L \propto 1/\omega^2$ by plotting different graphs with the aid of Excel. This arrangement, as later commented in the Evaluation Phase by teachers, was not as desirable because angular velocity was a difficult concept. Instead, the period (T) of rotation was much easier a concept to understand. Therefore, in the final version of the experiment, it was modified such that students were simply asked to investigate how centripetal acceleration *a* was related to the period *T* instead of ω. The whole process of development was in itself a scientific process that manifested a process of discovery, exploration, confirmation and dissemination (Kelly, 2003)

Copy raw data from SD card

(1)：$T(s)$

(2):$T^2(s^2)$

(3):$1/T(s^{-1})$

(4):$1/T^2(s^{-2})$

A	B	C	D	E	F	G	H
Time(s)	a(m/s^2)	w(rad/s)		T	square (T)	1/T	1/square(T)
0	61	9.1		0.6905	0.47674	1.45	2.10
0.026	58.93	9.47		0.6635	0.44021	1.51	2.27
0.052	57.88	9.56		0.6572	0.43196	1.52	2.32
0.078	56.95	9.46		0.6642	0.44114	1.51	2.27

Figure 4.24: Data treatment with Excel on the circular motion experiment

The Excel template automatically generated four columns of data from ω, namely T, T^2, $1/T$ and $1/T^2$ respectively, which were possible relationships between *a* and *T*. Students were asked to test which kind of relationship they would follow. Students observed the random nature of the data which scattered loosely about the trend line. However, as hundreds of data were obtained in 10 seconds, when a straight line was fitted on the curve and extrapolated, it went through the origin well. Random errors were filtered off. To cater for students' learning diversity, further challenging questions were set in the students' worksheet, such as physical meaning of the slope, its relationship with the radius of curvature L and the factors that would affect the results, etc. to arouse students' curiosity and stimulate their innovation.

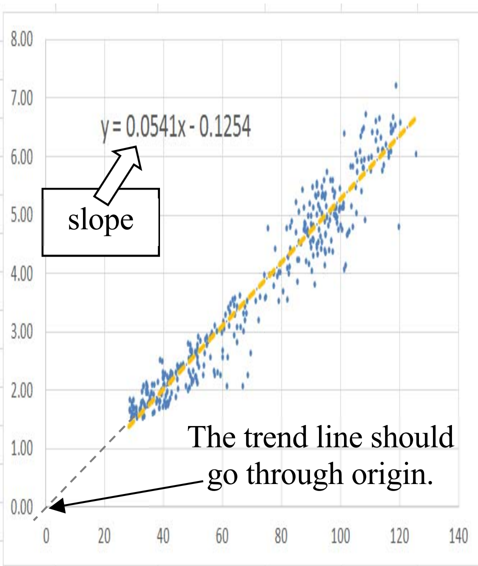


Figure 4.25: Line fitting to find out the relationship between a and

In this Development Phase, context-based knowledge, which focuses on problems and issues specific to a given TEL environment design, and meta-design knowledge, which emphasizes principles, procedures and frameworks, are interwoven in the DBR iterative design, development and implementation processes (Wang & Hannafin, 2005).

4.7 Evaluation Phase

4.7.1 Objectives

In the Evaluation Phase, all hardware, software and courseware of the seven Arduino-based experiments had already been developed and tested by the Development Team. In this phase, a Feedback Panel comprising experienced science and physics teachers, laboratory technicians and technical assistant was formed to perform a final test on each of the experiments before they were applied in the classroom. Feedbacks and comments of the Feedback Panel were crucial to the entire research. The author had consulted the teachers of the Feedback Panel while remaining mindful of the theory-generating goals to balance the theoretical and practical (Wang & Hannafin, 2005). The effectiveness of Arduino in innovative teaching and learning of the topic of mechanics in the physics HKDSE curriculum was critically examined. Through collaboration with teachers, the researcher recognized teachers' concerns and enacted refinements consistent with the immediate and ultimate research goals (Wang & Hannafin, 2005). Feedback of the Feedback Panel were gauged through formative evaluation approach, where survey, discourse and observation (Wang & Hannafin, 2005) were deployed to address the theoretical and practical needs of the design. Based on the comments gathered, a final refinement on each experiment was performed, before the intervention on F.4 students of the 2015/16 cohort was carried out. Both the setups and the worksheets of the experiments were fine-tuned.

4.7.2 Composition of the Feedback Panel

A Feedback Panel was formed in the 3rd quarter of 2015 with eleven members. The Feedback Panel was different from the Development Team in the way that more teachers were involved in the Panel to examine the effectiveness of the experiments in teaching and learning of physics, while the Development Team focused to solve the technical problems in the hardware and software. Apart from the author, the team comprised experienced teachers, laboratory technicians and technical assistant. Eight of them were science teachers, four were physics teachers and two were experienced laboratory technicians. In addition, a technical assistant with expertise in programming and electronics was recruited. Composition of the team was summarized in the table below:

Teacher A	Author of the dissertation, leader of the Feedback Panel, a senior physics teacher.
Teacher B	A senior science teacher, head of the science key learning area, panel head of biology/ chemistry subject
Teacher C	Integrated science panel head
Teacher D	Acting physics panel head
Teacher E	Experienced physics teacher
Teacher F	Experienced physics teacher (Temporary teacher)
Teacher G	Senior Integrated science teacher

Teacher H	Experienced Integrated science teacher
Laboratory Technician A (LTA)	Senior laboratory technician
Laboratory Technician B (LTB)	Experienced laboratory technician
Technical assistant (TA)	Technical assistant, specializing in computing and electronics, who provided technical support in Arduino hardware and software development.

Table 4.1: Composition of the Feedback Panel

4.7.3 Evaluation Methods

In seven consecutive weeks, members gathered at the physics laboratory to perform a final test on each of the experiments, in an order according to the teaching schedule. As majority of the team members were experienced science teachers or technicians, only brief introduction was necessary before each session. Members of the Feedback Panel worked in small groups with two to three members to test each experiment. They had to understand the procedures and instructions, carried out the experiments to collect data, manipulated data manually or with the aid of Excel, examined the worksheets, went through the questions and answered them. Teachers discussed with the author during the laboratory session and offered instant feedback. Immediately after completion of each experiment, they were asked to answer a questionnaire, which gathered their comments and suggestions in a structured manner. The author used multiple methods including discussions, observations, survey and document analysis (Wang & Hannafin, 2005), under the DBR framework in conducting this part of the research.

4.7.4 Questionnaires

The questionnaire, which was completed by the Feedback Panel, (refer to appendix D) was divided into Parts I, II and III. Parts I and II are multiple choice questions. In Part I, only two questions (I_1 and I_2) were asked regarding the length and the level of difficulty of the experiment. Teachers indicated their preference in a scale of "1", "2", "3", "4" and "5", which stood for "far below standard", "below standard", "appropriate", "above standard" and "far above standard" respectively. In Part II, check boxes were set to assess whether the learning targets (II_1-II_{11}) and the design principles (II_2-II_{16}) of the curriculum could be met in the experiments. Teachers indicated their preference in of "1", "2", "3", "4" and "N/A", which stood for "highly disagree", "disagree", "agree", "highly agree" and "Not Applicable" respectively. In Part III, all members of the Feedback Panel were invited to give views or directly correct the mistakes they found on the worksheets, or record their discussion with the author, including clarifying some misconceptions.

4.7.5 Findings in the Evaluation Phase

4.7.5.1 Overview of the Data Collected

Because of individual commitment, not all members of the Feedback Panel could attend each laboratory session. Six to eight questionnaires were collected for each experiment, together with the verbal feedback gathered and observations taken down by the author in the conduction of the experiments by the Feedback Panel. For the seven laboratory sessions held, a total of 53 questionnaires were collected. Although the teachers and laboratory technicians were all working partners of the author, they were critical friends who provided feedback objectively from an outsider's perspective. Team members fully understood the purpose of the research and were mindful not to be lenient.

Some academics had argued that the researcher's intimate involvement could make credible and trustworthy assertions a challenge (Barab & Squire, 2004). Norris (1997) argued that good research demanded skepticism, commitment and detachment, but DBR also required comradeship, enthusiasm and a willingness to actively support the intervention. The personal skill to hold all of the attitude simultaneously is a challenge and a defining feature of quality DBR (Anderson & Shattuck, 2012).

In this evaluation process, formative evaluation was adopted which focused on the local design (the hardware and software of the Arduino devices developed in the study), exposed issues to be addressed through design research and enabled researchers to identify problems and gaps (Edelson, 2002; Reigeluth & Frick, 1999, van den Akker, 1999). Specifically, gaps were identified during the evaluation of the seven experiments.

4.7.5.2 Teachers' Competence

The comments of the Feedback Panel should be understood against the background that Arduino technology was a completely new experience to the majority of the members of the Feedback Panel. Although some members had used data logger in their teaching, they envisaged a need to go through a steep learning curve to grasp this new technology. There were evident signs of anxiety among panel members in the first two sessions. Projecting this experience to the teaching of students, the Feedback Panel suggested that the first experiment was too lengthy and should be split into Experiment 1A and Experiment 1B. After the first two experiments, the Feedback Panel had better grasp of the Arduino technology. They found that the operation of Arduino and procedures in data capture and data manipulation were similar. The program ran smoothly and members of the Feedback Panel began to appreciate more the advantages of using Arduino in doing physics experiment which was fast, accurate, reliable and innovative. Towards the end the Evaluation Phase, they agreed that the experiments could develop the interest and arouse the curiosity of students. They no longer showed concern on the length and level of difficulty of other experiments, though the other five experiments were all more complex than the first two.

4.7.5.3 Misconceptions

Some misconception in Experiment 4 among members led to the generation of a different presentation and design so as to enhance understanding. Misconception stemmed from the confusion on the operation of the acceleration sensor. Some were puzzled by the use of the acceleration sensor which had been used in Experiment 3 (on Newton's 2nd Law) in measuring acceleration of a wooden board on a horizontal table. The horizontal acceleration recorded a zero reading at rest. In Experiment 4, the acceleration sensor was used to measure the vertical component of the acceleration. Members were puzzled that the sensors at rest could measure the magnitude of the gravitational acceleration ($9.81\ ms^{-1}$). The reason was that the sensor was a force field sensor, but the concept of force field was even more difficult to explain. In consideration of this, members tried to view the acceleration sensor as a micro-size spring balance. With the mass attached to the spring balance at rest, the spring balance still showed a reading. In order to strengthen students' understanding of this concept, the acceleration inside a lift were measured simultaneously with an acceleration sensor and a traditional spring balance as an analogy.

4.7.5.4 Modifications and Refinement

Throughout the Evaluation Phase, written comments, discussions and suggestions for modifications or refinement on each of the experiments were summarized after each laboratory session held for the Feedback Panel. As most members were not Arduino experts, they were less focused on the technical issues, but more on the implementation of the experiments and streamlining of the procedures. They were concerned about the details of the experiments, including the length and level of difficulty of the experiments, and even the formatting of texts and graphics in the worksheets. They were also concerned about whether the targets of the HKDSE Assessment Framework and other learning outcomes could be met, e.g. safety measures of the experiments, proper use of IT skills, tailor-made for learning diversity, development for inquiry skills, etc.

The team members also carefully examined the procedures of each experiment and identified defects in the hardware or software. They suggested that some safety measures be strengthened to prevent devices form damages. More guidelines or reminders were given in the worksheets to make the worksheet self-explanatory. Procedures were streamlined such as by adding "beep" sounds in the program, or displaying more messages on the LCD screen to prompt students to take actions. Students were advised to start the experiments by varying some suggested parameters so that they could be more focused in their experiments. On this point, Arduino demonstrated its immense potential not only for development of hardware and software, but also its integration into pedagogy to guide students in conducting experiments, thereby catering for learning diversity.

After the feedbacks, amendments and comments from the Feedback Panel, a final touch up on each experiment was followed immediately. That ensured the smooth implementation of the program in the Main Study.

Modifications were made to the experiments arising from the evaluation. Major were -

(i) In respect of Experiments 1A and 1B, as teachers were concerned that the two experiments if conducted in one practical lesson, were too lengthy and difficult for the students, it was split into two. This made a lot of sense in that this was the first Arduino-based experiment for students. Students needed to familiarize themselves with the technology. Scaffolding was required. The scaffolded knowledge framework was made reference to, that is, (a) making science accessible, (b) making thinking visible, (c) helping students learn from others, and (d) promoting autonomy and lifelong learning (Linn and Hsi, 2000).

(ii) For Experiment 2, the use of SD card and macros embedded in the Excel was widely accepted by the Feedback Panel as automation of graph plotting and the auto-fitting of the data into a straight line was a useful technology to deal with filtering random errors. Only minor hardware and software bugs were fixed.

(iii) In Experiment 4, the Feedback Panel found the concept difficult for students to understand when an acceleration sensor could give a reading of gravitational acceleration when it was at rest. After clarifying the concept as related to force field, it was suggested that for illustration purpose, an analogy should be introduced. A spring balance carrying a mass was used as an analogy to make an abstract concept easier to comprehend.

(iv) In order to cater for students' learning diversity, the worksheets for the experiments were fine-tuned to avoid easily making mistakes in the calculations. Difficult questions were included in the worksheets and students could score extra marks for answering them.

(v) In Experiment 6, worksheet was revised so that students with average ability could handle the experiment even though the concept of angular velocity was difficult to understand. Safety measures as proposed by the Feedback Panel were also incorporated into the experiments before they were put to students.

4.7.5.5 Analysis of the feedback

With regard to the questionnaires completed by the Feedback Panel, the tables in appendix I summarized the statistics. The sample size of the questionnaires on individual experiments might not be representative enough to draw definitive conclusion. However, opinions of the Feedback Panel could, to some extent, inform constructively on the design of the experiments.

The questions on whether the targets of the HKDSE Assessment Framework (questions II_1- II_{11}) and other learning outcomes (questions II_{12}- II_{16}) like learning diversity, critical thinking, creativity, IT skills and inquiry skills could be met with the Arduino-based experiments were answered with a high degree of consistency.

The highest score for each question was "4" and hence an average of "3" should be regarded as generally agreeable. If the score for individual evaluation item was greater or equal to "3", this was represented by a "✓", otherwise this was represented by a "×" in the check boxes below. A "✓" implied that Feedback Panel regarded that particular evaluation item had been significantly taken into account in that experiment.

No.	Evaluation Items	Expt. 1A	Expt. 1B	Expt. 2	Expt. 3	Expt. 4	Expt. 5	Expt. 6	Overall
II_1	recall and show understanding of the facts, concepts, models and principles of physics, and the relationships between different topic areas in the curriculum framework;	✓	✓	✓	✓	✓	×	✓	✓
II_2	apply knowledge, concepts and principles of physics to explain phenomena and observations, and to solve problems;	✓	✓	✓	✓	✓	✓	✓	✓
II_3	show an understanding of the use of apparatus in performing experiments;	✓	✓	✓	✓	✓	✓	✓	✓
II_4	demonstrate an understanding of the method used in the study of physics;	✓	✓	✓	✓	✓	✓	✓	✓
II_5	present data in various forms, such as tables, graphs, charts, diagrams, and transpose them from one form into another;	✓	✓	✓	✓	✓	✓	✓	✓
II_6	analyse and interpret data, and draw appropriate conclusions;	✓	✓	✓	✓	✓	✓	✓	✓
II_7	show an understanding of the treatment of errors;	✓	✓	✓	✓	✓	✓	✓	✓
II_8	select, organize, and communicate information clearly, precisely and logically;	✓	✓	×	✓	✓	✓	✓	✓
II_9	demonstrate understanding of the applications of physics to daily life and its contributions to the modern world;	✓	✓	✓	✓	✓	✓	✓	✓
II_{10}	show awareness of the ethical, moral, social, economic and technological implications of	✓	×	×	×	✓	×	×	×

	physics, and critically evaluate physics-related issues;								
II$_{11}$	make suggestions, choices and judgments based on the examination of evidence using knowledge and principles of physics.	✓	✓	✓	✗	✓	✓	✓	✓
II$_{12}$	Catering for learner diversity	✓	✓	✗	✓	✓	✗	✓	✗
II$_{13}$	Develop interest and arouse curiosity among students	✓	✓	✓	✓	✓	✗	✓	✓
II$_{14}$	Develop the ability to think scientifically, critically and creatively	✓	✓	✓	✓	✓	✓	✓	✓
II$_{15}$	Use of IT skills	✗	✓	✓	✓	✓	✗	✓	✓
II$_{16}$	Develop Inquiry skills	✗	✓	✗	✓	✓	✗	✓	✗

Table 4.2: Summary of the opinions of the Feedback Panel

All members of the Feedback Panel supported the implementation of the Arduino-based experiments. The scores on questions II$_{1}$ to II$_{9}$ were exceptionally high which were related to the concepts, knowledge, practical skills, data interpretation and manipulation in the study of physics. Members of the Feedback Panel agreed that the core targets as suggested in the HKDSE Assessment Framework could be fully met.

The relatively low score on question II$_{10}$ which was related to the ethical, moral, social, economic and technological implications of physics was expected. It was because within the limited time in a laboratory session, it was hard for students to contemplate these issues. However, the Feedback Panel envisaged that the Arduino experiments had potential to be further developed into project-based learning.

The average score on question II$_{12}$ on “catering for learner diversity” was also relatively low. Members of the Feedback Panel noted the diversified learning ability of the students in the School, and suggested fine-tuning the worksheets so that students with lower ability could be confident enough to complete the experiments. The worksheets were simplified accordingly so that students' requirements on computational skills, which should not be a focus, were minimized. Excel templates were created for students to plug in their raw data to check whether the results were correct. Difficult questions were set as challenging questions in the worksheets and students were encouraged to answer the question by scoring extra marks. The Feedback Panel particularly mentioned Experiment 6 that the concept of period was relatively easier than the concept of angular velocity. Therefore, the worksheet was revised to ask the students to find out how centripetal acceleration changed with period, but not angular velocity.

The average score on question II_{15} on "Use of IT skills" was lower than expected although various intense skills on IT were integrated into the experiments in this research. Further discussion with members of the Feedback Panel revealed that they in general regarded the use of Excel as IT skills but did not realize that the application of Arduino technology itself already involved much IT skills. With Excel introduced in data manipulation starting from Experiment 2, members were positive about the use of Excel as a good tool to facilitate students in plotting graph and retrieving useful information. They appreciated the use of macros embedded in the Excel to optimize automation of graph plotting. e.g. use of click box to select "zoom-in" area, auto-fitting a straight line onto data, finding slope and intercepts of the fitted line, etc. The use of SD card was recognized as a convenient and economical means for storage and transfer of data to the Excel table.

The average score on question II_{12} on "development inquiry skills" was slightly lower than expected. To further develop inquiry skills of students, two out of the seven experiments (Experiment 1B and 6) were developed into scientific investigations. More open-ended questions were set in the worksheets to stimulate students to think scientifically, critically and creatively. Students were encouraged to repeat the experiments and observe the changes if some parameters were altered. To explain the slightly lower rating of the Feedback Panel on this aspect, teachers' efficacy and their readiness in promoting inquiry learning was further looked into. Since in the school-based assessment (SBA), the suggested scientific investigation was not compulsory and could simply be replaced by a long report, teachers tended not to be as proficient in inquiring learning. This confined their perception on how an experiment could be further developed for inquiry learning.

4.8 Summary

DBR is a methodology designed by and for educators that seeks to increase the impact, transfer and translation of education research into improved practice. It could effectively bridge the chasm between research and practice in formal education (Anderson & Shattuck, 2012). In this research, the Feedback Panel with eleven members were deeply involved in testing the seven Arduino-based experiments. The Panel members collaborated closely to select and create the interventions which fully reflected the features of the DBR framework. The designs evolved from and led to development of practical design principles, patterns and/or grounded theory (Anderson & Shattuck, 2012). As Reeves (2000) had put it, the final phase of a DBR study was "reflection to produce design principles and enhance solution implementation".

The intervention developed in this research were meant to integrate innovative sustaining technologies and practice in classroom. Anderson and Shattuck (2012), after reviewing 47 articles on DBR, stated that most articles concluded that their interventions had resulted in improved outcomes on students' attitudes. As Barab and Squire (2004) had agreed, DBR "that advances theory but does not demonstrate the value of the design in creating an impact on learning in the local context of study has not adequately justified the value of the theory". Therefore, a key point about DBR is its ability to impact on learning. Here, for this research, the use of DBR aims to make a difference in education practice and learning environments of the students.

CHAPTER 5

OVERVIEW OF RESULTS

In this study, data were collected from various sources as set out in Chapter 3, including data gathered from within the author's school as well as data outside the author's school. This chapter is a summary of the data collected in the Study. The analysis of the data is discussed immediately after the data presentation in Chapter 6 and 7.

5.1 Data Sources

In this study, it was originally expected that there would be about 60 students participating in the Main Study, which included an intervention group with about 30 F.4 students of the 2015/16 cohort and a control group of about 30 F.4 students of the 2014/15 cohort. However, due to continuous decline in the birth rate in Hong Kong and the increase in the choices of NSS elective modules for senior secondary students under the NSS curriculum, the population of students in the author's school dropped from over 1000 to less than 400 students over the years, and the number of students taking physics as an option in the NSS curriculum dropped even more dramatically. At the time the research was conducted, altogether there were only 32 students (16 from each group) in the two cohorts taking physics as an NSS option. Therefore, the validity of the data in the pre-tests and post-tests of the intervention group and control group in the Main Study was not as satisfactory. Nevertheless, the research proceeded as planned since the results did throw some light on the impact of the intervention despite the sampling size. In addition, the instrument developed for this research informed future researchers on possible use of this framework for further study in other schools with a representative student population.

Apart from students and teachers in the author's school, 131 master teachers in Singapore were invited to participate in this study. In the STEM Olympiad 2016 held in Hong Kong, senior secondary students and local teachers participating in the event were also invited to join this study. Out of around 700 students and around 100 local teachers of the STEM Olympiad 2016, 20 students and 15 local teachers respectively joined this study in the form of going through the STEM workshops. In the workshops, the Arduino experiments were introduced to participants and tried by themselves. Written feedback was collected from them by means of a survey regarding the use of Arduino devices in the learning and teaching of "mechanics".

When the entire data collection process was completed, altogether 23 questionnaires from local teacher, technical assistant and laboratory technicians, 131 questionnaires from Singaporean teachers and 36 questionnaires from local students were collected. In addition, 4 teachers, 1 technical assistant and 22 students from the author's school were interviewed. The sample size (131) of the Singaporean teachers in the OEIR Program was sufficiently large statistically. However, the sample size of the students in the intervention group and the control group was not sufficiently representative to draw conclusive statements solely from the quantitative data in the pre-tests, post-tests and the survey. Therefore, the qualitative data obtained in the interviews of the students acted as an important source in the study and a mixed mode of quantitative and qualitative method was adopted in the study eventually.

5.2 Qualitative Data - Verbal and Written Comments

In the study, verbal and written comments on the implementation of the Arduino-based experiments were collected among teachers and students in the author's school and other Hong Kong local schools, as well as teachers of the Singaporean schools. In the author's school, 12 interview sessions had been held and 27 participants were involved in the interviews, which included 6 F.6 students in the 2015/16 cohort, 16 F.4 students in 2015/16 cohort, 4 teachers and the technical assistant. In the end, interview records lasting 537 minutes, as shown in Table 5.1 below, were collected and they were then transcribed into 12 source files. The interview records were broken down into simple statements and coded and 1089 views were coded according to the coding system elaborated in Section 5.5.

Target group	Number of interviewees	Total recording time in interviews / minutes	Number of views coded
F.6 students in the 2015/16 cohort	6	78	191
F.4 students in 2015/16 cohort	16	271	525
Teachers and Technical Assistant	5	188	373
Total	27	537	1089

Table 5.1: Qualitative data collected in the interviews in the author's school

Other than interview records, written comments were collected from various groups, as shown in Table 5.2. The written comments came from the Survey Forms (I and II) of the target groups after the experiments were conducted. Majority of the written comments were from the Singaporean teachers who participated in the OEIR programme 2016 (346 threads) and F.4 students in 2015/16 cohort in the author's school (69 threads).

	Target group	Number of threads coded
1	F.4 students in 2015/16 cohort in the author's school	69
2	Teachers & Technical Assistant in the author's school	16
3	Singaporean teachers participated in the OEIR Programme 2016	346

4	Teachers (from other Hong Kong schools) participated in the STEM Olympiad 2016	9
5	Students (from other Hong Kong schools) participated in the STEM Olympiad 2016	15
	Total	455

Table 5.2: Number of coded threads from written comments of various groups

The written comments from teachers in the author's school were integrated with their views obtained in the interviews to form 389 threads in total. However, the number of threads from the written comments of the teachers and students in the STEM Olympiad were minimal (only 9 and 15 threads), contributing little influence in the qualitative analysis. As a result, only their views in the quantitative analysis had been accounted for.

5.3 Quantitative Data collected from Pre-tests/post-tests

Paired t-test results on the Force Concept Inventory (FCI) and the Processing Skills (TIPS II) were carried out between two groups of students (the intervention group and the control group) to see if there was significant difference in knowledge on the Force Concept and the Processing Skills before and after intervention. Altogether, 16 students from each group in the two cohorts participated in the two pre-tests and post-tests, and t-test was conducted to analyse the results. Composition of these two groups of students were -

(1) Intervention Group: F.4 students of the 2015/16 cohort, who participated in the Intervention Programme in which they carried out seven Arduino-based experiments on the topic "mechanics".

(2) Control Group: F.4 students of the 2014/15 cohort, who did not go through the Intervention Programme, but had completed similar experiments in the topic "mechanics" with traditional methods.

5.4 Quantitative Data collected from the Survey Forms

Survey Forms had been distributed to students and teachers in Phase I and Phase II of the Main Study to collect both quantitative and qualitative data, after their going through an Arduino programme. Quantitative data collected from the Survey Forms included data from the following groups:

Group	Survey Form	Target group	Number of participants
1	II	Singaporean teachers participated in the OEIR Programme 2016	131
2	I	Students participated in the Intervention Programme in the author's school	16
3	II	Teachers, technical assistant and labratory technicians of the author's school	9
4	II	Teachers participated in the STEM Olympiad 2016	14
5	II	Students participated in the STEM Olympiad 2016	9
3+4	II	Hong Kong local teachers	23

Table 5.3: Five groups which had participated in the survey of the Main study

Data from the teachers in the STEM Olympiad 2016 were merged with that of the teachers of the author's school to form a larger data base for comparison with those of Singaporean teachers which was further elaborated in Chapter 7 Section 7.3.2.

5.5 The "CATEX" Coding System

To analyse the qualitative data totaling 1544 threads as set out in Section 5.2, the author has self-developed a coding system entitled the "CATEX" coding system which was the abbreviation for **C**hallenges (**C**), **A**rduino Technology (**A**), **T**eaching and learning of Physics (**T**), Conduction of the **E**xperiments (**E**), and Comparison with Traditional E**x**periments (**X**). The CATEX system shares some similarities of the clustering analysis techniques in that it aims to classify multivariate data by grouping objects together into classes. Cluster analysis is a tool that supports the identification of associations within qualitative data. It offers a classification tool that provides an initial step in organizing what is otherwise very complex data. Clustering techniques organize data by comparing the values assigned for variables across cases, determining their level of similarity. The agglomerative version of the clustering method identifies each element as its own cluster in the first step. All clusters are then compared, with those most similar merging and creating a new cluster and the process repeats until a single cluster is formed. Through this, a framework is constructed that helps reduce the data to a more manageable size for analysis (Marcia, 2015).

Sharing the broad principles of cluster analysis, the CATEX coding system aims to group the views collected in the interviews and the survey forms in this study into manageable size and sensible categorization. CATEX consisted of five categories of coding created for easy coding of the views collected in the interviews and the survey forms. The introduction of the coding system facilitated discussion in the following chapters and sections that followed.

In developing the CATEX coding system for qualitative analysis, the author has employed a simpler method using Excel. The methodology resembled that of the clustering analysis in that the 1544 coded threads from 17 source files were compared to identify similarities at the elementary level. Similar sub-categories were then merged to form a category at a higher level until an agglomerative tree-like CATEX mind map was formed. Specifically, the coded threads from the source files were copied into an Excel table. Macros written and embedded in the Excel table would automatically calculate the number of count of threads under different subcategories. The Excel table would also automatically update the total counts in the five CATEX categories, and showed the percentage of positive, negative or neutral comments in each category and subcategories in the CATEX mind map for easy comparison (as shown in Appendix L0-L6). By suitably selecting data from the source files, different mind maps for different combinations of concern groups could be instantly produced.

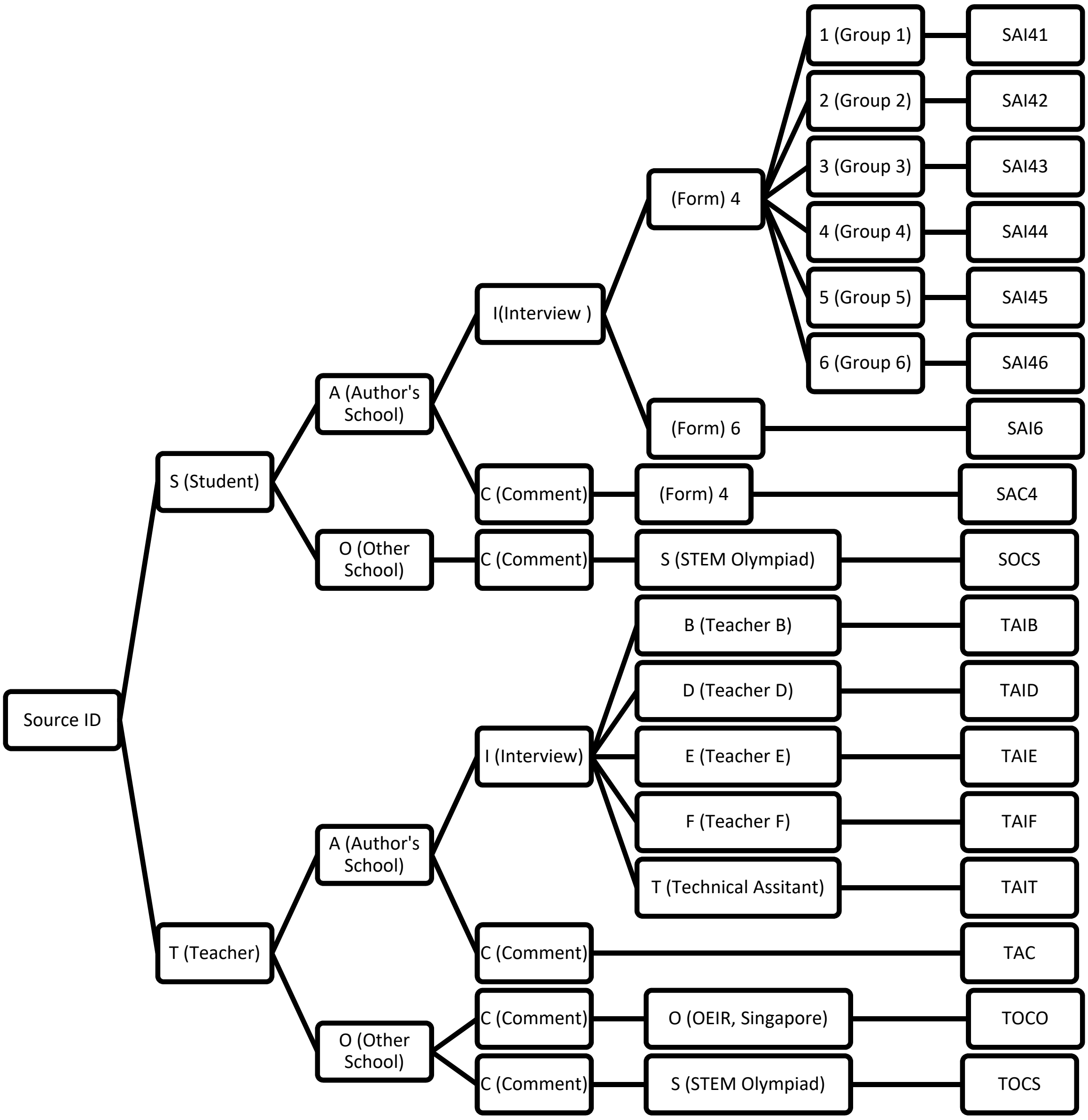


Table 5.4: "CATEX" coding system of the data from interviews and written comments of the surveys

Under the CATEX coding system, the name of the source files and the data collected from the interview records and written comments were coded in a systematic way as shown in Table 5.4 above, with the identity of the participants (**T**eacher or **S**tudent), school that the comments were gathered (**A**uthor's School, **O**ther Schools), the means of data collection (**I**nterview or Written **C**omments) and the groups of participants (group interviews of students) were taken into account. Finally, 17 different Source Identity (SID) codes were generated. The interview records and written comments from the survey forms were broken down into simple statements (or threads) for easy coding. The number of threads coded from the individual files was summarized in Table 5.5 below.

The coding system was constructed following rounds of reviews of the interview records and survey comments. Before coding, all source files were scanned once and a batch of initial codes were generated. The codes were classified under five major categories under "CATEX". Threads that were unrelated to the study were coded with "**N**ot **A**pplicable (**NA**)". Under each category, the threads in the source files were further classified into four to eight sub-categories. The coding was iterated many times until all threads could be categorized with minimum ambiguity. Each code was uniquely represented by two capital letters, for example, "**AW**" stood for "**A**ruduino Hard**W**are and software" and "**CT**" for "**C**hallenges: **Teacher** efficacy". 27 different sub-categories were generated in Table 5.6 below. Each sub-category was further appended with a "+", "-" or "=" to stand for whether the statement carried positive, negative or neutral meaning or connotation. For example, "AA" were further classified into "AA+", "AA-" and "AA=". Using this coding system, data analysis could be done with a mixed quantitative and qualitative method and further classification had resulted in 79 different codes for 27 sub-categories.

Source ID (SID)	Brief description of the data source	Number of threads coded
SAI41	Interview record of 16 F.4 students of the 2015/16 cohort in the author's school	95
SAI42		90

SAI43	(Group 1 to Group 6)	92
SAI44		53
SAI45		91
SAI46		104
SAI6	Interview record of 6 F.6 students of the 2015/16 cohort in the author's school	191
SAC4	Comments from F.4 students of the 2015/16 cohort in the author's school (from the Survey Form I)	69
SOCS	Comments from students participated in the STEM Olympiad 2016, extracted from the Survey Form II	346
TAIB	Interview record of teacher B in the author's school	95
TAID	Interview record of teacher D in the author's school	59
TAIE	Interview record of teacher E in the author's school	63
TAIF	Interview record of teacher F in the author's school	52
TAIT	Interview record of the technical assistant in the author's school	104
TAC	Comments from teachers, laboratory technicians and technical assistant in the author's school (from the Survey Form II)	16
TOCO	Comments from Singaporean teachers participated in the OEIR Programme 2016 (from the Survey Form II)	15
TOCS	Comments of teachers from other schools participated in the STEM Olympiad 2016 (from the Survey Form II)	9
	Total	1544

Table 5.5: Brief description of Source Identity (SID)

Category	**Codes for sub-categories**
Challenges (**C**)	CC: **C**urriculum
	CE: School **E**nvironment **(**Resources of and Financial Implication to Schools, elective subjects in Schools)
	CI: **I**T skills (Use of Arduino hardware, Programming, and use of Excel)

	CL: Students' readiness and attitude in **L**earning
	CM: Time **M**anagement (time allocation to subjects and laboratory session, tight syllabus, public examination, etc.)
	CT: **Teacher** efficacy, confidence and **T**raining needs
	CS: Technical **S**upport
	CO: **O**thers
Arduino Technology (**A**)	AA: Cost and **A**ffordability, **A**vailability of hardware and sensors
	AW: Hard**W**are and soft**W**are (Open-source, advanced technology, portability, ease of use, powerfulness, convenient, practical, etc.)
	AV: **V**ersatility and flexibility
	AO: **O**thers
Teaching and learning of Physics (**T**)	TA: **A**ffective Domain (Students' motivation, interest, learning habit, attitude and satisfaction, level of challenge, extent of inspiration, etc.)
	TC: **C**ontext (authenticity, real-life, hands-on experience, outside classroom, etc.)
	TH: **H**igher order thinking (critical thinking, innovation, creativity, proposal for improvement, metacognition)
	TI: Scientific investigation skills
	TK: **K**nowledge Transfer (Applicability in other fields of science, acquiring new knowledge other than Physics)
	TP: Understanding of **P**hysics (concepts or content knowledge)
	TO: **O**thers (e.g. collaboration, length, level of difficulty)
Conduction of the **E**xperiments (**E**)	EC: Data **C**ollection (automated data recording, data capture rate, ease of use, reliability, reduction of human error, accuracy, time saving, real time)
	EM: Data **M**anipulation (accuracy, time saving, ease of use of Excel templates, graph plotting and curve fitting feature, information retrieval from graph)
	EP: **P**rocedures (preparation, briefing, implementation, flow, design of worksheet, chance for repeating experiments, shorter time for completing the experiments.)
	ES: Laboratory **S**afety

	EO: **O**thers
Comparison with Traditional E**x**periments (**X**)	XT: Comments on the **T**raditional Experiments / Non-Arduino-based experiments.
	XC: **C**oncepts on the Traditional Experiments / Non-Arduino-based experiments.
NA	**N**ot **A**pplicable

Table 5.6: Sub-categories in the "CATEX" Coding System

Out of the 1544 threads, only 8 (about 0.5%) of them were marked "NA" (Appendix L0) which meant that vast majority of the comments gathered could be coded and were taken into account in the study. For some categories like "Arduino Technology", "Conduction of the Experiments" and "Teaching and learning of Physics", 953 out of 1048 threads (88%) were positive feedbacks. However, for the category "Challenges", which concerned about curriculum, school's policy, time management, IT skills, students' readiness, teacher efficacy and technical support, 243 out of 297 threads (81.8%) were negative feedbacks. For a few codes, no thread could be matched. For example, Experimental Safety (code "ES") which was often one of the concerns in conducting science experiments did not have any statement matched in the Main Study.

5.6 Samples of Codes used in the CATEX Coding System

Some typical examples of how coding was assigned to some of the threads according to the codes of each sub-category in "CATEX" were quoted in Table 5.7 below for illustration purpose. "SID-#" in the table was unique source code of the 1544 threads.

Code	Comment/ Feedback/ Opinion	SID-No
AA+	F4S7: The cost of ownership is low. Even if the Arduino device were broken, they would not cost much.	SAI43-22
AA+	Cheap and low cost. Therefore, more sets could be given to each class.	TOCO-59

AO-	If user friendly interface can be developed for student use, it is better for students to use other software.	TAC-11
AO=	Arduino may not be for everyone.	TOCO-225
AV+	F4S16: The same Arduino mother board could be used to perform many other different experiments only by changing the sensors (or program).	SAI46-69
AV+	The flexibility to build almost anything for own experiment is highly valued.	TOCO-85
AV-	F4S12: However, some experiments cannot not be replaced by the Arduino-based experiments.	SAI45-69
AV-	F4S13: The Arduino-based experiments may not be useful for simple experiments.	SAI45-70
AV=	Could accelerometers and GPS functionality in smart phone be used?	TOCO-345
AW+	Arduino apparatus was highly portable (or wearable) to carry around to do experiments. e.g. g-sensors in measuring acceleration in a lift.	TAID-33
AW+	(Arduino is) powerful and effective tool…in obtaining experimental data…and analysing the data collected.	TOCO-50
AW-	F4S7: The single board computer was a bit slow.	SAI43-88
AW-	F4S16: The Arduino device got no protection. They were fragile and might easily be damaged.	SAI46-101
AW=	F4S3, F4S2, F4S1: We knew that the Arduino apparatus had to be driven by a program.	SAI41-11
AW=	F4S16: The size of the Arduino apparatus could further be reduced.	SAI46-99
CC+	The experiments were well designed and matched the requirement of the NSS syllabus.	TAIE-26
CC+	…. even further programming applications (computer science, robotics, electrical engineering, app creation) can also be considered to be taught at the secondary level.	TOCO-33
CC-	There may not be enough time in our curriculum to do this.	TOCO-183
CC-	May have to re-teach to align it to the syllabus	TOCO-192

CC=	… and curriculum development is also a must so that the applications are within students' learning curriculum.	TAC-13
CE+	The class size in the school was small so that individual needs could be entertained.	TAID-42
CE+	will look forward to the ministry providing support for such tools in our classrooms.	TOCO-341
CE-	(difficulty in) acquisition of equipment as well.	TOCO-156
CE-	In an education system with high-stakes testing like Singapore, teachers may feel such innovative processes have limited returns compared to tried and tested, drill and practice.	TOCO-168
CI+	Students nowadays can manage to use computer well and quickly, e.g. skills in plotting graph and verifying data with Excel.	TAID-2
CI+	F4S5: Arduino motivated me in learning Arduino programming.	SAI42-71
CI-	More time could be spent to provide step-by-step guidance for students to use Excel, plot out and print out the graphs, etc.	TAIE-5
CI-	There is a high barrier with regards to ICT skills for both teachers and students	TOCO-253
CI=	Grasp of IT skills could facilitate students to carry out the Arduino-based experiments.	TAIE-6
CI=	F4S2: Some students thought that knowing how to write program would help do the experiment better.	SAI41-14
CL+	Teacher F thought that students with average ability or high achievers were able to accept the new technology better and could learn a lot from the experiments…	TAIF-16
CL+	F4S11: Even without the guidance from the teachers, we can follow the instructions and complete the experiments and worksheets.	SAI44-53
CL-	Some students of the School were weak in mathematics so that before each laboratory session, the teacher had to spend extra time to brief them.	TAIE-33
CL-	Students may also find the large quantity of data gathered overwhelming…	TOCO-305

CL=	If students had acquired relevant IT skills in their junior classes, they could apply the skills in learning NSS science. It is not necessary to revise with them the IT skills.	TAIE-2
CL=	However, for junior secondary or primary school students, the technology might be too difficult for them to master.	SAI42-52
CM-	Teachers do not have time to prepare so many teaching materials and preparation.	SOCS-5
CM-	Lots of time and resources should have been spent in developing the seven experiments.	TAIB-71
CO+	In fact, in designing the (Arduino-based) experiments, some uncommon method was employed. Data was first saved in the RAM and after the experiment was completed, the data stored in the RAM was transferred and saved in the SD card. That solved the problem of (slow) saving speed.	TAIT-61
CO+	After students had selected the area of data, I created an additional page in the EXCEL table in which the data out of the area would be automatically deleted. …Inserting this step enabled students who did not have much knowledge on the application of EXCEL to use EXCEL for (data) manipulation.	TAIT-94
CO-	As there were inadequate tools in the market which could facilitate the implementation of Scientific investigation, teachers very often ignore Scientific investigation in the school based assessment (SBA) and would replace it with a long report instead.	TAIB-39
CO-	Different Excel templates were tailor-made to manipulate data for different experiments. If the Arduino-based experiments were further promoted to other schools, it would be better to have a universal interface (like those provided by the data logger vendor) so that the users could manipulate the data more easily.	TAIE-39
CO=	The first experiment developed was that on the centripetal force. At that time, different methods had been tried, e.g. control the experiment with a mobile phone. However, in order to simplify the procedure, push buttons were used for the control.	TAIT-56

CO=	A community of teachers of like-mindedness will help in growing teachers who are interested.	TOCO-334
CS+	I think that what we are doing now is a better method, e.g. students could be given the open-source program that can be found on the web, so that students could use the sensors and do not need to understand programming.	TAIT-77
CS=	Author: If you came across hardware failure, you just had to replace it with another set, as if in the case when you got a broken multi-meter, what would you do? Student: Replace another one…	SAI6-136
CS-	Technicians needed to be trained in order provide technical support. In case the device broke down, teachers might not know how to fix it.	TAID-36
CS-	Trouble shooting will be a big issue if lesson is conducted big groups of students.	TOCO-202
CT+	F4S11: …but the teachers had given us appropriate advice and guidance, and helped us finish it (report writing) in time.	SAI44-44
CT+	F4S4: Teacher's guidance was very important to lead us to understand the whole process.	SAI42-59
CT-	The difficulties may come from teacher efficacy...	TAC-5
CT-	This is an initial learning curve that teachers must be willing to invest in.	TOCO-323
CT=	The focus of teachers should focus on ideation and testing the feasibility.	TOCO-326
EC+	With the Arduino technology, data collection could be collected within a few seconds to 15 minutes.	TAIB-56
EC+	More reliable measurement instead of basing on human observation and measurement using normal laboratory equipment.	TOCO-113
EC-	Some students might not be able to visualize how data was generated from the instrument and how these data was related to the experiment.	TAIF-13
EC-	too many raw data	TOCO-218

EM+	F4S8: Sometimes the data obtained (e.g, in Newton's 2nd Law Expt) were very scattered. If the average on hundreds or thousands of data points was taken, the random error could be reduced.	SAI43-18
EM+	F4S4: I preferred using Excel in graph plotting than free hand, as it was more convenient and accurate.	SAI42-60
EM-	F4S2: There could be many possible relationships between the data of the two columns, but various types of relationships made it a bit confusing.	SAI41-23
EM-	F4S15: I preferred more calculations on our own to that done by Excel.	SAI46-100
EM=	Author: Yes, there are hundreds of samples (collected). Would all hundred points fall onto the straight line? Students: No.	SAI6-154
EO+	F4S6: I preferred to carrying out the experiments on my own, but sometimes I needed to cooperate with others so that I could discuss with them and had better understanding.	SAI42-31
EO+	(Improvement?) Can increase the sessions in which students can participate more, e.g. calculations.	SAC4-40
EO-	The bars were not rigid enough so that they would be easily broken if they unfortunately hit onto the ground.	TAID-27
EO-	F4S15: In the falling bar experiment, the bar would easily touch the light gate and the bar was easily broken…	SAI46-92
EO=	F4S16: It would be better if the accuracy of the experiments could be further increased.	SAI46-104
EP+	F4S11: I encountered some difficulties when performing the first two experiments. After that, the procedures were more or less the same and I became adapted to it.	SAI44-42
EP+	F4S3: The experiments were time saving so that the experiments could be repeated many times to obtain more accurate results.	SAI41-51
EP-	F4S11: For the circular motion experiment, it was a bit difficult to control the rotation smoothly.	SAI44-46
EP-	F4S2: The worksheet seemed to be a bit lengthy, with more texts in the worksheet (than the experiments we had done before).	SAI41-78

EP=	F4S15: It is necessary to keep the track horizontal.	SAI46-25
NA	Author: The English group performs the experiment on the Newton's 2^{nd} Law first, while the Chinese group performs the experiment on circular motion.	SAI6-125
NA	Author: Please compare the merits and demerits between the traditional method and the new method with Arduino technology. Do you need more time for discussion? Students: No need.	SAI6-126
TA+	F4S8: I always look forward to these lessons, in which we can play with different types of Arduino device to do different experiments.	SAI43-63
TA+	Great attempt to push more students to learn science in a more engaging way.	TOCO-339
TA-	On the other hand, some students might be scared by high-end technology they were not familiar with.	TAIF-8
TA-	Students may not be very excited to see data as compared to animation or video.	TOCO-242
TA=	Whether these (Arduino-based) experiments could motivate students in learning physics depended on individual students.	TAIE-12
TC+	F4S10: If sensors could be small enough, they could be mounted onto basketball, lead ball in shot put, javelin, and running shoes to capture data of motion.	SAI44-37
TC+	F4S6: Real-life experience would be very important in learning physics.	SAI42-63
TH+	Able to stretch students' imagination to invent new things that are useful.	TOCO-37
TH+	It sparks creativity and innovation	TOCO-72
TH=	If the students could be involved in the design of the experiment, it would be a very good chance of providing them with high order thinking skills.	TAIF-44
TH=	In order to distinguish their abilities, Teacher E suggested not to introduce briefing session and observed whether they could perform the experiments after self-study.	TAIE-61

TI+	Scientific investigation is very important in learning science and it is the drive for learning science.	TAIE-17
TI+	It also helps to generate questions themselves, learn how to investigate and explore.	TOCO-58
TI=	F4S12: I remembered that in an investigative study of a falling bar (Expt. 2), the relationship between the velocity (v) and the height of released (h) was investigated.	SAI45-16
TI=	If students have resistance in doing Scientific investigation, they would not like this subject.	TAIE-18
TK+	Besides, the future is probably in computing and technology, hence learning computing and modifying programs for Arduino is useful as well.	TOCO-10
TK+	The experiments well echoed with the ideas in STEM education. In producing the Arduino-based device, mathematics, electronics, coding and even laser-cutting technology were involved.	TAIF-32
TK-	Data treatment, such as measuring pH values, would be less demanding. The chemistry or biology syllabuses are a bit alienated from high-end technology.	TAIB-45
TK=	Applying Arduino technology in other subjects would not be as easy as in physics. Many chemistry experiments like titration would usually be based on very traditional and fundamental experimental techniques such as using pipet and burette.	TAIB-44
TO+	The students could have a chance to understand the design of the electronics.	TAIF-42
TO+	(Arduino technology) could connect students with the latest advanced technology and make them easier to enter the workforce.	SAC4-52
TO-	The demerit (of using Arduino) may reduce the chance of students' participation.	SAC4-49
TO-	Students not as engaged.	TOCO-278
TP+	F4S15: In the bouncing ball experiment, I understood the meaning of the signs +/- in velocities (up/down).	SAI46-7

TP+	Allowing students to use technology to make their thinking more visible.	TOCO-97
TP-	F4S7: … even though I didn't learn much about physics.	SAI43-46
TP-	and it was quite difficult to understand that friction and mass of the trolley could be retrieved from the slope and the y-intercept, respectively.	TAID-51
TP=	Students might not easily relate the concepts to the course content but if they understood the principle behind, they were able to grasp the ideas.	TAIE-29
XC+	Author: How should the rubber band be pulled? F6S5：to keep the length (of rubber band) unchanged.	SAI6-11
XC+	Author: …Do you remember what does the slope of the velocity-time graph stand for? Students: Acceleration.	SAI6-21
XC-	Author: How to pull (the cart)? F6S3：with a piece of string (wrong answer)	SAI6-7
XC=	Author: … please show me how to achieve "friction compensated". (Students raised the angle of inclination until the cart just started to move and was stopped by the Author.)	SAI6-50
XC=	Author: Who can tell how the experiment was carried out? (Student discussing among them…) Author: F6S6, please tell me… F6S6：The method we used in school ...	SAI6-62
XT+	F4S14: In some traditional experiments, many pieces of equipment were involved. Students had to follow many steps to collect data and data were not accurate. Students would easily lose interest in doing the experiments.	SAI45-31
XT+	Only a few sets of data could be collected in the whole lesson and there was no time left for further discussion (in conducting the traditional experiment).	TAID-57
XT-	Some students might feel more comfortable working with some primitive and simple apparatus, e.g. using a timer to measure the number of revolutions per second.	TAIF-9

XT-	F4S4: I preferred using free hand to plot graph as it would be more realistic. When plotting the graph, if some data deviated from the main trend, the data could be deleted and removed (manually).	SAI42-13
XT=	(Most interested experiment)…as it is different from the traditional experiment.	SAC4-31
XT=	Arduino may result in students' decreased exposure to traditional experiments since many things can be done electronically	TOCO-271

Table 5.7: Samples of Codes used in the CATEX Coding System

CHAPTER 6

FINDINGS AND DISCUSSION

Phase I of the Main Study (Intervention Programme in the author's school)

The analysis of the data in the Main Study was divided into Phases I and II. This chapter focused on the data analysis in Phase I of the Main Study (the Intervention Programme) held in the author's school. Qualitative analysis of data of Phase I collected from the written comments and in-depth interviews constituted the most important part in Phase I of the Study. It was supplemented by the quantitative analysis of the data collected from the pre-tests and post-tests and the survey which is less reliable because of the small sample size. Quantitative data helps serve to triangulate or complement the findings from the qualitative data.

In the qualitative analysis discussed in this chapter and the next chapter, positive and the most mentioned views, extracted from the CATEX system (as introduced in Section 5.5 of Chapter 5) will be presented first, followed by less mentioned, negative views.

6.1 Students in the Intervention Group (F.4 students in the 2015/16 cohort)

Among the coded views of the intervention group, the aspects that were most commented (Table 6.1) were on the "Teaching and learning of Physics (T)" (43.1%), "Conduction of the Experiments (E)" (29.1%) and "Arduino Technology (A)" (18.2%). The complete mind map is at Appendix L1. 86.9% of the threads was on the positive side, 5% was neutral and 8.1% was on the negative side.

Total 594 100.0%	A 108 18.2%	A- A+ A= Atotal	11 87 10 108	10.2% 80.6% 9.3% 100.0%
	E 173 29.1%	E- E+ E= Etotal	17 148 8 173	9.8% 85.5% 4.6% 100.0%
	T 256 43.1%	T- T+ T= Ttotal	4 247 5 256	1.6% 96.5% 2.0% 100.0%
	C 34 5.7%	C- C+ C= Ctotal	13 16 5 34	38.2% 47.1% 14.7% 100.0%
	X 23 3.9%	X- X+ X= Xtotal	3 18 2 23	13.0% 78.3% 8.7% 100.0%
	NA 0 0.0%			

Table 6.1: Coded CATEX views of F.4 intervention group in the author's school

6.1.1 Teaching and Learning of Physics

Under the "Teaching and learning of Physics" category, a very high proportion (96.5%) of the threads were positively coded, indicating that students strongly agreed with the intervention in enhancing their learning of physics. Among the threads, 30.5% was in "TP", 27.7% in "TA", 13.3% in "TC", 12.9% in "TI" and 8.2% in "TH",

T-	4	1.6%
T+	247	96.5%
T=	5	2.0%
Ttotal	256	100.0%

TA	71	27.7%
TC	34	13.3%
TH	21	8.2%
TI	33	12.9%
TK	17	6.6%
TP	78	30.5%
TO	2	0.8%
T	**256**	**100.0%**

TA-	0	0.0%
TA+	71	27.7%
TA=	0	0.0%
TC-	0	0.0%
TC+	34	13.3%
TC=	0	0.0%
TH-	0	0.0%
TH+	21	8.2%
TH=	0	0.0%
TI-	0	0.0%
TI+	32	12.5%
TI=	1	0.4%
TK-	0	0.0%
TK+	17	6.6%
TK=	0	0.0%
TP-	3	1.2%
TP+	71	27.7%
TP=	4	1.6%
TO-	1	0.4%
TO+	1	0.4%
TO=	0	0.0%

Table 6.2: “Teaching and Learning” sub-category for the Intervention Group

“TP” referred to the “Understanding of Physics”. On this aspect, an overwhelming percentage of the views was positive. Students described their experience with the intervention that *“the Arduino-based experiments greatly enhanced their understanding on the concepts and knowledge” (SAI42-61)*, that *“learning physics was made simpler” (SAI41-64)* and that *“the equations were recalled when doing the experiments so that students could deepen their impression on the subject matter.”* (*SAI41-65)* Some even pointed out that *“with these Arduino-based experiments, they knew how the equations were generated” (SAI45-49)* and *“the Arduino-based experiments made them believe that what was taught in class was correct.” (SAI46-60)* Student F4S11 illustrated his understanding of physics with an example *“It is very hard to believe that the acceleration can be the same if a ball is released at rest while another one is thrown hardly.” (SAI44-23)* However, with the use of Arduino devices, this phenomenon could easily be verified. In brief, they thought that they *“could learn new things beyond textbooks.” (SAI43-60)*

"TA" represented 27.7% in the "Affective Domain" sub-category and all comments from the groups were positive. A student remarked that in the past, *"teachers tended to do demonstration instead of group experiments." (SAI43-27)* Actually, students were "*more interested in doing the experiments in small groups as we could manipulate the device and data on our own." (SAI43-27)* Students thought that *"the experiments were full of fun" (SAI42-27)* and they were "*very interested in doing the experiments." (SAI42-27)* Students expressed that *"they liked the lessons to be conducted in the laboratory much more than the formal lessons in classroom." (SAI44-21)* They *"liked the Arduino-based experiments particularly more than other physics experiments" (SAI44-29)* because *"only simple steps were involved in data treatment in the Arduino-based experiments and this would enhance their interest in participation." (SAI46-45)* Student F4S15 pointed out that *"doing scientific investigation is more interesting than verifying the law." (SAI46-80)* Students were motivated and they *"always look forward to these lessons." (SAI43-63)*

In the "Context" sub-category denoted by "TC", all the views fell onto the positive side "TC+". Many students agreed that *"Arduino technology could be applied in many real-life situations." (SAI46-61)* They realized that Arduino could be used out of the classroom and they could think of many examples in using the Arduino like *"The Arduino device could be used to measure the height of water level" (SAI43-52), "Motion sensors could be put onto a vehicle to give warning to driver if the velocity or the acceleration exceeded the limit"(SAI44-36), "IR light gate can be used to determine the winners in a race" (SAI45-55),* and *"Acceleration and angular velocity sensors can be put on motor-driven games in Ocean Park."(SAI45-59)*

In the "Scientific investigation" sub-category denoted by "TI", almost all the views were in "TI+" sub-category. Students agreed that *"they could have more time to do Scientific* *investigation in which they could alter some independent variables to see how they affected the results." (SAI42-45)* They could test the hypothesis *"with the Arduino apparatus and in a short time found out the truth." (SAI44-24)* For example, F4S15 said, *"I could do further investigation by changing some parameters. For example, in the Newton's 2nd Law, lubricant could be added to alter frictional force, mass on wooden board and strength of springs could be altered to see how the results would be affected." (SAI46-54)* Some students thought that *"Arduino would be very useful in inventions, e.g. in producing an Arduino-controlled music generator." (SAI42-2)*

On "TH" which represented "Higher-order Thinking", all comments were again positive. In the interview, students commented that they have applied higher-order thinking in the experiments. F4S15 said, *"Arduino involves more critical thinking." (SAI46-81)* Some students thought that *"Arduino technology could be applied to fun science competition" (SAI42-87)*, in which the potential of students in creativity and innovation could be unleashed. In doing the Arduino-based experiments, students had made many valid suggestions in improving the experiments, such as:

F4S16 said, *"I suggest putting the trolley on rails so as to ensure that the trolley can hit head on with the stationary one." (SAI46-23)*

F4S6 said, *"Some oil or lubricant could be added on the track (in the Newton's 2nd Law experiment) to reduce friction." (SAI42-46)*

6.1.2 Conduction of the Experiments

Under the "Conduction of the Experiments" category, a very high proportion (85.5%) of the views were positively coded indicating that students were very satisfied with the conduction of the experiments during the intervention. Among the coded views, 41.6% was in "EP", 28.9% in "EM", and 24.3% in "EC".

E-	17	9.8%
E+	148	85.5%
E=	8	4.6%
Etotal	173	100.0%

EC	42	24.3%
EM	50	28.9%
EP	72	41.6%
ES	0	0.0%
EO	9	5.2%
E	**173**	**100.0%**

EC-	0	0.0%
EC+	42	24.3%
EC=	0	0.0%
EM-	2	1.2%
EM+	48	27.7%
EM=	0	0.0%
EP-	14	8.1%
EP+	56	32.4%
EP=	2	1.2%
ES-	0	0.0%
ES+	0	0.0%
ES=	0	0.0%
EO-	1	0.6%
EO+	2	1.2%
EO=	6	3.5%

Table 6.3: "Conduction of the Experiments" sub-category for the Intervention Group

In this category, "Procedures" ("EP") were most commented on and the views were largely positive. Student F4S14 said, *"Arduino simplified the procedures so that the experiments could be finished by simply pushing a few buttons." (SAI45-32) "Less labour was required in the Arduino-based experiments. For example, the circular motion experiment could be finished by one student." (SAI42-84)* Even students encountered some difficulties when performing the first two experiments, *"after that, the procedures were more or less the same and they became adapted to it." (SAI44-42) "The experiments were time-saving so that the experiments could be repeated many times to obtain more accurate results" (SAI41-51)* and this *"challenged students to get higher score." (SAI42-41)* Students were satisfied with the design of the experiments, saying that *"the information in the report is rich and well organised" (SAI44-51)* with *"the level of difficulty just right to meet their needs." (SAI43-87) "The worksheets gave enough information, guidance and hints to students so that they did not have much difficulties* *in answering questions except the challenging questions." (SAI45-88) "They had enough time to finish the Arduino-based experiments and complete worksheets in time." (SAI42-43)* Even for the challenging questions in the worksheets, they were *"still able to answer most of them." (SAI45-72)*

"Data Manipulation" (denoted by "EM") was the second most mentioned aspect. Students preferred *"Excel plotting than free hand as in free hand plotting, wrong scale might be used and coordinates would easily be wrongly plotted." (SAI41-25)* Excel was *"more convenient, fast and more accurate", (SAI42-11) "useful in plotting a large volume of data" (SAI42-14)* and could *"avoid human error" (SAI42-12).* Once the students had learned the "copy and paste" function, they were *"able to follow the instructions in doing the experiments." (SAI43-79)* Students found that it was amazing that *"Excel could be used to generate graph, fit straight line, calculate slope and find y-intercept." (SAI43-13) "The results of the Arduino-based experiments could be presented on graphs and this made it easy for students to understand the relationship between data." (SAI45-35)* Some students even learned *"how to create graph on their own to find out the relationship between two physical quantities." (SAI41-21)* The skills equipped students to do more Scientific investigation.

"Data Collection" (as denoted by "EC") was the third most mentioned aspect and all the views were positive. Students thought that *"manual data collection was slow, but Arduino could do it fast and accurate" (SAI42-22).* Data collection using Arduino devices *"helped to reduce human error and was very convenient to use." (SAI42-28) "For some experiments like bouncing ball which would be finished within seconds, Arduino device had the advantage of capturing lots of data in a short time" (SAI43-55)* and *"hundreds of sets of data could be captured." (SAI42-36)* Students appreciated that Arduino devices *"were suitable for capturing* *data of transient events" (SAI43-56)*, *"collecting a large volume of data, or taking data over a long period of time." (SAI44-41)*

6.1.3 Arduino Technology

Under the "Arduino Technology" category, a high proportion (80.6%) of the views were positively coded, indicating that the intervention group favored this new technology. Among the views coded, 71.3% was in "AW", 16.7% in "AA" and 10.2% in "AV" respectively.

A-	11	10.2%
A+	87	80.6%
A=	10	9.3%
Atotal	108	100.0%

AA	18	16.7%
AW	77	71.3%
AV	11	10.2%
AO	2	1.9%
A	**108**	**100.0%**

AA-	0	0.0%
AA+	18	16.7%
AA=	0	0.0%
AW-	8	7.4%
AW+	61	56.5%
AW=	8	7.4%
AV-	3	2.8%
AV+	8	7.4%
AV=	0	0.0%
AO-	0	0.0%
AO+	0	0.0%
AO=	2	1.9%

Table 6.4: "Arduino Technology" sub-category for the Intervention Group

"Hardware and Software" (as denoted by "AW") were most commented on and views were largely positive. Students noticed that *"Arduino-based experiments are especially suitable for mechanical experiments as the sensors are small." (SAI44-39) "Various sensors could be applied in doing physics experiments." (SAI41-7)* The Arduino devices were *"portable and could be wearable to perform experiment related to gravity, e.g. bungy jump, roller roaster…" (SAI43-24) "Data captured could be displayed on an LCD screen" (SAI41-15)* or saved in SD card and then transferred to computer for further manipulation. Some students reflected that *"professional equipment was complicated to operate as there were many controls on the equipment but the Arduino device used in the experiments was relatively simple." (SAI43-23)* Some students when first came into contact with the Arduino-based experiments, said *"it was a bit difficult in adapting to the new technology but I could well adapt to it." (SAI43-74)*

"Affordability and Availability" as denoted by "AA" of the Arduino devices perceived by students (not actual experience) were the second most mentioned and the views were all positive. Students appreciated this *"inexpensive technology" (SAI41-43)* which favored the promotion of the use of the technology and students considered that *"it was very meaningful to promote Arduino technology to the students in rural areas as they could enjoy learning science with inexpensive technology." (SAI41-42)*

Although "Versatility and Flexibility" (as denoted by "AV") of the Arduino devices was relatively less mentioned, most students who responded appreciated the potential of Arduino. Students thought that Arduino *"could be used with infinite possibilities" (SAI43-7)* as *"many sensors could be connected to a single mother board" (SAI43-57)* and *"the same Arduino mother board could be used to perform many other experiments only by changing the sensors." (SAI46-69) "The program in Arduino device can be modified to meet personal needs." (SAI43-17)*

6.1.4 Comparison with Traditional Experiments

X-	3	13.0%
X+	18	78.3%
X=	2	8.7%
Xtotal	23	100.0%

XT	23	92.0%
XC	2	8.0%
X	**25**	**100.0%**

XT-	3	13.0%
XT+	18	78.3%
XT=	2	8.7%
XC-	0	0.0%
XC+	0	0.0%
XC=	0	0.0%

Table 6.5: "Comparison with Traditional Experiments" sub-category for the Intervention Group

In the category concerning "Comparison with Traditional Experiments (X)", 78.3% of the feedbacks were positive, indicating that Arduino had greater advantages over "Traditional experiments" as denoted by "XT". Students of the intervention group in fact had not carried out experiments in "mechanics" using traditional methods except one repeater. Their experience with the traditional experiments mainly came from other Non-Arduino experiments that they had performed before, such as that in thermal physics and optics. In comparing the Arduino-based experiments with the experiments using data logging system, which was commonly deployed in traditional physics experiments today, a student (a repeater) said, *"dataloggers are very expensive and complicated to use, but Arduino device is simple." (SAI43-14)* In the traditional experiment of circular motion, *"three students had to work together to take data" (SAI42-85)* and *"only 3 sets of data could be obtained in a lesson." (SAI42-35) "Non-Arduino-based experiments very often involve complicated data treatment procedures, so that students would lose interests in doing the experiments." (SAI46-43)* On the other hand, *"Arduino-based experiments could catch up with the trend of modern technology." (SAI42-39)* In the traditional "apparent weight experiment" inside a lift, where the gain or loss in weight was monitored, students found that *"the effect was not that obvious" (SAI43-70)* using traditional "spring balance". This was, however, very obvious when repeated with an Arduino device.

Notwithstanding the less favorable comments about the non-Arduino, traditional experiments, a small percentage of the students still felt more comfortable to use non-Arduino apparatus in certain experiments, for example "*a conventional thermometer was good enough to take data." (SAI43-54)* Some students *"preferred using free hand to plot graph as it would be more realistic." (SAI42-13)* Some students pointed out that *"for some experiments, like some thermal experiments, using Arduino technology would not have much advantage over conventional method. It would still be necessary for students to acquire basic skills to operate some simple equipment such as thermometer and Bunsen burner." (SAI44-38)*

Overall, students of the intervention group were largely in favor of the Arduino experiments though the technology might not be the fittest in all circumstances.

6.1.5 Challenges

C-	13	38.2%
C+	16	47.1%
C=	5	14.7%
Ctotal	34	100.0%

CC	1	2.9%
CE	0	0.0%
CI	18	52.9%
CL	8	23.5%
CM	0	0.0%
CT	7	20.6%
CS	0	0.0%
CO	0	0.0%
C	**34**	**100.0%**

CC-	0	0.0%
CC+	1	2.9%
CC=	0	0.0%
CE-	0	0.0%
CE+	0	0.0%
CE=	0	0.0%
CI-	7	20.6%
CI+	7	20.6%
CI=	4	11.8%
CL-	6	17.6%
CL+	1	2.9%
CL=	1	2.9%
CM-	0	0.0%
CM+	0	0.0%
CM=	0	0.0%
CT-	0	0.0%
CT+	7	20.6%
CT=	0	0.0%
CS-	0	0.0%
CS+	0	0.0%
CS=	0	0.0%
CO-	0	0.0%
CO+	0	0.0%
CO=	0	0.0%

Table 6.6: “Challenges” sub-category for the Intervention group

Under the “Challenge” category, views were more divided with 47.1% of the coded views on the positive side and 38.2% on the negative side. Most students (52.9%) showed concerns on the IT skills (CI) required for performing the Arduino-based experiments with positive “CI+” and negative “CI-” views carrying equal share. On the positive side, students said that they *“had come across with the use of Excel and knew some basic skills of it.” (SAI44-1)* Some students had not learned Excel before but *“the difficulty was soon overcome.” (SAI43-78)* They were well adapted to using Excel for data manipulation after the first two experiments. On the negative side, some students thought that “*Excel was a bit difficult.”(SAI41-91)* Students had some reservation in doing scientific investigation with Arduino as they misunderstood that *“they may need to know the programming.” (SAI46 -75)*

Some students commented on the difficulties in mastering the programming techniques, though this was in fact an impression more than the actual situation. Students were not expected to have knowledge in programming so as to perform the experiments. Introduction of the Arduino-based experiments to students did, nevertheless, inspire some students to learn more on programming. Some students said *"he would like to learn more about Arduino, now and in the future." (SAI42-90)* This was an unintended positive stimulus as learning programming would be useful if students wanted to further develop their scientific investigation skills in carrying out project or entering a science contest in the future.

The second most mentioned sub-category was on "Student's readiness and Attitude in Learning" ("CL"). Of relevance was that students of the intervention group were not high achievers, and hence their self-confidence level was relatively low. Students named a number of challenges they had come across in carrying out the Arduino-based experiments. For example, in the Newton's 2nd Law experiment, a student said, *"if the spring was pulled too hard, the wooden block might hit on to the wall and caused damage." (SAI41-73)* Student F4S3 thought that the circular motion experiment was the most challenging one as *"it was difficult to keep the ruler rotating smoothly in a horizontal circle. Appropriate force had to be applied on the apparatus in order to speed up and slow it down gradually." (SAI41-75)* F4S1 came across difficulty in the "collision experiment" that *"the trolley might not run in a straight line as expected and it might not hit head on with the stationary trolley so that the two trolleys could stick and keep moving together." (SAI41-76)* While citing the challenges, the students managed to figure out the exact problems they encountered, indicating that they could master the techniques and had actively participated in the experiments as well as solving the problems.

The third sub-category of "Challenges" was "Teacher efficacy". All respondents of the intervention group showed very positive comments in this sub-category. They had strong confidence in the teachers of the author's school and trusted that teachers would guide them properly through the experiments. This could be understood against the background that teachers in the author's school had received intensive training in carrying out the laboratory lessons with Arduino beforehand and some had even participated in the development and evaluation of the Arduino experiments. Teachers were highly appraised by the students. A student remarked that *"teachers' guidance helped us a lot in understanding and doing the experiments" (SAI42-58)* and *"(using Excel) was no longer a problem." (SAI43-81)* Students particularly expressed their appreciation to teachers for giving them briefing sessions before going into the laboratory. Such briefings proved to be most useful in explaining the procedures and difficulties they might encounter and *"it gave them a clearer understanding." (SAI41-24)* Teachers also helped them *"finish (report writing) in time." (SAI44-44)*

No student mentioned about the need for any "Technical Support" ("CS") since the seven Arduino-based experiments were smoothly carried out. Failure in Arduino device seldom occurred and the need for technical support was rare.

6.1.6 Concluding remarks

In brief, the intervention group was highly positive in their learning of physics with the Arduino technology. They enjoyed the process in the conduction of the experiments with few encountering difficulties. They appreciated the merits of the Arduino technology and a vast majority of them were in favor of Arduino over the traditional experiments. The only category with more divided views was on the "Challenges", with 47.1% on the positive side and 38.2% on the negative side. This category was only mentioned by a small percentage of students constituting only 3.9% of the threads collected from these students, implying that this should not be a cause of major concern.

6.2 F.6 students of the 2015/16 cohort

Total					
191					
100.0%					
A	8	4.2%	A-	0	0.0%
			A+	8	100.0%
			A=	0	0.0%
			Atotal	8	100.0%
E	27	14.1%	E-	4	14.8%
			E+	18	66.7%
			E=	5	18.5%
			Etotal	27	100.0%
T	38	19.9%	T-	1	2.6%
			T+	29	76.3%
			T=	8	21.1%
			Ttotal	38	100.0%
C	6	3.1%	C-	4	66.7%
			C+	0	0.0%
			C=	2	33.3%
			Ctotal	6	100.0%
X	104	54.5%	X-	8	7.7%
			X+	91	87.5%
			X=	5	4.8%
			Xtotal	104	100.0%
NA	8	4.2%			

Table 6.7: Coded CATEX views of F.6 students in the author's school

At the time of interview, six F.6 students of the 2015/16 cohort had already completed the whole physics syllabus and they were the only group of students who had performed the "mechanics" experiments with the Arduino technology and the traditional method. Before the interview, they were given some hands-on experience in conducting two Arduino-based experiments (circular motion and Newton's 2nd Law). Their memories on the procedures and the related concepts were recalled to ensure that they had a clear understanding of the experiments. The so-called "traditional" method did not imply it was an outdated technology as modern technology such as data logging systems were used. However, the way that the experiment was conducted was rather conventional. The views of this group of F.6 students contributed 191 threads (i.e. 12.3% of the coded threads) which carried weight. Of the 191 threads, 76.4% was on the positive side, 14.6% neutral or not applicable and only 9% on the negative side. The mind map of the F.6 group was at Appendix L2.

6.2.1 Comparison of the Arduino Technology with the Traditional Experiment

The views of the F.6 students were more focused on the "Comparison (of the Arduino Technology) with the Traditional Experiment" ("X") with 25.3% and 74.7% falling into the sub-categories of "Comments on the Traditional Experiments" ("XT") and "Concepts on the Traditional Experiments" ("XC") respectively. The distribution of the views of the F.6 students in these two sub-categories was set out in Table 6.8 below.

X-	8	7.7%
X+	91	87.5%
X=	5	4.8%
Xtotal	104	100.0%

XT	25	25.3%
XC	74	74.7%
X	**99**	**100.0%**

XT-	1	4.0%
XT+	24	96.0%
XT=	0	0.0%
XC-	7	9.5%
XC+	67	90.5%
XC=	5	6.8%

Table 6.8 Views of F.6 group on "Comparison with Traditional Experiment"

This group of students could fully recall the procedures in doing the two traditional experiments, and vast majority of them had clear concepts on the topic of "mechanics" as indicated by 90.5% of them having positive score in "XC". Below were some examples of their response:

"Author: If 'F' stands for Force, then what does 'a' stand for? …F6S2: Acceleration." (SAI6-4)

"Author: In order to keep the length (of rubber band) constant, how should the force be applied? …F6S2 ∶ constant (force)" (SAI6-13)

"Author: When doing this experiment (Newton's 2nd Law) what should we pay attention to? (Hint) Something that exists between the track and the cart… All: There will be friction." (SAI6-32)

Attributed to their solid grasp of concepts on the two experiments, their comparison of the Arduino-based experiments with that performed with the traditional method was made convincing. 96% of their views were in favor of the Arduino method, that they thought Arduino had more advantages. Some comments from the students helped illustrate how frustrated they were with the traditional experiments -

"It is very difficult to keep the length of the rubber band constant." (SAI6-43)

"It is very difficult to keep the bob rotating in a horizontal plane." (SAI6-89)

"Author: How long have you spent in collecting data in the (Newton's 2nd Law traditional) experiments? …F6S5: 30 to 40 minutes (out of 55minutes lesson time)." (SAI6-53)

"Author: Which one (of the traditional experiments) is more difficult, this one (circular motion experiment) or the Newton 2nd Law? All: This one." (SAI6-88)

6.2.2 Teaching and Learning of Physics

The group of F.6 students was also concerned about the "Teaching and Learning of Physics" with 52.6% of the views on the sub-category "Understanding of Physics" ("TP"), followed by 28.9% of views on "Scientific investigation" ("TI"), when applying Arduino in learning. Table

6.9 is an extract of the results the “TI” and “TP” categories. Views on “IT were all positive and majority of the views on “TP” were positive.

T-	1	2.6%
T+	29	76.3%
T=	8	21.1%
Ttotal	38	100.0%

TI	11	28.9%

TI-	0	0.0%
TI+	11	28.9%
TI=	0	0.0%

TP	20	52.6%

TP-	1	2.6%
TP+	11	28.9%
TP=	8	21.1%

Table 6.9: “Teaching and Learning” sub-category for the F.6 students

Some representative positive comments of “TP” included –

“Author: On the acceleration-time graph, the force is maximum at the beginning, and therefore the acceleration is greatest? Right?” … Student: Yes.” (SAI6-109)

“Author: Still remember the meaning of the slope? … Students: The mass (of the cart).” (SAI6-113)

Some representative positive comments of “TI” included -

“Author: When the experiment can be finished early, what could be done for the rest of the time? What do we expect students to do？ … F6S5: The experiment can be repeated with different setups.” (SAI6-140)

“Author: If time allowed, what would you further investigate by varying some parameters? What would you vary? …F6S4：change the weight on the cart.” (SAI6-57)

6.2.3 Conduction of the Experiments

Students of this group also commented about the “Conduction of the Experiments” regarding the Arduino experiments with 51.9% of the views on the sub-category of “Procedure” (“EP”) and 33.3% "Manipulation of Data" ("EM"). Positive views constituted the majority (66.7% of all the views under this category)

E-	4	14.8%
E+	18	66.7%
E=	5	18.5%
Etotal	27	100.0%

EC	4	14.8%
EM	9	33.3%
EP	14	51.9%
ES	0	0.0%
EO	0	0.0%
E	**27**	**100.0%**

EC-	0	0.0%
EC+	4	14.8%
EC=	0	0.0%
EM-	1	3.7%
EM+	6	22.2%
EM=	2	7.4%
EP-	3	11.1%
EP+	8	29.6%
EP=	3	11.1%
ES-	0	0.0%
ES+	0	0.0%
ES=	0	0.0%
EO-	0	0.0%
EO+	0	0.0%
EO=	0	0.0%

Table 6.10: "Conduction of the Experiments" sub-category for the F.6 students

The following were some supportive comments from the students on "EP" -

"F6S2: With the help of (Excel), we could finish the experiment in a short time." (SAI6-127)

"Author: If you follow what the teachers do, would it be difficult? … Students: Not difficult." (SAI6-160)

The following were some comments in favor of the Arduino experiments in the aspect of "EM"-

"Author: What happened if we could take the average value from a large number of data? A student: will be more accurate." (SAI6-156)

"Author: How many of you think that it (Arduino) is difficult or easy to use? All students except student F6S4: very easy to use." (SAI6-157)

6.2.4 Concluding remarks

For the F.6 student group, as compared to the traditional experiments, they found the Arduino technology outstood the traditional method and could, to a great extent, support students more in the learning of physics. Arduino-based experiments helped to achieve fast data collection and accurate data manipulation. The time saved in the experimental procedures allowed students more time for Scientific investigation and higher-order thinking. Their views on other categories also echoed with those of the F.4 intervention group.

6.3 Teachers / Laboratory Technicians / Technical Assistant in the author's School

Total	389	100.0%					
			A	64	16.5%		
					A-	8	12.5%
					A+	56	87.5%
					A=	0	0.0%
					Atotal	64	100.0%
			E	91	23.4%		
					E-	8	8.8%
					E+	75	82.4%
					E=	8	8.8%
					Etotal	91	100.0%
			T	145	37.3%		
					T-	5	3.4%
					T+	130	89.7%
					T=	10	6.9%
					Ttotal	145	100.0%
			C	62	15.9%		
					C-	39	62.9%
					C+	14	22.6%
					C=	9	14.5%
					Ctotal	62	100.0%
			X	27	6.9%		
					X-	2	7.4%
					X+	23	85.2%
					X=	2	7.4%
					Xtotal	27	100.0%
			NA	0	0.0%		

Table 6.11: Coded CATEX views of teachers, laboratory technicians and technical assistant in the author's school

The sources of data in this section were the interview records and written comments in the survey forms of teachers, laboratory technicians and technical assistant in the author's school. A total of 389 threads of views and comments were collected from this group who went through the seven Arduino experiments. Their comments were mostly in the aspect of "Teaching and learning of Physics (T)" (37.3%), "Conduction of the Experiments (E)" (23.4%) and "Arduino Technology (A)" (16.5%), in descending order. 76.6% of the threads was on the positive side, 7.5% was neutral and 15.9% was on the negative side.

6.3.1 Teaching and Learning of Physics

Under the this category, 89.7% of the views were positive about the Arduino experiment with the sub-categories on "Investigation" ("TI"), "Affective" ("TA"), and "Understanding of Physics" ("TP") and "Knowledge transfer" ("TK") well covered.

T-	5	3.4%
T+	130	89.7%
T=	10	6.9%
Ttotal	145	100.0%

TA	29	20.0%
TC	14	9.7%
TH	17	11.7%
TI	31	21.4%
TK	20	13.8%
TP	33	22.8%
TO	1	0.7%
T	**145**	**100.0%**

TA-	1	0.7%
TA+	27	18.6%
TA=	1	0.7%
TC-	0	0.0%
TC+	14	9.7%
TC=	0	0.0%
TH-	0	0.0%
TH+	14	9.7%
TH=	3	2.1%
TI-	0	0.0%
TI+	30	20.7%
TI=	1	0.7%
TK-	1	0.7%
TK+	18	12.4%
TK=	1	0.7%
TP-	3	2.1%
TP+	26	17.9%
TP=	4	2.8%
TO-	0	0.0%
TO+	1	0.7%
TO=	0	0.0%

Table 6.12: "Teaching and Learning of Physics" in the teacher group of the author's school

Teachers highly appreciated that the Arduino devices were very useful in performing Scientific investigation. They well understood the importance of Scientific investigation in the learning of science. A teacher described, *"Investigative study is a very essential part of science education. (TAID-16)* This view echoed the view that *"Scientific investigation is very important in learning science and it is the drive for learning science." (TAIE-17)* There was also remark that *"Even in public examinations nowadays, many questions were set on Scientific investigation." (TAIB-35)* Teachers agreed that Scientific investigation worked effectively on students with diversified capabilities. *"Different students might have different needs." (TAID-16) "Some high achievers might be able to modify the program to perform their own investigation" (TAIB-89)* and they *"had a better foundation to do more investigations and these experiments could inspire them more." (TAID-16)* Even for the low achievers, Teacher F thought that *"it was worth to try out Scientific investigation among them." (TAIF-29)* Teachers also revealed that *"students were very eager to try out the experiments under different circumstances."(TAIB-30) "When they (students) were familiar with the use of Excel, they could test out different possibilities on their own."(TAIB-78) "To some extent, students had developed more interest in adopting investigative approach in learning science." (TAIE-58)* The technical assistant who assisted in the development of the experiments found some students keen on asking *"whether the experiment would end up with different results and theory, if the setups of the experiments were altered." (TAIT-81)*

"Affective" was the second most mentioned sub-category and almost all the feedbacks were positive. *"Students were in general very enthusiastic."(TAID-43) "The experiments were very fresh to students and they found them very challenging." (TAIE-57) "Students had high expectation when going to the laboratory."(TAIE-41) "Students would have a very strong sense of achievement and found it very rewarding when they successfully used the Arduino apparatus to capture data." (TAIF-43)* Even some "Students with special education needs (SEN)" showed their concentration in doing the Arduino-based experiments. *"One of the SEN students suffering from Autism refused to work with others in group. However, he was one of the best performed students in the class and he was very active in learning and retrying the experiments many times in order to obtain better results." (TAIE-62) "Both low achievers and SEN students showed their interest in doing the experiments." (TAID-53)*

Whether Arduino could equip students to do better in "Learning Physics" was a core concern in this study. Vast majority of the views on "Understanding Physics" were certain, implying that the Arduino-based experiments successfully help students in learning of Physics. Teachers considered that after the intervention, the *"students could have more insight in learning physics." (TAIB-3) "The experiments somehow filled the gaps that might be difficult to explain in class."(TAID-11) "If experiments were carried out after the concept was taught, these would help students to consolidate what they had learned in lesson." (TAIF-24)* The technical assistant thought that *"students needed not spend all their time in solving the technical problems of the experiment, and more time could be spent on understanding the theory behind." (TAIT-30)* In fact, *"the marks that the students scored (in the seven Arduino-based experiments) were quite high when compared with other physics assignments." (TAIE-44)*

A few negative comments were noticed under the "Understanding of Physics" sub-category. There was remark that *"it was quite difficult to understand that friction and mass of the trolley could be retrieved from the slope and the y-intercept respectively (in the Newton's 2nd Law experiment). (TAID-51)* However, this problem was not particularly related to the Arduino technology. Instead, if it was a common weakness among students to understand this concept which was related to their ability in interpreting the slope and y-intercept of the graph.

Many teachers believed that the knowledge and techniques of the Arduino technology could be transferrable to learning in other science subjects or areas. They held the view that *"same Arduino technology could be applied in doing other physics experiments or in other science subjects" (TAID-19)* and the elements embedded in *"the experiments well echoed with the ideas in STEM education. In producing the Arduino-based device, mathematics, electronics, coding and even laser-cutting technology were involved." (TAIF-32) "Out of the seven* *experiments, most of them were integrated with STEM elements. Physics itself is a branch of science in which high-level Mathematics was involved. e.g. curve plotting, and fitting." (TAIB-47)* Teachers were positive about the potential of Arduino for development in STEM education.

6.3.2 Conduction of the Experiments

Under the "Conduction of the Experiments" category, 82.4% of the views were positive which mainly fell into the sub-categories of "Procedures" ("EP"), "Data Manipulation" ("EM") and "Data Collection" ("EC").

E-	8	8.8%
E+	75	82.4%
E=	8	8.8%
Etotal	91	100.0%

EC	14	15.4%
EM	21	23.1%
EP	47	51.6%
ES	0	0.0%
EO	9	9.9%
E	**91**	**100.0%**

EC-	1	1.1%
EC+	13	14.3%
EC=	0	0.0%
EM-	0	0.0%
EM+	21	23.1%
EM=	0	0.0%
EP-	5	5.5%
EP+	40	44.0%
EP=	2	2.2%
ES-	0	0.0%
ES+	0	0.0%
ES=	0	0.0%
EO-	2	2.2%
EO+	1	1.1%
EO=	6	6.6%

Table 6.13: "Conduction of the Experiments" in the teacher group of the author's school

"Procedures" ("EP") was the most mentioned sub-category (51.6%) with majority of the views being positive. Teachers in general considered that *"the experiments were thoughtfully planned and designed" (TA1F-17)* and they were "*overall satisfied with the design of the seven Arduino-based experiments." (TAIE-30)* Teachers agreed that "*the level of difficulty of the seven Arduino-based experiments matched with the syllabus requirement" (TALE-31)* and *"it was not difficult for students to follow the instruction in the manual." (TAIF-10)* Teachers remarked that "*as the experiments could be finished in a very short time, students could try out many sets of data." (TAIB-31) "Even some SEN students were eager to repeat the experiment many times in order to obtain better results" (TAM-30)* and "*for some* *weak students, they could still finish the Scientific investigation experiments as we had provided them with scaffolding to a certain extent at different stages." (TATE-19)* In fact, the teachers had taken some measures to ensure smooth progress of the experiments, for example, *"to group students with diversified abilities in a group so that higher achievers could help weaker students." (TAIE-43)* The technical assistant, when reviewing the development of the seven Arduino-based experiments which had undergone many iterations, was amazed that the *"experiments could be so simple" (TAIT-27)* to execute. The simple procedures made the experiments manageable and boost the confidence of the teachers in trying them out with the students.

"Data Manipulation" ("EM") was the second most mentioned sub-category (23.1%) and all the views were also positive. In designing the experiments, the technical assistant "*had created all the necessary templates. Students only had to paste the raw data onto the table, the Excel template could generate the graphs and students could easily visualize the relationship between the data." (TAIT-68)* This gave reinforcement to students in the process of learning of physics. Teachers agreed that *"data manipulation is essential in Scientific investigation." (TAIE-1) "With the aid of Excel, saved much time in plotting the graph automatically to prove the linear relationship and consolidate what they have learned in class." (TAIB-57)* Teacher B appreciated that *"the Excel template files were great help to students to reduce their workload and build up their confidence in manipulating data." (TAIB-75) "Students could easily check the answers using Excel so that they could be more confident in doing the experiments rightly." (TAID-47) "As students went through more experiments, they became more familiar with the use of Excel." (TAIE-50)* With students more acquainted with the data manipulation, it became easier to create an enabling environment for students to explore more with the technology and think further, thereby enhancing their learning.

“Data Collection” (“EC”) was the third most mentioned sub-category (15.4%) with almost all views positive. A teacher expressed that “*accurate sensors together with the microprocessor enabled accurate data capture easily” (TAIE-23)* and *“data collected were very accurate and promising.” (TA1B-54)* Students could focus more on learning the concepts rather than the data collection techniques. Teachers realized that *“the Arduino-based apparatus were also very useful in capturing some transient phenomena, which human eyes were not fast enough to detect.” (T4IE-24) “The Arduino apparatus could also be made to run on its own, without connecting to a computer.” (TAIF-47)* The technical assistant further pointed out that *“data could be uploaded to the Internet by wireless modules and there was no need to monitor the device once setup.” (TAIT-34)* The data collection process was made easy and interesting.

6.3.3 Arduino Technology

Under the “Arduino Technology” category, 87.5% of the views were positive which mainly fell onto the sub-categories of “Hardware and software” (“AW”), “Versatility and flexibility” (“AV”) and “Affordability and Availability” (“AA”).

A-	8	12.5%
A+	56	87.5%
A=	0	0.0%
Atotal	64	100.0%

AA	9	14.1%
AW	40	62.5%
AV	14	21.9%
AO	1	1.6%
A	**64**	**100.0%**

AA-	0	0.0%
AA+	9	14.1%
AA=	0	0.0%
AW-	7	10.9%
AW+	33	51.6%
AW=	0	0.0%
AV-	0	0.0%
AV+	14	21.9%
AV=	0	0.0%
AO-	1	1.6%
AO+	0	0.0%
AO=	0	0.0%

Table 6.14: “Arduino Technology” in the teacher group of the author’s school

“Hardware and software” (“AW”) was the most mentioned sub-category (62.5%) with majority of the views being positive. All teachers agreed that “*the Arduino apparatus was a very fast and powerful tool in data collection” (TAIF-46)* and some highlighted that its portability made it *"very suitable for outdoor application." (TAIB-79) "The bare sensors that the students came across enabled the students to understand the real engineering behind" (TAIB-48)* so that *"students could visualize most of the components parts of the whole system, and that widened students' horizons." (TAIB-2)* The technical assistant pointed out that *"with the use of appropriate sensor, Arduino could directly measure the acceleration and the centripetal force. Data measurements could be more visualized." (TAIT-3)* Many teachers appreciated that *"Arduino could be connected to numerous sensors to detect changes in the real world" (TAIB-92)* and it could even *"be connected to many output devices and control the flow of the experiments."* *(TAIB-94)* For example, motors mounted on an Arduino-driven robot could move the robot from place to place to collect data; the growth of plants could be monitored with the aid of an auto-irrigation system operated in an Arduino setting. As *"the source codes of the Arduino-based experiments were open and could be shared on the web" (TAID-58),* that facilitated the promotion of Arduino technology to other schools.

"Versatility and flexibility" ("AV") was the second most mentioned sub-category (21.9%) with all views being positive. *"The teachers could develop tailor-made program to fit the need of a specific experiment." (TAIE-36)* Many teachers commented that *"Arduino would be very flexible in the data collection, and was particularly useful in projects in science competitions and invention." (TAIB-95)* For example, *"the Arduino-based device could obtain raw data in the format we wanted" (TAIE-37)* and *"data could be collected according to the rate of change of data" (TAIB-91).*

"Affordability and availability" ("AA") was the third most mentioned sub-category (14.1%) also with all views being positive. Teachers in general agreed that *"Arduino-based apparatus was very economical and affordable" (TAIE-34)* and the *"availability of sensors and Arduino* *equipment could increase the motivation of teachers in integrating Scientific investigation into the syllabus." (TAIB-41)* For example, *"in a roller coaster experiment, the school could afford each student a set of equipment on their own" (TAIB-83)* to collect data on acceleration. The technical assistant further pointed out that *"the Arduino platform could break the barrier between the rich and the poor (in carrying out Scientific investigation) as the cost of Arduino could be very low." (TAIT-103)*

6.3.4 Challenges

"Challenges (C)" was a category which was less mentioned by the teacher group (15.9%). The teachers' views on this category were more on the negative side (62.9%) but not one-sided. Negative views were mostly on the sub-categories "Students' readiness and attitude in Learning" ("CL"), "Technical support" ("CS") and "Time Management" ("CM").

C-	39	62.9%
C+	14	22.6%
C=	9	14.5%
Ctotal	62	100.0%

CC	5	8.1%
CE	1	1.6%
CI	8	12.9%
CL	13	21.0%
CM	6	9.7%
CT	5	8.1%
CS	12	19.4%
CO	12	19.4%
C	**62**	**100.0%**

CC-	1	1.6%
CC+	3	4.8%
CC=	1	1.6%
CE-	0	0.0%
CE+	1	1.6%
CE=	0	0.0%
CI-	5	8.1%
CI+	1	1.6%
CI=	2	3.2%
CL-	9	14.5%
CL+	2	3.2%
CL=	2	3.2%
CM-	6	9.7%
CM+	0	0.0%
CM=	0	0.0%
CT-	4	6.5%
CT+	1	1.6%
CT=	0	0.0%
CS-	11	17.7%
CS+	1	1.6%
CS=	0	0.0%
CO-	3	4.8%
CO+	5	8.1%
CO=	4	6.5%

Table 6.15: Sub-categories under "Challenges" in teacher group of the author's school

The most mentioned challenge was under the sub-category "Students' Readiness and Attitude in Learning" (21.0%). Teacher F showed his concern on *"whether students with lower ability* *were ready to adopt the new technology in doing the experiments which seemed to be a bit difficult for students in the (author's) School." (TAIF-15) "For some students who were weak in Mathematics, they had problems in linking up the concepts with the data as some physics concepts relied very much on mathematical computation." (TAIE-21)* Some teachers were still unsure of students' readiness to accept the new technology even after the seven experiments. A teacher pointed out that *"briefing sessions for students had to be done before going to the laboratory." (TAIB-51)* In effect, it was observed that teachers in the author's school had offered students best assistance possible which led to positive feedbacks from students of the intervention group on the Arduino experiments. This worry of the teachers should have been dispelled.

The second most mentioned challenge was about inadequate technical support (19.4%) even when a strong technical support team was there in the author's school. They noted that *"Arduino experiments were self-developed by a small team" (TAIB-70)* and *"experts were needed to develop the tailor-made Arduino apparatus." (TAID-37)* Teachers in general opined that *"technical support was the most important thing. If the technicians could not fix the software and hardware, it would be difficult to use Arduino long term." (TAC-9)* Teachers suggested giving them proper training and *"technicians needed to be trained in order to provide the needed technical support. In case the device broke down, teachers might not know how to fix it." (TAID-36)*

As the syllabus was very tight in the Hong Kong education system, "Time Management" was always a concern of most teachers (9.7%), though it did not feature as the most challenging item on the list. Teachers commented that *"in real life, many science teachers are very examination-oriented and tend to spend more time to prepare students to sit for the public* *examination." (TAIB-38) "Lots of time and resources should have been spent in developing the seven experiments" (TAIB-71)* and *"some more time is needed to allow time for the product to evolve." (TAIB-74)* The teacher group was not optimistic that science teachers of other schools would be ready to try the Arduino-based experiments because of the tight syllabus.

The results from the surveys and interviews indicated that the concern of the teachers of the author's school on the "Teacher efficacy" was relatively low (1.6%). They nevertheless stressed the prerequisite that *"certainly, training is a must for teachers…" (TAC-12)* In fact, teachers in the author's school were provided with a long period of training (more than seven hours across a period of time) on these experiments. After the first two sessions, it was observed that teachers could adapt entirely to the new technology and used it proficiently.

However, some teachers might misunderstand that *"teachers or the laboratory technicians needed to learn how to write or run the Arduino Technology." (TAC-7)* Therefore they made the comment that *"it was difficult for a physics teacher to learn Arduino programming languages." (TAC-15)* In fact, teachers were not expected to know about programming in performing the experiments. The devices should be used as simple tools, like voltmeters or ammeters in the laboratory. As such, this concern should not be an issue.

6.3.5 Comparison with Traditional Experiments

Most views on the "Comparison with Traditional E**x**periments (**X**)" category were that when comparing the traditional experiments with the Arduino-based experiments, the use of Arduino was far more favorable (85.2% in "XT+").

X-	2	7.4%
X+	23	85.2%
X=	2	7.4%
Xtotal	27	100.0%

XT	27	93.1%
XC	2	6.9%
X	**29**	**100.0%**

XT-	2	7.4%
XT+	23	85.2%
XT=	2	7.4%
XC-	0	0.0%
XC+	0	0.0%
XC=	0	0.0%

Table 6.16: Sub-categories under "Comparison with Traditional Experiments" in the teacher group

It was revealed that *"data collection was a very time-consuming procedure in traditional experiment settings." (TAID-4) "Students would be bored in doing experiments which involved very slow data collection processes. Students spent the whole lesson just collecting data and the lesson would end without learning something new." (TAIB-55)* Even in some traditional experiments where data logging system was used, teachers expressed that *"it was very difficult to obtain promising results even with the aid of data logger in the traditional experiment."(TAID-56)*

Some teachers specifically pointed out an advantage of Arduino over the traditional method, namely *"In the newly designed Newton's 2nd Law experiment, the settings and the procedures of the experiment were quite different from the traditional ones, which was performed on a friction compensated inclined plane." (TAIE-27)* The problem with error arising from friction in the traditional experiments was aptly addressed in the Arduino experiments.

6.3.6 Other findings

It was also noted that in the study, no thread matched with the sub-category "**E**xperimental **S**afety, (**ES**)", neither in the student group nor in the teacher group. This might be understood that teachers felt safe in operating the Arduino devices. In fact, Arduino devices were low-current devices powered by low-voltage direct current and would not generate safety problem to the experiments. The only experiment that teachers might have some concerns on laboratory safety might be the circular motion experiment in which the Arduino device had to be swung on a ruler over a student's head. Nevertheless, such concern did not feature in the interview or the written comments.

6.4 Triangulation of data from teacher group and student group of the author's school

Teachers: category	Teachers			Students			Students: category
Total 389 100.0%							Total 785 100.0%
A 64 16.5%	A-	8	12.5%	A-	11	9.5%	A 116 14.8%
	A+	56	87.5%	A+	95	81.9%	
	A=	0	0.0%	A=	10	8.6%	
	Atotal	64	100.0%	Atotal	116	100.0%	
E 91 23.4%	E-	8	8.8%	E-	21	10.5%	E 200 25.5%
	E+	75	82.4%	E+	166	83.0%	
	E=	8	8.8%	E=	13	6.5%	
	Etotal	91	100.0%	Etotal	200	100.0%	
T 145 37.3%	T-	5	3.4%	T-	5	1.7%	T 294 37.5%
	T+	130	89.7%	T+	276	93.9%	
	T=	10	6.9%	T=	13	4.4%	
	Ttotal	145	100.0%	Ttotal	294	100.0%	
C 62 15.9%	C-	39	62.9%	C-	17	42.5%	C 40 5.1%
	C+	14	22.6%	C+	16	40.0%	
	C=	9	14.5%	C=	7	17.5%	
	Ctotal	62	100.0%	Ctotal	40	100.0%	
X 27 6.9%	X-	2	7.4%	X-	11	8.7%	X 127 16.2%
	X+	23	85.2%	X+	109	85.8%	
	X=	2	7.4%	X=	7	5.5%	
	Xtotal	27	100.0%	Xtotal	127	100.0%	
NA 0 0.0%							NA 8 1.0%

Table 6.17: Teacher group versus student group in the author's school

To have an overall perspective of the impact of the series of Arduino-based experiments on the participants in the author's school, the views of the teacher group were compared with that of the student group item by item to find out their commonalities and differences and more importantly, to triangulate the results gathered comparison of their views are shown in Table 6.17 above. (Detailed comparison is at Appendix L5). The teacher group included teachers, laboratory technicians and the technical assistant in the author's school while the student group included the F.4 and F.6 students of the 2015/16 cohort in the author's school. The total number of threads coded in the teacher and student groups were 389 and 785 respectively.

It was revealed that the views of the two groups on the "Arduino Technology (A)" "Conduction of Experiments (E)" and "Teaching and Learning (T)" categories and the "Comparison with Traditional Method (X)", constituting 84.1% of the teachers' views and 94% of the students' views and, had very high resemblance while there were visible differences in the category of "Challenges (C)". The results were summarized in Table 6.18 below. This revealed that the triangulation confirmed the validity of data collected from the two groups.

Category	Categories with high resemblance				Category with some differences
	A	E	T	X	C
Teachers (T)	16.5%	23.4%	37.3%	6.9%	15.9%
Students (S)	14.8%	25.5%	37.5%	16.2%	5.1%

Table 6.18: Categories with commonalities or differences
in the teacher and student group of the author's school

When the sub-categories were further examined, it was found that the percentages in the "A", "E" and "T" categories between the two groups were mostly positive and the percentages of positive views were also very similar. However, in the "Challenges (C)" category, most views were negative but the extent differed (62.9% in the teacher group versus 45.2% in the student group in "C-"). Relatively higher percentage of positive views was noted among students (42.5% in "C+"). Some differences between the two groups were found in the "X" category. They were summarized in Table 6.19 below, and their commonalities and differences were discussed in the ensuing paragraphs.

	Sub-categories with high resemblance					Sub-category with great differences	
Category	A+	E+	T+	X+	X-	C+	C-
Teacher	87.5%	82.4%	89.7%	85.2%	7.4%	22.6%	62.9%
Student	81.9%	83.0%	93.9%	85.8%	8.7%	42.5%	42.5%

Table 6.19: Distribution of positive and negative views in the teacher group versus student group in the author's school

6.4.1 Teaching and Learning of Physics

Teachers			Students		
TA-	1	0.7%	0.0%	0	TA-
TA+	27	18.6%	24.8%	73	TA+
TA=	1	0.7%	0.0%	0	TA=
TC-	0	0.0%	0.0%	0	TC-
TC+	14	9.7%	11.6%	34	TC+
TC=	0	0.0%	0.0%	0	TC=
TH-	0	0.0%	0.0%	0	TH-
TH+	14	9.7%	8.5%	25	TH+
TH=	3	2.1%	0.0%	0	TH=
TI-	0	0.0%	0.0%	0	TI-
TI+	30	20.7%	14.6%	43	TI+
TI=	1	0.7%	0.3%	1	TI=
TK-	1	0.7%	0.0%	0	TK-
TK+	18	12.4%	6.1%	18	TK+
TK=	1	0.7%	0.0%	0	TK=
TP-	3	2.1%	1.4%	4	TP-
TP+	26	17.9%	27.9%	82	TP+
TP=	4	2.8%	4.1%	12	TP=
TO-	0	0.0%	0.3%	1	TO-
TO+	1	0.7%	0.3%	1	TO+
TO=	0	0.0%	0.0%	0	TO=

Table 6.20: Teacher group versus student group in the author's school in the "T" category

Under the "Teaching and Learning of Physics (T)" category, the sub-category that was most mentioned as well as the greatest difference was in the "Understanding of Physics" ("TP") sub-category. High percentage of positive views of students in the "TP" sub-category indicated that students were more certain on the effectiveness of Arduino in teaching and learning of physics than teachers. What the students gained from the experiments went beyond the expectation of the teachers.

The "Affective Domain" ("TA") was the second most mentioned sub-category. Students were very keen on participating in the laboratory sessions and craved for doing the Arduino-based experiments with better results. Teachers also found that students were highly motivated and the students could complete their worksheets within the lesson and score high marks. However, they did not perceive the affection among the students as much as students viewed it.

The "Scientific investigation" ("TI") was the third most mentioned sub-category (20.7% in teacher group versus 14.6% in student group in "TI+"). Both groups agreed that Arduino-based experiments could stimulate students' inquiry learning. Nevertheless, students were not as conscious as teachers in understanding this underlying motive.

6.4.2 Arduino Technology

Under the "Arduino Technology" category, it was revealed that views of the teacher group and student group in the "AA+" and "AW+" sub-categories resembled closely, while there was greater difference in the "AV+" sub-category.

Teachers			Students		
AA-	0	0.0%	0.0%	0	AA-
AA+	9	14.1%	19.0%	22	AA+
AA=	0	0.0%	0.0%	0	AA=
AW-	7	10.9%	6.9%	8	AW-
AW+	33	51.6%	54.3%	63	AW+
AW=	0	0.0%	6.9%	8	AW=
AV-	0	0.0%	2.6%	3	AV-
AV+	14	21.9%	8.6%	10	AV+
AV=	0	0.0%	0.0%	0	AV=
AO-	1	1.6%	0.0%	0	AO-
AO+	0	0.0%	0.0%	0	AO+
AO=	0	0.0%	1.7%	2	AO=

Table 6.21: Teachers versus Students in the author's school in the "A" category

Over half of the views in the "AW" sub-category (51.6% versus 54.3% in the teacher and student groups) were positive from both groups and the positive views mainly fell onto the "Arduino Hardware and software" ("AW") sub-category, indicating that both groups highly agreed that the open-source Arduino devices were very powerful, easy to be used in practical lessons of physics. These have been discussed in Sections 6.1.3 and 6.3.3. However, participants still raised some drawbacks about the Arduino devices (10.9% versus 6.9% in the teacher and student groups respectively in the "AW-" sub-category). Students' comments on the drawbacks were mostly minor problems related to the design of the Arduino hardware, such as *"the Arduino devices got no protection and were fragile and might easily be damaged." (SAI46-101)* The negative views of the teacher group stemmed from the technical problems that were encountered in the development of the Arduino devices, including *"poor quality of the cheap components and accessories purchased from the web" (TAIT-53)*, *"poor stability and reliability of the sensors and the blue tooth module"(TAIT-55 and TAIT-59)* and *"calibration problems of individual sensors".(TAIT-95)* All problems had been fixed before the implementation. As such, the problems technically did not exist in the Main Study.

"Affordability and Availability of the Hardware and Sensors" ("AA") was the second most mentioned sub-category (14.1% versus 19.0% in the teacher and student groups respectively in "AA+"). This favorable factor significantly reinforced the proposal to widen the use of the technology in small-group collaborative study, self-directed learning or further promotion of the technology to other schools especially those located in rural areas.

The greatest difference was observed in the "Versatility and Flexibility of Arduino" ("AV") sub-category (21.9% versus 8.6% in "AV+"). This made sense in that teachers had a broader view on the potential of Arduino than students, and they also had more ideas on how the Arduino technology could be applied in other science areas or scenarios.

6.4.3 Conduction of Experiments

Teachers			Students		
EC-	1	1.1%	0.0%	0	EC-
EC+	13	14.3%	23.0%	46	EC+
EC=	0	0.0%	0.0%	0	EC=
EM-	0	0.0%	1.5%	3	EM-
EM+	21	23.1%	27.0%	54	EM+
EM=	0	0.0%	1.0%	2	EM=
EP-	5	5.5%	8.5%	17	EP-
EP+	40	44.0%	32.0%	64	EP+
EP=	2	2.2%	2.5%	5	EP=
ES-	0	0.0%	0.0%	0	ES-
ES+	0	0.0%	0.0%	0	ES+
ES=	0	0.0%	0.0%	0	ES=
EO-	2	2.2%	0.5%	1	EO-
EO+	1	1.1%	1.0%	2	EO+
EO=	6	6.6%	3.0%	6	EO=

Table 6.22: Teacher group versus student group in the author's school in the "E" category

Under the "Conduction of Experiment" category, "Procedures" ("EP") was the most mentioned as well as the sub-category with the greatest difference between the two groups. The teacher and student groups strongly agreed that the procedures were streamlined and smooth. As teachers were highly involved in the evaluation of the procedure and the worksheets in the development stage, they understood more about what improvements had been made in streamlining the procedures. They were therefore more satisfied with the procedures of the Arduino experiments than the students.

Smooth, fast and accurate data manipulation and data collection were further reiterated in the second and third most mentioned sub-categories in "Data Manipulation" ("EM") (23.1% vs 27.0% in "EM+") and "Data Collection" ("EC") (14.3% vs 23.0% in "EC+"). These reaffirmed the major advantages of the Arduino experiments over the traditional experiments.

6.4.4 Challenges

Teachers			Students		
CC-	1	1.6%	0.0%	0	CC-
CC+	3	4.8%	2.5%	1	CC+
CC=	1	1.6%	0.0%	0	CC=
CE-	0	0.0%	0.0%	0	CE-
CE+	1	1.6%	0.0%	0	CE+
CE=	0	0.0%	0.0%	0	CE=
CI-	5	8.1%	17.5%	7	CI-
CI+	1	1.6%	17.5%	7	CI+
CI=	2	3.2%	10.0%	4	CI=
CL-	9	14.5%	22.5%	9	CL-
CL+	2	3.2%	2.5%	1	CL+
CL=	2	3.2%	2.5%	1	CL=
CM-	6	9.7%	0.0%	0	CM-
CM+	0	0.0%	0.0%	0	CM+
CM=	0	0.0%	0.0%	0	CM=
CT-	4	6.5%	0.0%	0	CT-
CT+	1	1.6%	17.5%	7	CT+
CT=	0	0.0%	0.0%	0	CT=
CS-	11	17.7%	2.5%	1	CS-
CS+	1	1.6%	0.0%	0	CS+
CS=	0	0.0%	5.0%	2	CS=
CO-	3	4.8%	0.0%	0	CO-
CO+	5	8.1%	0.0%	0	CO+
CO=	4	6.5%	0.0%	0	CO=

Table 6.23: Teacher group versus student group in the author's school in the "C" category

Under the "Challenges (C)" category, the students and teachers showed major differences in their views in a number of sub-categories indicating that their views were diversified or even polarized. Nevertheless, this only constituted 15.9% of the teachers views and 5.1% of the students' views. Examples of differences included 1.6% versus 17.5% in "CI+"; 8.1% versus 17.5% in "CI-"; 9.7% versus 0% in "CM-"; 1.6% versus 17.5% in "CT+" and 6.5% versus 0% in "CT-". The differences could be explained from the different roles and the background of the teachers and students.

Students showed more concern in the “IT skills” (“CI”) sub-category than teachers, no matter on the positive or negative sides (1.6% in the teacher group versus 17.5% in the student group in “CI+”; 8.1% in the teacher group versus 17.5% in the student group in “CI-”). The greater concern in the student group both arose mainly from the programming techniques of Arduino. Students who held positive views were interested in learning Arduino programming but those with negative views misunderstood that they had to learn Arduino programming in order to perform the experiments.

In the sub-category concerning “Technical Support” (“CS”), negative views from teachers and students were 17.7% versus 2.5%. As observed during the laboratory lessons, students in the intervention group could run their Arduino-based experiments very smoothly and did not come across much technical problem. However, the teachers, technicians and the technical assistant, especially those involved in the development of the experiments in the author’s school, had encountered a number of technical problems during the development stage so that they tended to be more concerned about technical problems even when all problems had been fixed before the implementation.

From the data in “Time Management” (“CM”) sub-category, it was revealed that teachers had more concerns than students (9.7% versus 0% in “CM-”). Teachers’ concerns arose from the tight syllabus they were facing and the preparatory work that might be involved. For students, they sufficient enough time to go through the experiments and therefore time management was not a concern.

The results in “Teacher efficacy” (“CT”) was interesting (1.6% in the teacher group versus 17.5% in the student group in “CT+”; 6.5% in the teacher group versus 0% in the student group in "CT-") Teachers were more concerned about their efficacy in conducting the Arduino-based experiments, while the students had great confidence in the teachers in the author's school in guiding them through the experiments. Teachers had higher expectation on the competency level and hence they were more worried about their own efficacy. On the other hand, students trusted that their teachers were knowledgeable and could offer assistance when needed.

The "Students' Readiness and Attitude in Learning" ("CL") was the sub-category that both groups held similar concerns, that students might not be ready for the new technology. To make up for this concern, teachers took extra time and held extra briefing sessions for the students before entering into the laboratory and students found the briefing sessions very useful. It turned out that students could score high marks in these experiments.

6.4.5 Comparison with Traditional Experiments

Under the "Comparison with Traditional Experiments (X)" category, both groups showed similarity in the "XT+" sub-category (85.2 versus 87.5% in the teacher and student groups respectively) indicating that the Arduino-based experiments were more advantageous than the traditional experiments. The positive views on the "XT" sub-category in the teacher and student groups had been discussed in Sections 6.1.4 and 6.3.5 respectively.

Teachers			Students		
XT-	2	7.4%	8.3%	4	XT-
XT+	23	85.2%	87.5%	42	XT+
XT=	2	7.4%	4.2%	2	XT=
XC-	0	0.0%	9.2%	7	XC-
XC+	0	0.0%	88.2%	67	XC+
XC=	0	0.0%	6.6%	5	XC=

Table 6.24: Teachers group versus students group in the author's school in the "X" category

To conclude, both the teacher and student groups were largely positive about the Arduino experiments, especially in the teaching and learning aspects. Both groups appreciated the merits of the Arduino device. Teachers were nevertheless more concerned about technical support and their efficacy.

6.5 Supplementary results from quantitative data

As mentioned before, the quantitative data collected from the pre-test and post-test and survey of students are too small in sample size for making reliable analysis. However, the findings may be used for triangulation with the aforementioned qualitative findings.

6.5.1 Pre-test and Post-test Results of the FCI and TIPS II between the Intervention Group and the Control Group

The scores (which were normalized to 100 as full mark) in the pre-test and post-test of FCI and TIPS II for the intervention group and control group were combined to form four sub-groups for comparisons. The scores of students in the pre-test and post-test were fitted into a paired t-test software to calculate their significance of difference. Detailed results were shown in Appendices Q. Table 6.25 below summarized the results of the t-tests.

Test	Group	Mean of Pre-test (SD)	Mean of Post-test (SD)	Sample size in pre-test / post-test	Two-tailed P value	Significance of difference
FCI	Control	42.2 (17.8)	45.8 (20.1)	15/14	0.515	insignificant difference
	Intervention	30.9 (19.9)	37.8 (20.8)	17/15	0.0169	significant difference
TIPS II	Control	67.9 (18.3)	65.2 (21.9)	16/15	0.481	insignificant difference
	Intervention	62.2 (21.5)	62.9 (20.2)	17/15	0.877	insignificant difference

Table 6.25 Summary of the results of the t-tests

Findings from the comparison were as follows –

(i) As mentioned in Section 5.1, at the time the research was conducted, due to a drastic drop in student population in the author's school, there were only 16 students in the intervention group and control group respectively. The quantitative results could not be very conclusive as the sample size was small. That notwithstanding, the pre-tests and post-tests still proceeded as scheduled as the results obtained might offer good basis for reference. The effectiveness in learning of physics could also be studied using data collected from the interviews and written comments of students and teachers who had participated in the intervention programme. Therefore, the quantitative results in this section only contribute a small portion in the whole study though its significance should not be neglected.

(ii) For the FCI Test, performance of the control group obviously outstood the intervention group in the pre-test. This might be due to the average ability of students in the control Arduino group being better than that of the students in the intervention group. After one year of study in physics, both the Non-Arduino group and the Arduino group showed improvement which was reflected in their increment in scores in the post-tests, by 8.5% and 22.3% respectively. The t-test illustrated that the improvement of the control group statistically showed no significant difference while the improvement of the intervention group was statistically significant. The qualitative analysis for the intervention group also showed a high percentage of positive views in students' learning of physics and grasp of physics concepts. It was reflected in Sections 6.1 and 6.1.1 that among the coded views of the intervention group, the most commented views (Table 6.1) were on the "Teaching and learning of Physics (T)" (43.1%) in which 96.5% (Table 6.2) of the threads were positive. This, to a certain extent, lent support to the argument that using Arduino technology has enhanced students' effectiveness in learning physics.

(iii) For the TIPS II Test, the average scores of the intervention group, no matter in the pre-tests or post-tests, were lower than that of the control group. The scores of the two groups in the pre-tests were similar and the control groups showed no advantage over the intervention group. On the whole, the scores on TIPS II were higher than that on FCI. After one year of study, the improvement was not obvious. The differences of the two groups in the TIPS II test were both statically insignificant. Of relevance was that the questions in the TIPS II test were not set on content knowledge in physics but rather on concept on the processing skills such as the relationship among dependent, independent and controlled variables. Knowledge on processing skills was taught in junior form science syllabus and the content knowledge should be much simpler than the concepts in "mechanics". The processing skills would not be explicitly taught in the NSS physics syllabus. That might be the major reason why after one year of study, the students' mastery of the processing skills showed insignificant change. Nevertheless, even students did not know much about the processing skills, it posed no difficulty in their carrying out the Arduino-based experiments or investigative study using the Arduino device. It was reflected in Section 6.1.2 under the "Conduction of the Experiments" category that a very high proportion (85.5%) of the views (Table 6.3) were positively coded indicating that students were very satisfied with the conduction of the experiments using the Arduino technology in the Intervention Programme. Students could conduct the experiments smoothly with high confidence and they were able to complete the worksheets for the experiments in time.

6.5.2 Quantitative Analysis of the Survey Results of the Intervention Group (F.4 students of the 2015/16 cohort)

Only 16 students were involved in the survey as explained in Section 6.5.1 The outcomes would be used as a supplement to support or explain the results in qualitative analysis. The full details of the survey results of the intervention group were found in Appendix K1.

Findings of the quantitative analysis were as follows –

(i) In part A of the survey form that was distributed to the students who participated in the Intervention Programme, additional questions were asked to understand the IT background of the students prior to the intervention as shown in Table 6.26. The average score of the students, on a five-point scale from "1" to "5", with the maximum score of "5", was "3" representing a state of "neither agree nor disagree". The statistical results in this part, before the intervention, showed that average rating for all items was 2.36 which was below "3" and on average only 14.4% of the students chose "agree" and "strongly agree" in the six questions. This purported that the average ICT skills prior to the intervention of the students were below standard. Although students in general agreed that they had used mobile device, tablet or PC to support their learning, their skills in using Excel for finding statistical results and graph plotting was weak and they were unfamiliar with open-source Arduino hardware and software in science learning. This was reflected in the very low ratings in their answers to questions A4, A5 and A6 (as shown in Table 6.26).

No.	Evaluation item	Percentage in "agree" + "strongly agree"	Average
A1	I use mobile device, tablet or PC to support my learning. e.g. web searching, reading, running educational Apps, simulation or virtual experiments, as a communication tools.	40.0%	2.93
A2	I use data loggers for capturing physical data in my science laboratory classes.	20.0%	2.67
A3	I conduct scientific investigations (or experiments) using sensors (e.g. light, motion, temperature, sound, acceleration…)	13.3%	2.47
A4	I use Excel for finding statistical results (calculating mean, maximum, minimum, number of counts…)	6.7%	2.00
A5	I use Excel for graph plotting, curve fitting.	6.7%	2.00
A6	I use open-source hardware and software in science learning.	0.0%	2.07

Table 6.26 Questions to understand IT background of the students in the Survey Form I

(ii) After the intervention, despite the student's weak background in ICT, the average ratings on the items in parts B and C which were focused on the learning effectiveness were relatively high. The statistical results showed that the average rating in all items (in part B and C) was 3.89 which was much higher than "3" and on average 73.3% of the students chose "agree" and "strongly agree" in the twelve questions in part B. The items which were highest rated was B2, B3, C8 and C12, as listed in Table 6.27 below, with more than 80% of the population choosing "agree" and "strongly agree" in the items and the average rating was above "4". The ratings of the four highly ranked items were set out in Table 6.27 below which included that Arduino was versatile and effective tool in scientific investigation and science learning (items B2, B3 and C12) and the conduction of the Arduino-based experiments was smooth (item C8). The results echoed with the findings in the qualitative analysis as shown in Section 6.1.3 and Table 6.4. Among the views on the "Arduino Technology", 80.6% of the views were positive, which supported the usefulness of the technology in scientific investigation. Section 6.1.2 and Table 6.3 under the "Conduction of Experiments" also revealed that students highly apprised (85.5% positive views) the smooth conduction of the experiments.

No.	Evaluation item	Percentage in "agree" + "strongly agree"	Average rating
B2	Arduino technology is useful in scientific investigation.	86.7%	4.33
B3	Arduino technology is useful for supporting science learning within the school.	80.0%	4.20
C8	I can carry out the Arduino-based activities as expected	86.7%	4.13
C12	The programmability of Arduino made it a versatile tool in scientific investigation.	80.0%	4.00

Table 6.27: Highly ranked items in the Survey Form I

The ratings in items B6, C9 and C11 as shown in Table 6.28 below were relatively lower but still two-third of the students agreed or strongly agreed with the items. As a matter of fact, the Arduino technology was not the only technology that was useful in science learning. In fact, some students still preferred the data logging systems which were widely used in the author's school. The traditional experiments had their merits although vast majority of the students opined that Arduino-based experiments outstood the traditional experiments, even with the use of data logging system. As stated in Section 6.1.4, a small percentage of the students still felt more comfortable to use non-Arduino apparatus in certain experiments. It was natural that no single system could fit all. That would depend on the circumstances and the purpose.

Table 6.2 in Section 6.1.1 showed that only a minute percentage (6.6%) of the intervention group students mentioned "Knowledge transfer to other learning area" in respect of Arduino technology in the qualitative analysis and it echoed with the low rating in item C11 (Table 6.28 below) of the quantitative survey as students seldom contemplated applying Arduino technology in learning other science subjects.

No.	Evaluation item	Percentage in "agree" + "strongly agree"	Average rating
B6	Every secondary school student should be able to apply Arduino technology for science learning.	66.7%	3.60
C9	The Arduino-based activities can enhance my learning of the course content as compared to the traditional one.	60.0%	3.60
C11	I can apply similar Arduino technology in learning other science subjects.	66.7%	3.53

Table 6.28: Low-ranked items in the Survey Form I

CHAPTER 7

FINDINGS AND DISCUSSION

Phase II of the Main Study (Extension Programme outside the author's school)

The findings in Phase II of the Main Study were from the data collected outside the author's school, mainly from the Singaporean teachers in the OEIR Programme 2016. As the number of Singaporean teachers involved in the study was considerable, the results as obtained from the qualitative as well as the quantitative analysis were sufficiently representative and significant. Similarly, qualitative analysis is carried out first in this chapter and the results are compared with those of the Hong Kong teachers. This is followed by analysis based on the quantitative data collected from the Singaporean teachers in the survey form. This is again compared with that of the Hong Kong teachers. Apart from the descriptive statistics, "t-test" for inferential statistics is carried out to compare the average ratings of the teachers in the two areas on the 13 questions in the survey to find out whether their views are aligned or diversified. At the end of this chapter, the limitations and specific strategies adopted to improve the validity of the data are discussed.

7.1 Qualitative Analysis of Data of the Singaporean Teachers in the OEIR Programme

The sources of data were the written comments in the survey form of the Singaporean teachers in the OEIR Programme 2016. A total of 346 threads of comments were collected. Positive views were observed mainly on the category of "Teaching and learning of Physics (T)" (28.9%) followed by the category of "Arduino Technology (A)" (10.4%) and "Conduction of the Experiments (E)" (7.5%). However, the most mentioned category was "Challenges (C)" (52.9%) and most of the views were negative. A summary of the categorization of the threads was at Table 7.1 below.

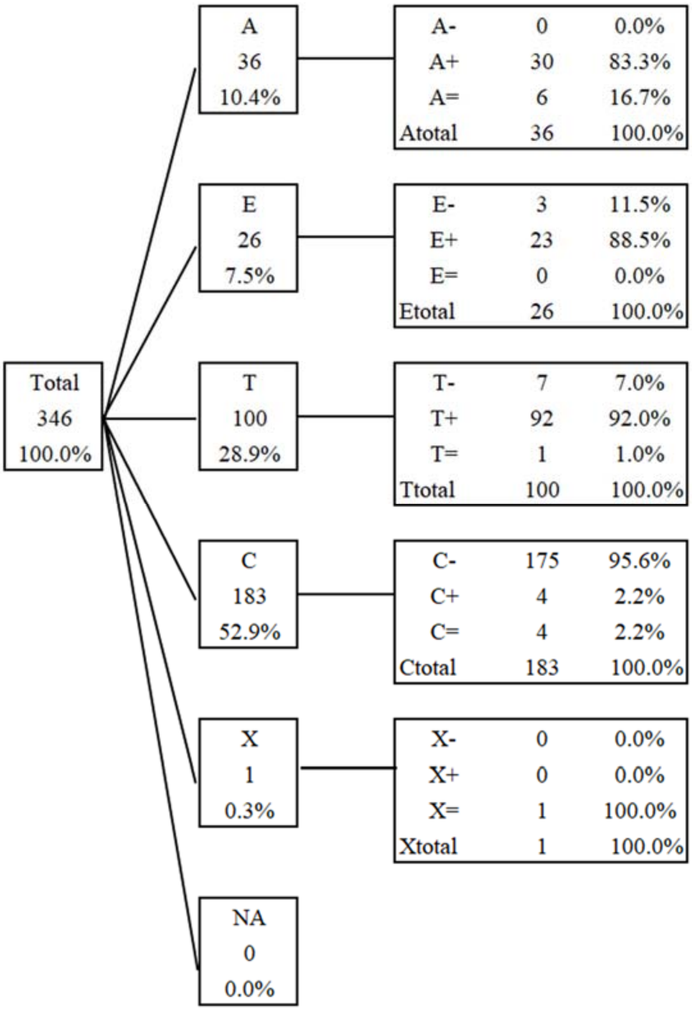


Table 7.1: Coded CATEX views of Singaporean teachers

7.1.1 Teaching and Learning of Physics

Under the "Teaching and Learning" category, 92% of the views were positive, which fell mainly onto the sub-categories of "Knowledge Transfer" ("TK"), "Affective Domain" ("TA"), "Higher-order Thinking" ("TH") and "Understanding of Physics" ("TP").

T-	7	7.0%
T+	92	92.0%
T=	1	1.0%
Ttotal	100	100.0%

TA	23	23.0%
TC	10	10.0%
TH	15	15.0%
TI	12	12.0%
TK	20	20.0%
TP	17	17.0%
TO	3	3.0%
T	**100**	**100.0%**

TA-	4	4.0%
TA+	19	19.0%
TA=	0	0.0%
TC-	0	0.0%
TC+	10	10.0%
TC=	0	0.0%
TH-	0	0.0%
TH+	15	15.0%
TH=	0	0.0%
TI-	0	0.0%
TI+	12	12.0%
TI=	0	0.0%
TK-	0	0.0%
TK+	20	20.0%
TK=	0	0.0%
TP-	2	2.0%
TP+	14	14.0%
TP=	1	1.0%
TO-	1	1.0%
TO+	2	2.0%
TO=	0	0.0%

Table 7.2: Views of Singaporean teachers on “Teaching and Learning of Physics”

On the “Affective Domain” (“TA”) which was the most mentioned sub-category, Singaporean teachers mostly agreed that the application of Arduino in science learning was *“very interesting and practical sharing on possibilities of Arduino in physics education.” (TOCO-328)* Arduino was seen as a technology that *“opened the mind of the students, of how technology and science was aligned” (TOCO-25)* and was *“able to stretch students' imagination to invent new things that were useful.” (TOCO-36)* Singaporean teachers even saw the merits of the Arduino-based experiments which could *“arouse interest in grooming budding scientists.” (TOCO-108)* There was also remark that *“The engagement (of students) might be higher, especially if out-of-school activities are done.” (TOCO-239)*

The results should be viewed against the background that Singapore had launched STEM education in their country since 2014. More teachers learned of the Arduino technology in the context of STEM education and were aware that Arduino was highly related to coding techniques. As such, under the “Knowledge Transfer” (“TK”) sub-category, majority of the feedbacks from the Singaporean teachers were related to coding, such as the Arduino technology could "*spark interest in programming and coding." (TOCO-43)* Teachers were aware that *"coding is very important! Students must learn this skill! Arduino makes it easier." (TOCO-87)* They suggested that *"students should be exposed to coding, as there are many industries that require students to the necessary skills." (TOCO-56)* Some teachers envisaged that Arduino technology was *"applicable to a very broad-based subjects not just for physics but other applied sciences e.g. life science, forensic science, design and technology reading measurement of a 3D figure" (TOCO-104).* Their comments on "Knowledge Transfer" were all positive.

Under the "Understanding of Physics" ("TP") sub-category, teachers' views were positive on the whole. The Arduino-based experiments were found *"very effective in helping student learning physics." (TOCO-335) "Sometimes, teacher may place emphasis teaching the topic rather than understanding concepts" (TOCO-133)* and teachers thought that *"the use of Arduino enhanced the latter." (TOCO-133)* The experiments *"helped students to understand applications of theory better." (TOCO-115) "It makes verification of physics Law in a simple way" (TOCO-128)* and *"can prove theories using practical". (TOCO-88)* The experiments *"enhanced visual learning, good for kinematic learners to extend understanding" (TOCO-55)* and *"allowed students to use technology to make their thinking more visible". (TOCO-97) "Data obtained from Arduino technology shows that formulae are true, and students can see it for themselves using the hands-on activity." (TOCO-123)* Positive views even extended to the point that *"students could go through scientific method and get to be young scientists." (TOCO-126)*

Under the "Higher-order Thinking" ("TH") sub-category, all the views were positive. Singaporean teachers unanimously agreed that Arduino could *"allow more thinking time"*

(TOCO-105) and *"allow students to get equipment to have their own self-exploratory experiments." (TOCO-77) "It sparks creativity and innovation" (TOCO-72)* among students. *"The technology can be used for the planning / design of experiment and thereafter carry out the experiment to see real data." (TOCO-63) "It can also serve as good tool for students to learn an abstract concept something for them to see" (TOCO-132)* and *"to promote self-directed learning in which students can create their own Arduino-based experiment." (TOCO-103)*

7.1.2 Arduino Technology

Under the category of "Arduino Technology" ("A"), 83.3% of the views were positive as shown in Table 7.3 below.

A-	0	0.0%
A+	30	83.3%
A=	6	16.7%
Atotal	36	100.0%

AA	10	27.8%
AW	14	38.9%
AV	10	27.8%
AO	2	5.6%
A	**36**	**100.0%**

AA-	0	0.0%
AA+	10	27.8%
AA=	0	0.0%
AW-	0	0.0%
AW+	11	30.6%
AW=	3	8.3%
AV-	0	0.0%
AV+	9	25.0%
AV=	1	2.8%
AO-	0	0.0%
AO+	0	0.0%
AO=	2	5.6%

Table 7.3: Views of Singaporean teachers on "Arduino Technology"

The teachers were particularly positive in the sub-category "Arduino Hardware and Software" ("AW"). Most teachers highly appreciated that Arduino was a *"powerful and effective tool in obtaining experimental data and analysing the data collected." (TOCO-50)* The Arduino devices were commented as *"compact and therefore very portable." (TOCO-131) "Wearable Arduino* provided more flexibility *"e.g. measuring accelerations on roller-coaster, lifts, cars" (TOCO-107)* in science learning. The feature that it is *"easily programmable"(TOCO-11)* and the comment that *"open-source software meant lots of opportunities for development" (TOCO-1)* support the argument for the use of the Arduino technology.

Teachers all appreciated the “Affordability of the Arduino devices” (“AA”) which facilitated the promotion of the Arduino technology. Arduino devices were *“not expensive” (TOCO-19)* and *“easily accessible” (TOCO-48)* in the market. When compared with the data logging systems that many schools were using, some said funding for acquisition of the device for a *“bigger group of students is less than ready-made data loggers and sensors” (TOCO-333)* and it would *“not discriminate them (students) even though they are of lower income / less fortunate since Arduino is cheap and affordable.” (TOCO-110)*

“Versatility and Flexibility” (“AV”) was one of the key advantages of Arduino. Vast majority of the teachers highly appraised its versatility, claiming that *“the use of Arduino technology is not limited and it can be used for anything.” (TOCO-13)“The flexibility to build almost anything for own experiment is highly valued.” (TOCO-85) “Students can modify the hardware or program to suit different situations.” (TOCO-61)* The Arduino devices are *“flexible and customizable” (TOCO-114)* and the *“modular structure enable different usage of the equipment”. (TOCO-46) “(Arduino) can be paired/ matched with smartphone apps” (TOCO-49) “to control other devices / gadgets” (TOCO-112),* thereby providing a wide spectrum for its integration into the science curriculum.

7.1.3 Conduction of the Experiments

Teachers paid less attention to the “Conduction of Experiments (E)” category, with only 7.5% of the views recorded in this aspect. Among the comments, majority laid in the sub-categories “Collection of Data” (“EC”) and “Data Manipulation” (“EM”).

E-	3	11.5%
E+	23	88.5%
E=	0	0.0%
Etotal	26	100.0%

EC	12	46.2%
EM	10	38.5%
EP	4	15.4%
ES	0	0.0%
EO	0	0.0%
E	**26**	**100.0%**

EC-	1	3.8%
EC+	11	42.3%
EC=	0	0.0%
EM-	2	7.7%
EM+	8	30.8%
EM=	0	0.0%
EP-	0	0.0%
EP+	4	15.4%
EP=	0	0.0%
ES-	0	0.0%
ES+	0	0.0%
ES=	0	0.0%
EO-	0	0.0%
EO+	0	0.0%
EO=	0	0.0%

Table 7.4: Views of Singaporean teachers on “Conduction of the Experiments”

“Data Collection” (“EC”) was the most mentioned sub-category. Teachers viewed Arduino as a *“powerful and effective tool in obtaining experimental data” (TOCO-51),* that *“data could be collected fast” (TOCO-24)* and *“more data was collected.” (TOCO-80)* The data collected were *“more reliable measurement instead of basing on human observation and measurement using normal laboratory equipment.” (TOCO-113) “Students need not be too overly concerned about data collection.” (TOCO-17)*

After data collection, the data were transferred to the Excel templates for further treatment. Teachers were of the views that the macros embedded in the Excel templates made it *“easy to analyse the data collected”. (TOCO-23)* The *“results are instantaneous.” (TOCO-99)* The Excel template was a *“time-saver*” *(TOCO-98)* and student “*no longer has a need to plot graph manually.” (TOCO-98)* Overall, Singaporean teachers were very satisfied with the conduction of the Arduino experiments.

7.1.4 Comparison with Traditional Experiments

Almost no data was collected in respect of the category of “Comparison with Traditional Experiments (X)” as the sharing session with the Singaporean teachers was very tight, focusing only on the Arduino-based experiments but not traditional experiments in the OEIR Programme.

There was no corresponding question in the Survey to prompt teachers to make comments in this regard.

X-	0	0.0%
X+	0	0.0%
X=	1	100.0%
Xtotal	1	100.0%

XT	1	100.0%
XC	0	0.0%
X	**1**	**100.0%**

XT-	0	0.0%
XT+	0	0.0%
XT=	1	100.0%
XC-	0	0.0%
XC+	0	0.0%
XC=	0	0.0%

Table 7.5: Views of Singaporean teachers on “Comparison with Traditional Experiments”

7.1.5 Challenges

Under the category “Challenges (C)”, which was the category that drew 52.9% of the Singaporean teachers’ views, 95.6% of the views were negative, showing that the Singaporean teachers were particularly conscious about the challenges posed by application of a new technology in their curriculum. The anticipated challenges were mainly in the aspects set out in Table 7.6 below, which were sub-categorized according to the codes.

“Teacher efficacy” (“CT”) topped the list of concerns. The point about the *“readiness and willingness of teachers to take up and use Arduino” (TOCO-289)* and consideration on *“teachers' competency and capability” (TOCO-162)* were raised. Participating teachers cited challenges as to whether “*teachers would be able to answers all students' answers” (TOCO-162)* and brought up the point that *“one teacher may not be able to solve the problems on the spot.” (TOCO-200) “This is an initial learning curve that teachers must be willing to invest in.” (TOCO-323)* The challenges to *“teachers and students' comfort level in handling and developing microelectronics” (TOCO- 254)* had to be addressed. To cope with the challenge, training was a necessity *“to empower the teachers to be familiar with Arduino system” (TOCO-234)*, though there were other concerns such as “*training of teachers might be difficult and teachers might not be easily convinced of usefulness of Arduino technology.” (TOCO-167)*

C-	175	95.6%
C+	4	2.2%
C=	4	2.2%
Ctotal	183	100.0%

CC	10	5.5%
CE	14	7.7%
CI	28	15.3%
CL	25	13.7%
CM	22	12.0%
CT	46	25.1%
CS	35	19.1%
CO	3	1.6%
C	**183**	**100.0%**

CC-	8	4.4%
CC+	2	1.1%
CC=	0	0.0%
CE-	13	7.1%
CE+	1	0.5%
CE=	0	0.0%
CI-	28	15.3%
CI+	0	0.0%
CI=	0	0.0%
CL-	24	13.1%
CL+	0	0.0%
CL=	1	0.5%
CM-	22	12.0%
CM+	0	0.0%
CM=	0	0.0%
CT-	45	24.6%
CT+	0	0.0%
CT=	1	0.5%
CS-	35	19.1%
CS+	0	0.0%
CS=	0	0.0%
CO-	0	0.0%
CO+	1	0.5%
CO=	2	1.1%

Table 7.6: Views of Singaporean teachers on "Challenges"

The second most concerned item was on "Technical support" ("CS"). Teachers stressed the importance of *"technical support in the programming and set up of the hardware" (TOCO-149)*, including how *"to* piece *the (Arduino) parts together" (TOCO-194)* and the importance of support to *"trouble shooting when equipment failed" (TOCO-270).* Remarks such as *"trouble shooting would be a big issue if lesson was conducted in big groups of students" (TOCO-202)* were noted.

Teacher's confidence level on the use of IT skills ("CI") was third on the list of concerns. There was a common misunderstanding that teachers and students need to know programming in using the Arduino devices to perform the physics experiments. There were concern about *"poor understanding of Arduino programming by teachers and students as its programming is too complex for some." (TOCO-272) "Students at secondary school level may not be too IT saving, Excel may be difficult for them, as they (students) need to go through training fast." (TOCO-182) "Competitive thinking and programming ability" (TOCO-154)* would be a hurdle in promoting the Arduino technology.

"Students' readiness and attitude in Learning" ("CL") also affected the effective use of the Arduino technology. Some teachers raised the point about *"students' readiness and the fact that they are used to spoon-feeding / non-inquiry approach" (TOCO-193)* and highlighted the concern about *"Teachers and students' comfort level in handling and developing microelectronics" (TOCO-255)*. Some teachers commented that *"students need scaffolding in learning" (TOCO-318) "and students require adjustments to get used to using Arduino." (TOCO-260)*

"Time management" ("CM") was another area of concern in the implementation as many Singaporean teachers expressed that *"not all sessions can incorporate the implementation due to time constraint ..." (TOCO-170)* and the schools needed *"more curriculum time" (TOCO-302)* in order to accommodate extra lessons to perform the Arduino-based experiments. The teaching environment in Singapore was very similar to that of Hong Kong in that both areas had a very tight syllabus. Many teachers were compelled to give up the laboratory sessions in order to rush through the syllabus. Students in general tended to be examination-oriented and competition among them was very keen. Teachers always thought that *"time factor"* was a key concern and *"there is always not enough time" (TOCO-208)* for teaching. *"Time had to be taken to prepare the relevant Arduino-based lessons" (TOCO-228)* and *"time investment was needed in setting up the various set-ups."(TOCO-286)*

Most of the Singaporean teachers who participated in the OEIR Programme were master teachers in physics. Many of them occupied important, influential positions in the schools. They shared a wider outlook on the limitations of the school environment (7.1% in "CE-") in implementing the Arduino-based experiments. From the management perspective, *"hardware resources" (TOCO-237)* and *"financial support" (TOCO-179)* were always their main concerns.

7.2 Comparison of Qualitative Data between Singaporean teachers and Hong Kong teachers

Hong Kong and Singapore were two very competitive areas which bear lot of similarities in the education system. In 2016, the author was invited by the Ministry of Education, Singapore to hold Master classes for Singaporean teachers in the OEIR Programme. Workshops on the Arduino-based experiments were conducted and the views of 131 Singaporean teachers were collected and compared with that of Hong Kong teachers.

The collective term "Hong Kong teachers" in this Section referred to the teachers, laboratory technicians and technical assistant in the author's school and local teachers joining the STEM Olympiad 2016. Given that views collected from the STEM Olympiad teachers were relatively few, their influence on the overall results was not as significant. Although the number of Hong Kong teachers involved in the comparison was relatively few (23) when compared with that (131) of Singapore, the views collected from Hong Kong teachers were extensive (398 threads), which were comparable to that from Singaporean teachers (totaling 346 threads). It was on this basis that the comparison was carried out.

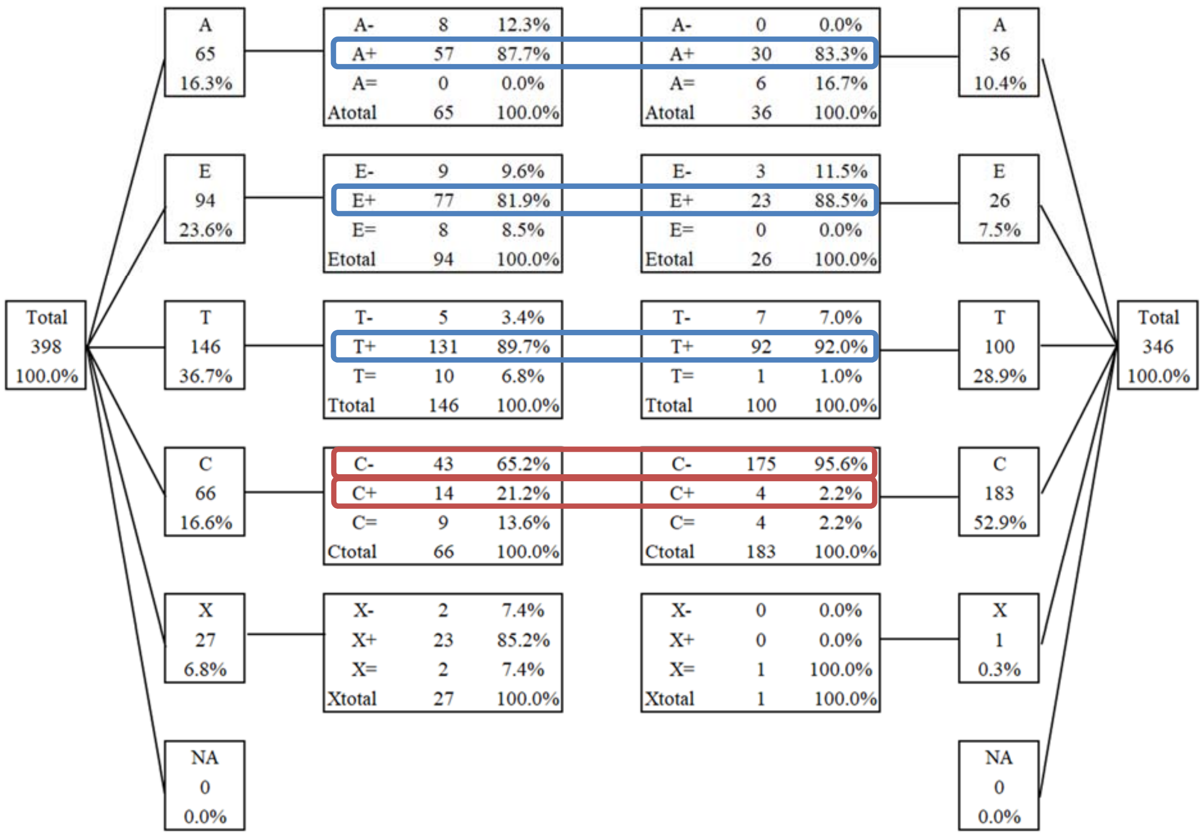


Table 7.7: Views of “Hong Kong Teachers” versus
“Singaporean teachers in the OEIR Programme”

The areas of concern of the teachers in the two areas according to the CATEX categories were summarized in Table 7.8 below. Views were particularly different in two areas, namely “Challenges (C)” and “Conduction of the Experiments (E)”. These were ranked in descending order, in Table 7.8 as shown below:

Hong Kong	T 36.7%	E 23.6%	C 16.6%	A 16.3%	X 6.8%
Singapore	C 52.9%	T 28.9%	A 10.4%	E 7.5%	X 0.3%

Table 7.8: Views of Hong Kong and Singaporean Teachers according to CATEX

The “Teaching and Learning (T)” category was a category of high concern in the two areas, ranking first in Hong Kong and second in Singapore. When classified according to the percentage of positive feedbacks, the “Arduino Technology (A)”, “Conduction of Experiment (E)” and “Teaching and Learning (T)” sub-categories in both areas all recorded high percentages of positive views while the "Challenges (C)" category registered a majority of negative views in Hong Kong (65.2%) and Singapore (95.6%), as shown in the Table 7.9 below. Singaporean teachers were more uncertain about the implementation of the Arduino-based experiments than Hong Kong teachers, whose views were more diverse, with 21.2% of the Hong Kong teachers' views was that the "Challenges" posed a positive drive.

Sub-category	Percentage of views	
	Hong Kong	Singapore
A+	87.7%	83.3%
E+	81.9%	88.5%
T+	89.7%	92%
C-	65.2%	95.6%
C+	21.2%	2.2%

Table 7.9 Comparison of views of Hong Kong and Singaporean teachers by sub-categories

Views of Hong Kong and Singaporean teachers largely converged in the sub-categories of "Arduino Technology (A)", "Conduction of the Experiments" and "Teaching and Learning of Physics (T)" and the views were positive, supporting the argument for implementation of the Arduino-based experiments. Data collected in the category of "Comparison with Traditional Experiments (X)" were few, which was not worthy of any serious comparison.

7.2.1 Arduino Technology

Under the "Arduino Technology" category, the most mentioned sub-category as well as the one with the greatest difference between the two groups of teachers was found in the "Hardware and Software" ("AW") sub-category (50.8% versus 30.6% for Hong Kong and Singaporean teachers respectively). Most of the Hong Kong teachers in this study were subject to a longer period of training. They had more authentic experiences in applying the Arduino devices in various experiments. As a result, they could appreciate more the powerfulness, ease of use and portability of the Arduino devices. Singaporean teachers were only introduced with the Arduino experiments in a one-hour programme. It took time for them to consolidate and further explore the use of the Arduino technology. That explained why they were not as affirmative as Hong Kong teachers.

Hong Kong Teachers			Singaporean Teachers		
AA-	0	0.0%	0.0%	0	AA-
AA+	10	15.4%	27.8%	10	AA+
AA=	0	0.0%	0.0%	0	AA=
AW-	7	10.8%	0.0%	0	AW-
AW+	33	50.8%	30.6%	11	AW+
AW=	0	0.0%	8.3%	3	AW=
AV-	0	0.0%	0.0%	0	AV-
AV+	14	21.5%	25.0%	9	AV+
AV=	0	0.0%	2.8%	1	AV=
AO-	1	1.5%	0.0%	0	AO-
AO+	0	0.0%	0.0%	0	AO+
AO=	0	0.0%	5.6%	2	AO=

Table 7.10: Hong Kong versus Singaporean Teachers in the “A” category

On the other hand, higher percentage of the Singaporean teachers mentioned about the “Affordability and Availability (AA)” of the technology (15.4% versus 27.8% for Hong Kong and Singaporean teachers respectively) and all the comments were positive. Singaporean teachers found this a favorable point for promotion of the use of the Arduino technology, especially in some rural areas. Experiments in small groups became possible as the costs for the hardware were low and the software could be free of charge. The concern about the cost was not as evident among Hong Kong teachers.

Teachers in the two areas had similar positive views on the “Versatility and Flexibility” (“AV”) sub-category (21.5% versus 25.0% for Hong Kong and Singaporean teachers respectively). They shared that the versatility and flexibility of the Arduino devices made them very suitable for Scientific investigation or project which involved higher-order thinking.

7.2.2 Conduction of Experiment

Under the “Conduction of Experiment (E)” category, greatest difference was noticed in the “Procedures” sub-category (42.6% versus 15.4% in “EP+” for Hong Kong and Singaporean teachers respectively) and in the “Data Collection” sub-category (16.0% versus 42.3% in “EC+” for Hong Kong and Singaporean teachers respectively) with the views in reverse order.

Hong Kong Teachers			Singaporean Teachers		
EC-	1	1.1%	3.8%	1	EC-
EC+	15	16.0%	42.3%	11	EC+
EC=	0	0.0%	0.0%	0	EC=
EM-	1	1.1%	7.7%	2	EM-
EM+	21	22.3%	30.8%	8	EM+
EM=	0	0.0%	0.0%	0	EM=
EP-	5	5.3%	0.0%	0	EP-
EP+	40	42.6%	15.4%	4	EP+
EP=	2	2.1%	0.0%	0	EP=
ES-	0	0.0%	0.0%	0	ES-
ES+	0	0.0%	0.0%	0	ES+
ES=	0	0.0%	0.0%	0	ES=
EO-	2	2.1%	0.0%	0	EO-
EO+	1	1.1%	0.0%	0	EO+
EO=	6	6.4%	0.0%	0	EO=

Table 7.11: Hong Kong versus Singaporean Teachers in the “E” category

As mentioned in Section 6.3.4, the teachers in the author’s school were highly involved in developing, evaluating and conducting the seven Arduino-based experiments for students. The teachers could observe the changes in the learning behaviors among students for a longer period of time. It would be normal that their attention on students during the conduction of the experiments shifted mostly to the effectiveness of the intervention on students’ learning behavior (as mentioned in Chapter 6 Section 6.3.1). Singaporean teachers only participated in workshops for a short period of time and they were invited to make evaluation without really conducting the experiments with their students. It was expected that less depth observations on students’ learning effectiveness could be made. However, Singaporean teachers were highly impressed in the areas of “Data Collection” (42.3% in “EC+”) and “Data Manipulation” (30.8% in “EM+”) as fast data collection and easy data manipulation (as mentioned in Section 7.1.3) were key elements for smooth conduction of the experiments and these merits were most easily observable in the workshops.

7.2.3 Teaching and Learning of Physics

Teachers of the two areas placed the "Affective Domain" at the top of their lists of concern and their views resembled (18.5% versus 19%) as shown in the Table 7.12 below.

Hong Kong Teachers			Singaporean Teachers		
TA-	1	0.7%	4.0%	4	TA-
TA+	27	18.5%	19.0%	19	TA+
TA=	1	0.7%	0.0%	0	TA=
TC-	0	0.0%	0.0%	0	TC-
TC+	14	9.6%	10.0%	10	TC+
TC=	0	0.0%	0.0%	0	TC=
TH-	0	0.0%	0.0%	0	TH-
TH+	14	9.6%	15.0%	15	TH+
TH=	3	2.1%	0.0%	0	TH=
TI-	0	0.0%	0.0%	0	TI-
TI+	30	20.5%	12.0%	12	TI+
TI=	1	0.7%	0.0%	0	TI=
TK-	1	0.7%	0.0%	0	TK-
TK+	19	13.0%	20.0%	20	TK+
TK=	1	0.7%	0.0%	0	TK=
TP-	3	2.1%	2.0%	2	TP-
TP+	26	17.8%	14.0%	14	TP+
TP=	4	2.7%	1.0%	1	TP=
TO-	0	0.0%	1.0%	1	TO-
TO+	1	0.7%	2.0%	2	TO+
TO=	0	0.0%	0.0%	0	TO=

Table 7.12: Hong Kong versus Singaporean Teachers in the "T" category

Teachers appreciated the Arduino-based experiments were inspiring and challenging and at the same, time easy to use. The experiments could inspire students' interest and motivation towards learning physics. This was mentioned in Section 6.1.1, 6.3.1 and Section 7.1.1. The differences in other sub-categories were not particularly obvious. The greatest difference was in the "Scientific investigation" ("TI") sub-category. Hong Kong teachers were more affirmative about the Arduino experiments in sharpening the Scientific investigation skills of students as this had been put to test by most of the teachers in the Intervention Programme. They observed students' active participations in Scientific investigation. Singaporean teachers had yet to use the Arduino devices in their physics lessons. It was therefore natural that Singaporean teachers less mentioned about this sub-category.

7.2.4 Challenges

Hong Kong Teachers			Singaporean Teachers		
CC-	2	3.0%	4.4%	8	CC-
CC+	3	4.5%	1.1%	2	CC+
CC=	1	1.5%	0.0%	0	CC=
CE-	0	0.0%	7.1%	13	CE-
CE+	1	1.5%	0.5%	1	CE+
CE=	0	0.0%	0.0%	0	CE=
CI-	6	9.1%	15.3%	28	CI-
CI+	1	1.5%	0.0%	0	CI+
CI=	2	3.0%	0.0%	0	CI=
CL-	9	13.6%	13.1%	24	CL-
CL+	2	3.0%	0.0%	0	CL+
CL=	2	3.0%	0.5%	1	CL=
CM-	6	9.1%	12.0%	22	CM-
CM+	0	0.0%	0.0%	0	CM+
CM=	0	0.0%	0.0%	0	CM=
CT-	6	9.1%	24.6%	45	CT-
CT+	1	1.5%	0.0%	0	CT+
CT=	0	0.0%	0.5%	1	CT=
CS-	11	16.7%	19.1%	35	CS-
CS+	1	1.5%	0.0%	0	CS+
CS=	0	0.0%	0.0%	0	CS=
CO-	3	4.5%	0.0%	0	CO-
CO+	5	7.6%	0.5%	1	CO+
CO=	4	6.1%	1.1%	2	CO=

Table 7.13: Hong Kong versus Singaporean teachers in the "C" category

When the sub-categories under the "Challenges (C)" category were further examined, it was observed that negative views of the Singaporean teachers predominated by a great extent as compared to Hong Kong teachers which was illustrated Table 7.13 above. Negative views of the teachers in the two areas were mainly in the sub-categories "Teacher efficacy" ("CT") and "Technical Support" ("CS"), followed by "Readiness and attitude of Students in Learning" ("CL") and "IT skills" ("CI").

The greatest difference was observed in the "Teacher efficacy" ("CT") sub-category (9.1%

versus 24.6% for Hong Kong and Singaporean teachers respectively). This however need to be read with caution that Hong Kong teachers participating in this study were mostly from the author's school who had received very intensive and long period of training on Arduino before they conducted the laboratory sessions. Many of them were also involved in the development and evaluation phase of the Arduino-based experiments. They were therefore more prepared for the challenge. The figures informed that proper training was very important in increasing the confidence level of the teachers to master the new technology. Views of the two areas on "Teacher efficacy" were elaborated in Section 6.3.4 and Section 7.1.5.

"Technical Support" ("CS") was another most mentioned sub-category and the level of concern between teachers of the two areas was comparable (16.7% versus 19.1% for Hong Kong and Singaporean teachers respectively). Of relevance was that the software and hardware of the Arduino devices were open-source, the devices were designed as simple tools, and Excel templates and laboratory worksheets were well prepared beforehand to integrate into the curriculum. The peripheral support should have been appropriate. Even so, teachers were concerned that in case of failure, they might not be able to do the trouble shooting on their own. This type of technical work required certain degree of proper training and therefore the worries of the teachers were well understood. To address this concern, a well-trained technical staff should be able to give teachers the assurance. The views of the two areas on "Technical Support" were elaborated at Section 6.3.4 and 7.1.5.

Some difference was also noted in the "School Environment" ("CE") sub-category (0% versus 7% for Hong Kong and Singaporean teachers respectively). As the Singaporean teachers were mostly master teachers who might be policy makers in their schools, they had a role to play in determining how school policy should be changed to favor the implementation of the Arduino-based experiments. As for the Hong Kong teachers, especially in the author's school, this concern was not evident when school policy was already set and teachers were not in the positions to exert influences for change.

7.2.5 Comparison with Traditional Experiments

Under the "Comparison with Traditional Experiments (X)" sub-category, the Hong Kong teachers expressed more views than Singaporean teachers (85.2% versus 0% in "XT+").

Hong Kong Teachers			Singaporean Teachers		
XT-	2	7.4%	0.0%	0	XT-
XT+	23	85.2%	0.0%	0	XT+
XT=	2	7.4%	100.0%	1	XT=
XC-	0	0.0%	0.0%	0	XC-
XC+	0	0.0%	0.0%	0	XC+
XC=	0	0.0%	0.0%	0	XC=

Table 7.14: Hong Kong versus Singaporean Teachers in the "X" category

The Hong Kong teachers, especially teachers in the author's school, have been conducting traditional "mechanics" experiments over the years and they could make comparison between the two approaches readily. The syllabus in "Newtonian mechanics" in Singapore was similar to that of the DSE syllabus of Hong Kong, both including the topics of kinematics, dynamics, forces, work, energy, power and circular motion. The Singaporean teachers had similar traditional experiments on these topics. However, the comparison was not mentioned among the Singaporean teachers during the one-hour programme because the time allocated to the Singaporean teachers on the Arduino-based experiments was very short. No interview was conducted with the Singaporean teachers and questions on such comparison were not explicitly asked in the survey form. Hence the result in Table 7.14 did not imply Singaporean teachers were satisfied with the traditional experiments.

7.3 Quantitative Analysis of Data of the Singaporean Teachers

7.3.1 Survey results of the OEIR group

Out of the five groups participating in this study, the sample size of the Singaporean teachers who had participated in the OEIR Programme 2016 was the largest, totaling 131. It was large and significant enough to draw concrete conclusions from the data. The sample size of the other survey groups turned out to be less representative. Detailed statistical results of the other groups were listed in Appendix K2B. Based on the classical test theory, ratings "1", "2", "3", "4" and "5" for each survey question are assigned for "strongly disagree", "disagree", "neutral", "agree", "strongly agree" respectively. A score above "4" referred to more than generally "agree" and the full mark was "5". These values will be used for subsequent statistical analysis.

The population of Singaporean teachers who agreed (in "4"+"5") with the items in the survey questions was in general high. Particular attention should be given to six of the items (1, 2, 6, 8, 12, 13), the scores of which were exceptionally high, with ratings "4"+"5" greater than 90% and average score greater than 4. They were arranged in descending order in Table 7.15 below.

No.	Evaluation item	Percentage in "agree"+ "strongly agree"	Average Rating
1	It would be an interesting experience for students to apply Arduino technology in doing science experiments.	97.7	4.31
8	The Arduino system is a powerful tool for enhancing students' ability in scientific investigation.	95.4	4.29
13	The versatility (programmability, connection to different sensors, output device and wireless device...) of the Arduino system makes it useful in science teaching and learning.	93.9	4.32
2	The Arduino-based activities can arouse students' motivation in learning science.	93.9	4.25

12	The relatively low cost of the Arduino systems would be conducive in promoting science Education.	93.1	4.32
6	Arduino technology is useful for developing students' hands on skills in science learning within the school.	92.4	4.15

Table 7.15: Highly rated items in the Survey Form II (Singaporean teachers)

The item that was ranked at the top of the list was item 1. There was remark that "It would be an interesting experience for students to apply Arduino technology in doing science experiments." Singaporean teachers highly agreed that the Arduino system is a powerful tool for enhancing students' ability in scientific investigation, and can arouse students' motivation in learning science. The versatility and low cost of the Arduino system makes it useful in promoting science teaching and learning and to develop their hands-on skills in science learning within the school.

However, the score of item 4 in the survey as shown in Table 7.16 was only slightly above 50%. Singaporean teachers were not as confident about that the capability of students in carrying out the Arduino-based experiments on their own. The score of item 3 was not as high as (71%) the scores of the other items, but Singaporean teachers still generally agreed that "students would prefer using Arduino-based devices to traditional equipment in conducting scientific investigation." Although the Singaporean teachers were not as certain about promoting the Arduino-based experiment in their Schools, they agreed that the new technology was worth trying in place of the traditional ones. Overall, the quantitative data collected from Singaporean teachers indicated a high level of support for the Arduino technology.

No.	Evaluation item	Percentage in "agree"+ "strongly agree"	Average rating
3	Students would prefer using Arduino-based devices to traditional equipment in conducting scientific investigation.	70.8	3.92
4	Students are capable of carrying out on their own the Arduino-based experiments demonstrated.	55.7	3.54

Table 7.16: Relatively low-rated items in the Survey Form II

7.3.2 Comparison of Quantitative Data between Singaporean teachers and Hong Kong teachers

7.3.2.1 Sample size

The sample size of the participating teachers in Hong Kong was relatively small when compared with that of Singaporean teachers. However, the teachers in Hong Kong, especially the teachers (including laboratory technicians and technical assistant) in the author's school had received prolonged training in the use of Arduino. As such, their views carried significant weight. In order to increase the sample size of the local Hong Kong teachers, teachers participated in the STEM Olympiad and the teacher group participated in the Intervention Programme in the author's school (Table 5.2 of Chapter 5) were combined together to form a larger sample group of 23 participants. Their survey results were compared with that of Singaporean teachers (Appendix K2F).

No	Questions	Singaporean teachers SINT			Hong Kong teacher HKT			P-value
		"4" +"5"	R_1	SD	"4" +"5"	R_2	SD	
1	It would be an interesting experience for students to apply Arduino technology in doing science experiments.	97.7%	4.31	0.51	95.7%	4.35	0.57	0.76

2	The Arduino-based activities can arouse students' motivation in learning science.	93.9%	4.25	0.59	91.3%	4.26	0.62	0.95
3	Students would prefer using Arduino-based devices to traditional equipment in conducting scientific investigation.	70.8%	3.92	0.77	73.9%	3.96	0.71	0.80
4	Students are capable of carrying out on their own, the Arduino-based experiments.	55.7%	3.54	0.87	69.6%	4.00	0.80	0.02
5	As compared to the traditional method, the Arduino-based activities can enhance students' learning of the course content.	82.4%	3.95	0.55	78.3%	4.00	0.67	0.76
6	Arduino technology is useful for developing students-hand skills in science learning within the school.	92.4%	4.15	0.53	87.0%	4.04	0.71	0.49
7	Arduino technology is useful for developing students-hand skills in science learning outside the school.	87.7%	4.10	0.61	91.3%	4.17	0.72	0.65
8	The Arduino system is a powerful tool for enhancing students' ability in scientific investigation.	95.4%	4.29	0.55	95.7%	4.35	0.57	0.66
9	Apart from physics, similar Arduino technology should be applied in learning other science subjects.	87.7%	4.18	0.65	87.0%	4.17	0.65	0.98
10	For STEM education, every secondary school student should be able to apply Arduino technology for science learning.	81.7%	4.02	0.72	60.9%	3.74	0.81	0.13
11	The Arduino-based activities can help to promote STEM education in schools.	89.2%	4.20	0.64	91.3%	4.17	0.58	0.85
12	The relatively low cost of the Arduino systems would be conducive in promoting science Education.	93.1%	4.32	0.60	91.3%	4.43	0.66	0.45
13	The versatility (programmability, connection to different sensors, output device and wireless device...) of the Arduino system makes it useful in science teaching and learning.	93.9%	4.32	0.59	78.3%	4.13	0.76	0.26
	Mean	86.3%	4.12		43.0%	4.14		

N_{HK} : number of Hong Kong teachers = 23 N_S: number of Singaporean teachers = 131

"4"+ "5": percentage of participants who "agreed" or "strongly agreed" with the item

SD: standard deviation; R: average rating

Table 7.17 Survey results of Singaporean teachers (SINT) and Hong Kong teachers (HKT)

7.3.2.2 Unpaired t-test results

An unpaired t-test was carried out to compare the average ratings (R_1 and R_2 columns in Table 7.17) of the Singaporean teachers (SINT) with that of the Hong Kong teachers (HKT) in the 13 survey questions. The results were shown in Table 7.18 below. The two-tailed P value was found to be 0.836 and by conventional criteria, this difference is considered to be not statistically significant. That implied the views on the 13 survey questions were similar in many areas.

Group	SINT	HKT	P-value
Mean	4.119	4.136	0.836
Standard Deviation (SD)	0.222	0.190	
Sample Size (N)	130	23	

Table 7.18: Summary of data of Hong Kong and Singaporean teachers in the survey

7.3.2.3 Comparison on some individual survey items in the two areas

T-tests were further carried out for individual survey questions and the P-values were calculated as shown in the last column of Table 7.17. The smaller the P-value, the greater the likelihood that the two sets of data were different from one another, i.e. the views of the two groups of teachers were different from one another. Among the p-values in the last column, the p-value of item 4 was evidently low at 0.02 and the difference was statistically significant. The differences in item 10 and 13 were 0.13 and 0.26 respectively which could not be regarded as statistically significant. Nevertheless, the deviations of the responses in the two areas were not entirely negligible and were still worth mentioning. Details of deviations of the items are set out in Appendices R2, R3 and R5.

Score of Item 4 revealed that Singaporean teachers were less confident (55.7%) about their students' ability to carry out the Arduino-based experiments on their own, when compared with

Hong Kong teachers (69.9%). This could be read in the context that the teachers in Hong Kong, especially the teacher group (including teachers, laboratory technicians and technical assistant) in the author's school had received prolonged training and that explained why they were more confident in scaffolding the students. This point was discussed in Section 7.2.3 when the views of Hong Kong teachers and Singaporean teachers on "Challenges" were compared. It reaffirmed that the increase in confidence level was commensurate with longer training period and stronger technical support.

P-value of item 10 indicated some differentiations in how Singaporean teachers and Hong Kong teachers viewed the application of Arduino technology for science learning. Singaporean teachers had a stronger belief that "for STEM education, every secondary school student should be able to apply Arduino technology for science learning." The conviction of the Singaporean teachers was by 21% higher than that of the Hong Kong teachers. In Singapore, the Ministry of Education had launched the STEM education programme in primary and secondary schools since 2014. A STEM Inc. was established in 2014, which was a unit in science Centre Singapore, dedicated to promote STEM education in Singapore. The STEM Inc unit was led by the Principal with a team consisting of Managers, Curriculum Specialists, STEM Educators and Administrative Officers. Hong Kong started to launch the STEM programme at secondary level two years later, in September 2016, which was after the data collection in this study was completed. Therefore, at the time when data was collected for the study, STEM education was still novel to Hong Kong teachers. But to the Singaporean teachers, the programme had been running for two years. Therefore, there was a large gap in the perception of STEM education in these two areas.

Item 13 also revealed some differences between Singaporean teachers and Hong Kong teachers in perceiving the versatility of the Arduino technology. Singaporean teachers appreciated the versatility and usefulness of Arduino technology in science teaching and learning more than that of the Hong Kong teachers by almost 16%. In 2014, after STEM education had been launched in Singapore, a series of STEM Applied Learning Projects were rolled out, including a series of Arduino projects, e.g. Smart Home & Home Automation, drone programming, beverage dispenser, etc. Therefore, Arduino was already made known among Singaporean teachers and they had learned about how powerful and versatile Arduino was in science or STEM education. This explained the variation in the ratings in this item. Awareness of Hong Kong teachers on the versatility of the Arduino technology was, nevertheless, picking up fast.

7.4 Limitations of the Study

7.4.1 Validity of Data

In this study, data were collected from various sources as set out in Chapter 3, including data gathered from within the author’s school as well as data outside the author’s school. As the validity of the data was crucial to the study, specific strategies were adopted to improve its validity as explained in Section 3.8 of Chapter 3. When the strategy was applied in the study, there was still some unforeseen circumstances and how these problems were circumvented is discussed below.

7.4.2 Sample size

As discussed at Section 5.1, the sample size of the students participating in the study was far smaller than what was originally expected, first because of the declining birth rate and second because of the introduction of a wide range of elective modules in the NSS curriculum. Therefore, the validity of the data comparison in the pre-tests and post-tests of the two groups of F.4 students of the 2014/15 and 2015/16 cohorts in the Main Study became an issue. The sample size of the students in the intervention group and the control group was not sufficiently representative to draw conclusive comparison with reference to the pre-test and post-test results. Given the limitations of these quantitative data collected, both quantitative and qualitative analyses were employed in this study to improve the data quality. The quantitative and qualitative data gathered from the survey and interview of the students and the teachers in the author's school became the core data for detailed analysis in this study.

7.4.3 Working relationship with colleagues

Working relationship of the author with the colleagues might also affect the validity of the data collected from the participating teachers in the author's school as the author was the physics panel head in the School and he had a close working relationship with the teachers and the laboratory technicians participating in this study. The author was also accountable to the head of the science key learning area (KLA) of the School, who also participated in the study. Mindful of this close working relationship, those who participated in the Development or Evaluation Phases of the DBR and the subsequent intervention were reminded to give their critiques openly and fairly. Team members fully understood the purpose of the research and were conscious not to be lenient. This helped preserve the objectivity of the data gathered.

As regards qualitative data gathered from local teachers other than those form the author's school and those from the Singaporean teachers, since these participating teachers were not known to the author before, they provided objective, reliable data to the study from other perspectives.

7.4.4 Role of author in class observation in Pilot Study

For the Pilot Study, qualitative data were collected from 21 F.6 students of the 2014/15 cohort with a view to assessing the feasibility of applying Arduino technology in conducting experiments in the topic of “mechanics”. To ensure structured, purposeful collection of data, a checklist was devised to record the attitude, level of competency and performance of students in the workshops. The author was not only involved in the introduction of the programme to students, but also in the discourse with the students to attain a deeper understanding of the difficulties that the students encountered in the course of the experiment. Settings and course design that could best facilitate their scientific investigation and unleash their innovation were examined. The author occasionally challenged the students to test the extent of their problem-solving ability. This informed the author the degree of scaffolding that was necessary for the intervention group. Hence, the author did not merely sit at the back row to observe but often walked through the working benches for close observation and necessary probing, for examples, whether there was active participation, stimulation for further exploration, enhancement of self-motivation, and increased competency in operating the Arduino device, etc.

7.4.5 Hawthorne effect

During the Study, the author was conscious to be more withdrawn when students were performing the experiments as the class was led by their own physics teachers who were acquainted with the Arduino technology. In addition, views of students could adequately be probed during the subsequent interviews. Hawthorne effect refers to the inclination of change in the behavior when participants are under observation and study. In this study, students and teachers were subject to close observation of the author. This might induce changes in the behavior of the students and teachers, not because of changes in the design of the experiment but simply because of the observation they were subject to. Improvement in the learning effectiveness of the students might be attributed to these external factors rather than by the fact that the students were genuinely enthusiastic about the experiments. Given this potential influential factor, students were fully briefed beforehand to perform the experiments at ease. The author made it clear before the experiments that his role was an observer and his observation had no bearing on the academic performance of the students.

CHAPTER 8

CONCLUSIONS AND IMPLICATIONS

This study set out to reply to two research questions raised in Chapter 1, namely:

1. How can the open-source hardware and software be appropriately employed to develop courseware for the effective learning and teaching of physics at the senior secondary level?
2. What are the crucial factors underlying the effective use of the open-source digital technology in students' learning of physics?

In particular, the study looked into how innovative experiments on the topic of "mechanics" could be developed by applying the DBR methodology and using the Arduino technology. The effective integration of the new technology into the physics curriculum lent support to the argument for integration of ICT into the curriculum, as advocated by many educators that were discussed in Section 2.2.3 of Chapter 2. Insofar as the education landscape in Hong Kong is concerned, this study informed about possible full-fledged integration of Arduino into the NSS physics curriculum in the topic of "mechanics", which proved to yield positive learning outcomes among students. The study also sought to find out the factors affecting the effective use of the open-source digital technology in students' learning of science from different stakeholders and perspectives. How the two research questions were addressed in the study and how the study helped bridge the existing gap in the application of open-source digital technology in the learning and teaching of physics are discussed in the ensuing paragraphs.

8.1 Integration of ICT in Science Education

Findings of the study revealed that the open-source Arduino technology could feasibly be integrated into the senior secondary physics curriculum to conduct experiments and pursue scientific investigation. The CDC the EDB (2017) recommended for use in schools the "Science Education Key Learning Area Curriculum Guide", which set forth renewed emphasis, among others, on promoting IT in Education, e-learning, and information literacy to develop self-directed learning. While high-level direction was clear, the question as to how IT skills were applied across school curricula was an area yet to be worked on closely between the Education Bureau and tertiary institutions in the context of curriculum design, as pledged in the "Report on the Fourth Strategy on Information Technology in Education" (EDB, 2015). When reviewing the use of Arduino in science education in Hong Kong, there were several successful stories released in the Hong Kong Education City. They were either project-based learning activities or integrated into one or two experiments at the junior secondary level. There exists a gap in its full-fledged, holistic integration into the senior secondary curriculum. This study vividly demonstrated the possibility of developing seven Arduino-based experiments and an entire set of courseware that covered a wide range of experiments on the topic of "mechanics" in the secondary physics syllabus, ranging from basic concepts on displacement, velocity, acceleration and free falling to Newton's Second Law, conservation of momentum and energy in collision, and finally, centripetal acceleration in a circular motion. The study shed light on how the Arduino technology could be used in meaningful ways to reform pedagogical practices. The fact that Arduino seamlessly could be integrated into the curriculum instead of out-of-syllabus activities also increased the incentive for its use among schools, particularly when the effectiveness of its use among students was proven. As such, this study carried significance and contributed to bridging the gap between the theoretical framework and the practical application in an authentic setting.

For this study, DBR was adopted in the design settings of the experimental setups and the courseware. Under this approach, participants of the Development Team, comprising the author, the technical assistant, and the laboratory technician, immersed themselves in an authentic setting, engaged themselves in rounds of constructive discourse, and collaborated to design and continuously refine the setups and courseware for the seven Arduino-based experiments. A primary consideration of the Development Team was to ensure that experiments favored the teaching and learning of physics and were conducive to promoting STEM education. The Development Team first constructed one Arduino-based experiment, including the hardware, software, and courseware, for trial among students. Modifications were made to the experiment in response to feedback gathered, and the lesson learned was taken into account in developing six other Arduino-based experiments.

In developing the other experiments, the iterative cycle was repeated to ensure that the Arduino hardware, software, and the worksheets worked coherently. In the end, seven experiments were produced, and the Feedback Panel comprising experienced science and physics teachers, a laboratory technician, and a technical assistant tested them. Feedback from the panel was systematically, purposely, and timely gathered and analysed by the author for refinement and modification. The seven Arduino experiments in this study were the results of rounds of interaction, feedback, and modification, and they proved to be appropriate for students, both at the lower and higher academic achievement sectors. Highly positive results were gathered from the surveys and interviews of the participating teachers and students in the Main Study, as set out in Chapters 6 and 7.

Surveys and interviews gathered from participating students of the author's school revealed that the vast majority of students were enthralled with the Arduino experiments and considered the experiments easy to perform. Much of the positive feedback was about how Arduino had made the physics experiments interesting (Sections 6.1.1, 6.3.1, 7.1.1, and 7.3.1). Students found it far easier to grasp abstract topics in mechanics, such as circular motion and Newton's Law, through the conduct of the Arduino-based experiments. The real-world learning experience that the Arduino experiments offered, such as the experiment using the Arduino device to measure transient weight in the lift, made them understand the dynamic settings they had to face within a real-life situation. Textbooks could hardly replace such experience, and Chinn and Malhotra (2002) and German, Haskins, and Auls (1996) highly appraised the authentic epistemology of science and pointed out that textbooks might, in fact, promote an inauthentic or unrealistic view of science as a process of accumulating simple facts about the world. The hands-on, trial-and-error experiential learning helped students enhance their creative skills and problem-solving abilities and helped them realize the value of collaboration (Shieh & Chang, 2014). Students were more eager to engage in discourse and collaborate to understand the cause of the problems and to consider alternative ways to carry out the experiments so as to address real-life problems. Some of the graph-plotting work in the worksheets, when taken over by the specially designed Excel functions, supported students with learning diversities in deriving meaningful experimental results. The outcome, to some extent, resonated with the findings of Chang and Shieh (2014), when exploring the value of using a formula sheet for physics examinations in that the use of a formula sheet was reported to facilitate conceptual understanding, highlight cognitive demands in learning physics, and alleviate stress in examinations. The formula sheet could take various forms, including Excel. In this study, it was revealed that the Excel templates further extended to facilitate students in performing experiments and in the cognitive process.

The worksheets guided students with lower educational attainment systematically to complete experiments while offering ample opportunity for higher achievers to challenge their higher-order thinking through extended questions specially incorporated into worksheets to gain bonus marks. From the worksheets submitted by and the performance of the students during the laboratory lessons, there was solid evidence that the Arduino experience deepened students' understanding of difficult concepts, boosted their confidence in the study of physics, fueled their desire to learn more about the Arduino technology, and enhanced their learning effectiveness.

Participating teachers from Hong Kong and Singapore alike were equally positive about the effectiveness of the Arduino technology in enhancing the teaching and learning of physics among students. They believed that the technology provided students with a learning environment that was conducive to scientific investigation and aroused students' interest in science. They appreciated that the experiments were inspiring and easy to use. Data manipulation was simplified with the aid of Excel template files so that students could confidently perform experiments. Teachers in the author's school found that even low achievers and students with special educational needs were eager to try.

Arduino experiments were found to have an edge over traditional experiments in terms of accuracy, sustainability, time in data collection, and manipulation, authenticity, expediency, and portability or a mix of these merits. The versatility and affordability of Arduino were other areas that made the device favorable, as compared to other technologies, for integration into the senior secondary science curriculum. Specifically, the many possibilities it offered, when connecting to different sensors to perform a myriad of experiments for physics and other science subjects, made it a device worthy of full-fledged development. In addition, the low cost and portability of the device favored its wide application when conducting investigative study in groups or on an individual basis, in an authentic setting outside the classroom, or in the laboratory, which was difficult to achieve in the past with traditional experiments.

To effectively put this to good use, a careful design and development of experiments under the DBR approach incorporating both theory and practice is necessary, with the participants and researcher collaborating and interacting iteratively and dynamically to purposely design the hardware, software, and courseware to guide students. There are other known limitations and difficulties in widespread application in school physics education, as discussed in the previous chapter (Sections 6.3.4, 7.1.5, and 7.2.4). However, the present study opened up grounds for other researchers and educators to further explore how to adapt the device to investigative studies in other topics of the physics curriculum and other science subjects, or even to revolutionize teaching processes at school.

8.2 Factors Affecting Effective Use of Open-Source Digital Technology in Students' Learning of Science

The use of the Arduino hardware and software to conduct innovative, non-traditional experiments inside and outside the classroom was proven viable and effective in the author's school. Based on the data gathered from surveys and interviews, it was revealed that the effectiveness of use of the technology hinged on a host of factors, including those at the student level, at the teacher level, and at the school level. Contributing factors identified in this study largely echoed those of past researches, including school-wide decision-making practices and policies related to ICT (Anderson, 2002), confidence of teachers and their general acceptance of technology in the learning process (Bradshaw, 1997; McLaughlin & Talbert, 1990; Zammit, 1992) teachers' consideration of issues of content and technological integration from pedagogical and content perspectives (Pedersen & Yerrick, 2000), and the need to retain students' interest in science (Millar, 2006). Contributing factors at the student level, teacher level, and school level are discussed in the ensuing paragraphs, which give answers to the second research question set out in Chapter 1, which is re-stated at the outset of this chapter.

8.2.1 Student Dimension

From the student dimension, their ability to master new technology has always been a concern among teachers when debating the integration of ICT in the learning and teaching of science. The open-source digital technology used in this study, namely Arduino, is an innovative ICT tool that supports inquiry-based learning. In conducting this research study, participating teachers did express concerns about the possible difficulty of low achievers and students who were used to the non-inquiry-based approach in mastering the Arduino technology, including the use of Arduino devices and Excel templates for data manipulation, as students had no prior experience with the technology. The series of Arduino-based experiments was therefore designed with students working in groups to first familiarize themselves with the Arduino technology in the first two experiments and progressively pick up the use of Excel in data manipulation in the remaining six experiments. Experimental setups and procedures were made simple and clear for students to follow so that students readily built up their confidence.

The innovative device turned out to have aroused students' interest and stimulated the comparatively high-achieving students to investigate further and to achieve integration in STEM education. In the interviews of the students, enhancements in their understanding of physics, motivation, and interest to learn were most mentioned. They were enchanted by the powerfulness of Arduino in data collection. Shieh and Chang (2014) highlighted, in their study on fostering students' creative and problem-solving skills through a hands-on activity, that, because of the various learning needs, the varying degrees of effort exerted by each team, and the various work habits of the individual students, the teacher's role in the project becomes pivotal. The importance of the teacher's subtle scaffolding and adequate pedagogical strategies was mentioned. This was also featured in this study – that the teachers were mindful to apply suitable scaffolding in light of students' pace of learning and confidence levels.

The students rated the learning experience highly and valued teachers' support in helping them conduct experiments. Students showed little concern about their readiness to use Arduino in experiments, and no major difficulties were observed in the students' performing the experiments on their own. This observation lent support to the argument of the Project Team of the "Phase (I) Study on Evaluating the Effectiveness of the 'Empowering Learning and Teaching with Information Technology' Strategy (2004/2007)", that more guidance and opportunities of project-based learning, especially for secondary school students, are necessary to attract their interest in self-learning as well as to create opportunities for their use of higher-order thinking skills in the learning tasks (HKIEd, 2007).

The positive results from the students in this study (Sections 6.1.1, 6.1.2, 6.1.3, and 6.1.4) affirmed the assertion that, with the right technology, careful planning of experiments, and suitable scaffolding by experienced teachers, low achievers could equally master the Arduino technology, learn abstract physics concepts through experiments, and solidly construct their own knowledge. Specifically, factors contributing to the effective use of the open-source digital technology for learning science from student dimension were the adoption of simple technology and procedures, progressive introduction of new technology to students, incorporation of technology that stimulated students' affection, room for engaging students in meaningful, authentic study, and careful scaffolding by teachers to address the needs of students with diversified learning abilities.

8.2.2 Teacher Dimension

As teachers played a pivotal role in the implementation of ICT in science education, teachers' conviction was central to the effective integration of ICT into the teaching and learning of science. The mindset of the teachers in support of integration of ICT was a prerequisite for its successful implementation in the learning and teaching of science. As Sato (2003) remarked, without changing the teachers' mindsets, there would be no more than a superficial enactment. In this study, participating teachers shared that Arduino experiments were conducive to the teaching and learning of physics. They appreciated that Arduino raised students' motivation to learn and enhanced their understanding of physics. They were in support of use of Arduino in the curriculum.

Teachers' mindsets aside, the pedagogical content knowledge (PCK) of teachers in using Arduino also determined how effectively the technology could be used in science education. Shulman argued for teachers' PCK, which was the ways of representing and formulating the subject that make it comprehensible to others and "an understanding of what makes the learning of specific topics easy or difficult" (Shulman, 1986). In this study, Singaporean teachers were provided with a one-hour session to understand and experience the integration of Arduino into the senior secondary curriculum before their views were collected by way of survey. They did mention in the survey the point about teacher efficacy and confidence and the need for training when asked about challenges in the use of Arduino in the teaching and learning of physics (Sections 7.1.5 and Table 7.6). With STEM education implemented for some time in Singapore, teachers could readily envisage the issues for which they need to prepare when introducing new elements to the curriculum. Their focus on the challenges was explicable. Participating teachers in the author's school had gone through intensive training in conducting the Arduino experiments before introducing them to students. They were evidently less concerned about teacher efficacy (Sections 6.3.4 and Table 6.15). This confirmed the belief that, with proper and intensive training, teachers would be adept at guiding students to perform Arduino experiments, and students could be empowered to be responsible for their own knowledge construction (Section 7.2.4 and Table 7.13). Therefore, at the teacher level, the need for adequate training for and personal experience by the teachers to enhance their teaching efficacy and enrich their PCK was central to the effective use of ICT, which was Arduino in this research study, in the learning and teaching of science.

Apart from teacher training, another major concern among participating teachers was the sufficiency of technical support (Table 7.13). Given that Arduino was a novel ICT tool to teachers from both Hong Kong and Singapore, the two groups of teachers stressed the importance of technical support in case the device was out of order. To ensure the effective use of Arduino in learning science, it was necessary that proficient technical support be provided in schools. The technical support staff must be fully conversant on the use of Arduino hardware and software, programming, and the construction of various Excel templates for experiments. Their presence considerably offloaded the teachers' burden to attend to both the subject matter and technology during the laboratory lesson.

Another concern among teachers was time management (Table 6.15 and 7.6), and the concern was two-fold. First, to acquire skills on the use of Arduino, teachers need to squeeze time out of their packed schedules for training, not to mention the time required to develop courseware for integration into the curriculum. As Hollingsworth (2005) pointed out, exhausted teachers are not ready to take on new projects that are additions to an already-demanding schedule. Given the tight senior secondary curriculum in Hong Kong and Singapore, teachers faced difficulty in freeing time and energy to acquire a new teaching mode using ICT on their own and to develop the technology for integration into the curriculum. To effectively implement the Arduino technology, teachers must be spared from their normal schedule to enrich their PCK. A dedicated development team should also be available to collaborate with teachers to develop courseware for shared use. Support from networking among peer groups, as in the case of teachers in the author's school, also helped sustain teachers' efforts in the use of the Arduino technology. Peer group support and interaction proved to be an integral factor in teachers' development of PCK for the nature of science and scientific investigation (Lederman et al., 2002). The Project Team of "Phase (I) Study on Evaluating the Effectiveness of the 'Empowering Learning and Teaching with Information Technology' Strategy (2004/2007)" further advocated the merits of community-school collaboration in that it enhanced sharing opportunities for keeping up the latest trend of IT in education development with regard to innovative use of IT in learning among schools and between schools and IT-related organizations in the community (HKIEd, 2007). Second, the packed senior secondary curriculum, both in Hong Kong and Singapore, which remained examination oriented, permitted little time for students to explore through experimental learning and authentic science experimenting. Complex inquiry tasks generally took time. Learning authentic scientific reasoning required a commitment by teachers and schools to spend time needed to learn reasoning strategies that go beyond simple observation and simple control of variables (Chinn & Malhotra, 2002). Against the present curriculum design, it was a challenge for teachers to re-prioritize the teaching schedule to accommodate more integration of ICT into the curriculum. The first concern was more related to the school's policy and resources in freeing teachers and is further discussed in Section 8.2.3 below. As for the second concern, the Arduino technology could help address the point to a certain extent in that considerable time of students was saved in carrying out Arduino experiments, as compared to traditional methods. Coupled with strong technical support, the time for experiments could be reduced while offering students the authentic scientific reasoning environment to learn and conduct more inquiry-based learning.

8.2.3 School Dimension

The school policy, the curriculum and readiness of the school's infrastructure all affected the effectiveness of integration of ICT in the learning and teaching of science. As the Project Team of "Phase (I) Study on Evaluating the Effectiveness of the 'Empowering Learning and Teaching with Information Technology' Strategy (2004/2007)" has put, involvement of schools in exploring new technology and developing innovative pedagogy will not emerge without the lead and guidance of school leadership teams (HKIEd, 2007). In this study, participating teachers were less fixated on how the outer environment affected their effective use of Arduino in the teaching and learning of science. Singaporean teachers, most of whom held influential positions in schools, shared a wider outlook in this respect, namely on school environment and curriculum that could facilitate integration of ICT in science education. The points about resources, financial support, and adjustment to the curriculum to encourage integration of ICT were found instrumental to smooth implementation.

With regard to resources and financial support, Arduino could address the concern to a considerable extent, given its low cost and availability of open-source software for development. The experimental setup was entirely affordable, and this favored implementation in schools where resources are particularly limiting. Viewed from these perspectives, Arduino devices should be a push factor that enables schools to implement ICT. The only concern with resources was manpower resources for developing Arduino for integration into different science subjects and resources to free teachers to acquire new skills. If central support were obtained for the setup of a dedicated team to develop and share the technology and to free teachers for development, this would no longer be an issue at the school level.

As for the curriculum, if schools remained focused on the academic results of students in public examinations, chances for renewing curriculum and transforming pedagogy for integration of ICT would likely be limited. Hence, for effective implementation of ICT, school management must have the determination to introduce ICT widely in class, allocating teachers time for equipping themselves with new practices, or else teachers would find it hard to rise to all challenges encountered in integrating ICT into the learning and teaching of science single-handedly. The current landscape shows a positive sign in that the Arduino technology is becoming popular. Many schools are aware of STEM education, so the present approach serves as a very good study point for developing school-based STEM curriculum.

8.3 Implications of the Study

This study aims to demonstrate how open-source digital technology can fittingly be incorporated into physics curriculum, in support of the statement of the Institute for Prospective Technological Studies of the European Commission's Joint Research Centre (2008) that "learning digital skills not only needs to be addressed as a separate subject but also embedded within teaching in all subjects". It also aims to support the argument for the potential of enhanced learning with ICTs, as advocated by many educators (Hawkins & Collins, 1993; Jenkins, 2000: Law, Yuen, & Chow (2003); Lockard et al., 1994; Salomon et al., 1991), for which it has been empirically accounted in a previous review of the Joint Research Centre of the European Commission (2006). Factors affecting effective use of the open-source digital technology in learning science are ascertained with a view of informing how to rise to future challenges to revolutionize the teaching process at school, to equip teachers with full understanding and complete mastery of ICTs as pedagogical tools, and to get those who have not yet used ICTs on board.

After going through more than one year of development and continuous refinements of experiments using the DBR methodology, the study confirms the suitability of the DBR framework for developing open-source Arduino hardware, software, and courseware for integration into the physics curriculum. As the first major implication of the study, it informs of the great potential of DBR methodology for customization of Arduino for integration into other science subjects or cross-disciplinary teaching and learning of STEM, based on collaboration among researchers and practitioners in real-world settings (Wang & Hannafin, 2005). It lends support to what Barab and Squire (2004) advocate, that the DBR design is not just to meet local needs but also to advocate a theoretical agenda. This study is timely, in the wake of the HKSAR Government's setting forth the future direction in implementation of STEM education in late 2015. With STEM being widely promoted among primary and secondary education sectors since 2016, under the notion that a holistic approach be adopted through different strategies focusing on strengthening students' ability to integrate and apply knowledge and skills of different disciplines in school education (EDB, 2015), much could be done using DBR methodology for development of Arduino to offer new modes of teaching practices and open up new grounds for meaningful cross-disciplinary STEM education.

The second key implication of this research study derives from the empirical data that were collected from participating teachers and students in support of use of open-source Arduino-based experiments in the teaching and learning of physics. These data are important in informing whether further research into the development of an open-source device such as Arduino for integration into the science curriculum is worthy of pursuit. The encouraging feedback gathered from students on how Arduino experiments helped them understand abstract concepts of physics and increase their motivation to study science, as well as on how they were satisfied with the efficient and accurate collection of experimental data from the Arduino setup, approves further development of the Arduino technology for science education. Teachers shared observations similar to the students' on Arduino experiments, though they were less certain about readiness of students for the new technology and teacher efficacy.

To respond to the concern from teachers, data were collected on challenges perceived by participants with use of Arduino. Findings in this regard give rise to the third implication of the study, namely, to ascertain factors that are conducive to effective use of the open-source digital technology in the teaching and learning of science. From the teacher dimension, a change of mindset to accept new technology, adequate training, peer group support, and strong technical backup are instrumental in the effective implementation of ICT in the teaching process. From the student dimension, the technology must be simple to operate and capable of arousing their interest and learning motivation, and teachers must suitably scaffold knowledge and skills in the conduct of experiments, having regard for different academic attainments of students. School management must have the determination to introduce ICT widely in class, allocating teachers time for equipping themselves with new practices.

In practice, no single type of ICT can universally solve all problems related to science education. To select an appropriate technology, first, the technology must be easy to acquire and operate; second, the teacher should have relevant experience and be competent in applying the technology; third, it is not necessary for students to have extensive prior knowledge and skills on mastery of the technology for investigative study; and fourth, the selected technology should arouse the interest of students in science learning. In addition, courseware should be carefully designed to cater to students with diversified learning abilities, and teachers should be mindful of applying suitable scaffolding to engage students to construct knowledge. Policymakers, schools, teachers, and designers of curriculum should pay attention to these factors so that open-source digital technology can effectively be applied for enhancing the teaching and learning of science among students.

8.4 Future Direction

In this study, students' readiness to use the Arduino technology in conducting seven experiments related to the topic of mechanics was analysed qualitatively. As mentioned in Section 5.1, the original plan was to gather pre-test and post-test data from 60 students to ascertain the effect of intervention of Arduino experiments on their understanding of physics. However, because of the decline in student population, the validity of the qualitative data gathered was not as satisfactory. Nevertheless, the instrument developed for this research offers a possible framework for further study, where the student population is representative. Hopefully, the framework can be applied to validate the outcomes of this study.

Apart from the research methodology, Arduino also provides ample opportunity for future integration into the curriculum. Both Hong Kong and Singaporean teachers agreed that the use of the low-cost Arduino device could be unlimited and could go beyond imagination. Abundance of hardware and open-source software of the Arduino system facilitates the promotion of Arduino technology in different learning areas. The following section discusses further possible development of Arduino-based experiments and future directions for promoting applications of Arduino in various educational fields.

8.4.1 Integration into Syllabus

The results of this study gave rise to a favorable environment for further integration of Arduino into the syllabus, in other topics of physics or other subjects, like chemistry or biology.

Different stakeholders also raised the possibility of engaging students more in scientific investigation with the adoption of the seven Arduino-based experiments. For future research, experiments can be re-developed to put more stress on scientific investigations, which are often not given adequate attention by teachers, although developing skills for making scientific inquiries is one of the aims in the physics curriculum in Hong Kong (2017). Scientific investigation is one of the important learning objectives in Secondary 4-6 physics curriculum. Students are expected:

> "to plan, design and conduct scientific investigations with multiple variables to control; to conduct risk assessment in planning and designing investigations; to make detailed observations and precise measurements by using appropriate equipment and instruments; to analyse and interpret the data obtained, and draw conclusions for the investigations; to evaluate the validity and reliability of the investigations and make suggestions for further improvement; to write a full report for the scientific investigation (p.34)"

The Arduino-based experiments in this study could not only fulfill these objectives but also deliver outcomes with considerable success. Given the particular features and capabilities of Arduino, the author believes that Arduino technology could readily be promoted to other schools in Hong Kong and areas other than Hong Kong.

8.4.2 Possible Enhancement to the Seven Arduino-based Experiments

Some of the Arduino-based experiments that had been developed and conducted in the study basically collected and saved data on internal memory or SD cards for temporary storage, and further data manipulations were done with Excel. To further improve the setup, a touch screen module available in the market could be added so that the entire data-collection process could be navigated by finger movements on a touch screen without the need to transfer data to a computer for analysis. The system would become a standalone data-logging system in which more complex messages and graphics could be displayed on the screen, including charts and graphs, and data analysis could be done at the same time.

The Arduino boards in the Arduino-based experiments could also be connected to other devices with different means of wireless connections, such as blue tooth for short-range data transfer to a tablet or mobile phone. Special applications could be written for a mobile device to collect, display, and manipulate the data real-time. A WIFI module or a GSM/GPRS shield added onto an Arduino mother-board are also viable means to allow Arduino access to the Internet. Teachers could contrive limited learning activities involving the use of mobile technologies in a range of subject areas within the school environment (Cheng & Kong, 2010). With a wireless connection, students could collect data from different sites and upload data to the Internet for a large-scale or global-scale investigation. Sharing data on the Internet allows collaborative learning by comparing data collected from different sites.

Conventional data loggers usually can only be connected to input devices to collect data passively at a regular sampling rate. However, Arduino could be connected to a wide range of output devices, like a stepper motor, actuator, light, heater, relay, etc. The Arduino device could be turned into a robotic system that makes data collection more flexible; for example, the device could determine on its own the rate of sampling and when or where to collect data. The device could be reprogrammed to embed real-time data treatment procedures while collecting data, for example, to filter off some unwanted signals. Data collection and treatment of some kind of Artificial Intelligence (AI) or automation integrated into the Arduino system is an area to be explored, especially in creative and innovation science.

8.4.3 Arduino in School Science Activities

With Arduino technology, the learning and teaching of science could also be achieved outside the classroom or school so that students could completely immerse themselves in a scientific investigation environment and enjoy the study of science. This is another area for possible future research for understanding how school environment encourages students' self-directed learning of science. In the author's school, different trial schemes had been launched to promote the use of Arduino in education with a view of cultivating a scientific learning environment to sustain students' interest in science exploration. Installation of Interactive Display Windows is one of the examples.

Interactive Display Windows were installed at the author's school building to attract students to play around with the interesting science exhibits controlled by Arduino devices. Students are expected to experience for themselves some science phenomena through self-learning and self-construction of knowledge. "Mushroom growing in a well climate-controlled environment" and "Newton's cradle" were setups showcased in the display windows in school. Students found the displays interesting and interactive. The idea of the Interactive Display Windows could further be promoted in other schools, and exhibits could be shared for use by other schools to maximize their utilization. Consideration may also be given to installing web-cameras and remote-control panels in the Interactive Display Window so that it could easily be converted into a Remotely Controlled Laboratory (RCL) for students from different schools to learn and gain access to the exhibits in a remote site. This takes learning beyond the boundaries.

8.4.4 Application of Arduino in Problem-based Learning Projects

The Arduino technology could also be applied in various investigation projects and in student science competitions, through which students could polish their higher-order thinking and problem solving. This is another front for research study so as to understand in-depth that the path of scientific investigation leads to higher-order thinking and achieves breakthroughs.

In the author's school, students made use of Arduino to invent devices like "Multi-Sensory Finger for Dyslexia", which helped students with dyslexia practise writing, and the "Sea Level Measurement Device" to measure the depth of the sea level at different locations. Each project provides students a good opportunity for problem-based learning, which requires higher-order thinking. The flexibility, versatility, simplicity, and programmability of Arduino makes it particularly useful for innovative or invention projects.

8.4.5 Application of Arduino in STEM Education

With STEM education widely promoted, a key discussion is how STEM could appropriately be integrated into curriculum to promote cross-disciplinary study. An integrated approach was seen to help the next generation of students to solve real-world problems by applying concepts that cut across disciplines as well as capacities for critical thinking, collaboration, and creativity (Burrows & Slater, 2015). Chalmers, Carter, Cooper, and Nason (2017) specifically pointed out that an integrated STEM curriculum should mediate not only the width of knowledge across STEM but also the depth of knowledge within the STEM disciplines. The facts that most teachers have received training only in one discipline (Honey, Pearson, & Schweingruber, 2014) and that most schools and classes still have separate departments and class periods pose a valid challenge for educators and administrators in promoting integrated STEM (Shernoff, Sinha, Bressler, & Ginsburg, 2017). English (2017) remarked that there are no straightforward answers to the issues and attempted to address the issues in his study to advance elementary and middle school STEM education through, among others, approaches to STEM integration and STEM discipline representation. Kelly and Knowles (2016) pointed out difficulties that teachers face in making appropriate links across STEM domains and saw a need for a STEM conceptual framework that is blended with learning theories. Shernoff et al. (2017) identified the need for more collaboration, more modelling, more exemplars, and more mentoring in teacher education, and professional development for implementing STEM education in an integrated approach is necessary. Other challenges include the lack of time, school structure and organization, state, testing, assessments for STEM achievement, perceived lack of resources and teacher education, and visible models of STEM integration. English (2017) envisaged that, as long as the integrity of respective disciplines is maintained and teachers are equipped with necessary knowledge, commitment, and resources, curricula that incorporate one or more forms of integrated STEM activities would seem a positive step towards advancement.

In this study, some Singaporean teachers as well as some teachers in the author's school envisaged the potential of the Arduino-based experiments to be introduced into the school syllabus as a cross-discipline STEM programme. Teachers from different disciplines could work together on Arduino-based STEM projects to enable students to acquire different skills. Design and Technology (DAT) teachers could teach students to construct the Arduino circuits, which involves techniques of electronic engineering. IT teachers could teach students the use of Excel and Arduino programming to carry out different tasks, while mathematics teachers could teach students the treatment of data, including graph and chart generation. Science teachers could conduct different experiments with Arduino devices for investigating various science phenomena. The development of the STEM curriculum is an uncharted area where Arduino has much to offer and where continued research is worth conducting.

In response to this call, the author has developed a prototype "Magic Ruler" from an Arduino circuit, which could be further developed into a large-scale STEM learning programme for application across schools. Through the hands-on process, students could learn essential skills in electronic and software engineering. This STEM project could be integrated into syllabi across different subjects – for example, measuring the human's response time in learning the subjects of physics and integrated science, checking the blind spot of the eye ball and measuring the shortest time of persistence of vision in learning the subject of biology, acting as a pitch tuner for music teachers to teach musical notes, or monitoring the performance of an athlete by a physical education teacher. The "Magic Ruler" is merely one example of the use of Arduino, and it is believed that the potential for further development and application of Arduino in various subjects, projects, and learning activities is enormous.

8.4.6 Embracing Challenges

In the Main Study, the most mentioned sub-categories under the "Challenges" category in the survey and interviews were "teacher efficacy" and "technical support" (Sections 6.3.4, 6.4.4, 7.1.5, and 7.3.4). For teachers who do not have time to attend the training workshop, or for laboratory technicians who encounter technical problems in setting up Arduino-based experiments, web-based support is an alternative and viable solution. Teacher guidelines, user manuals, circuit diagrams, hardware construction diagrams, source codes of Arduino programs, soft copies of courseware, frequently asked questions (FAQ), and so on can be uploaded onto a specific website for free sharing. On this website, teachers and students could share data collected and compare data across different sites. The website could also serve as an opinion-sharing platform to share globally the views on the use of Arduino devices, to encourage social discourse, to stimulate innovation on development of more Arduino-based experiments, and to enhance teaching effectiveness. Teachers from other science subjects like biology and chemistry could also suggest their needs for development of Arduino-based experiments in their curriculum.

The study gave strong evidence that proper training of teachers and laboratory technicians could increase the confidence and efficacy of teachers as well as trust that students have in teachers. A systematic training programme packaged as a STEM Programme could help address the need, and the EDB and tertiary education institutions can join hands to launch the programme for teachers and laboratory technicians. In the programme, participants should have hands-on experience of the whole process, from start to end, up to the evaluation of students' performance.

8.5 Conclusion

This study brings out an important finding, that the Arduino open-source digital technology plays a key, positive role in enhancing the effectiveness of the teaching and learning of physics. Through careful selection of the device, adoption of simple design, easy-to-follow experimental procedures, and appropriate scaffolding by teachers, students with diversified learning abilities are empowered to acquire knowledge on abstract concepts through participating in experiments, and higher achievers are enticed to pursue further scientific investigation on their own. The study also reveals the concern of teachers in rising to challenges of adopting Arduino into the curriculum. Training, peer group support, and proficient technical backup are essential.

Moreover, the versatility of the Arduino device opens up immense opportunities for further development to support use of ICT, not only in science education but also in STEM education and STEM activities, which have become a focal point of discussion in the past few years in anticipation of the need for nurturing more talents in technological and scientific fronts. Hopefully this study sheds some light on future development of this front.

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Appendix A: Time line

Tasks / Milestones	2014				2015				2016				2017				2018
	1st qr	2nd qr	3rd qr	4th qr	1st qr	2nd qr	3rd qr	4th qr	1st qr	2nd qr	3rd qr	4th qr	1st qr	2nd qr	3rd qr	4th qr	1st qr
Systematic/ Literature review	✓	✓	✓							✓	✓						
Feasibility Study of Arduino equipment		✓	✓	✓													
Creating Prototype for the 1st Arduino based experiment (circular motion) and preparing a workshop on the use Arduino.				✓													
Design of the pre-test and post-test on FCI and SPI				✓													
Pre-test on FCI and SPI for F.4 students in the 2014/15 cohort				✓													
Design of questionnaire for students in Main Study					✓												
Presentation of proposal					✓												
Preparing certification of Chinese translation on SPI						✓											
Pilot Study Trial Run on F.6 Students of the 2015/16 cohort						✓											
Post-test on FCI and SPI for F.4 students in the 2014/15 cohort						✓											
Main Development: develop Arduino hardware, software and courseware for the other Arduino-based experiments					✓	✓	✓										
Pretest on FCI and SPI for F.4 students in the 2015/16 cohort								✓									

Tasks / Milestones	2014				2015				2016				2017				2018
	1st qr	2nd qr	3rd qr	4th qr	1st qr	2nd qr	3rd qr	4th qr	1st qr	2nd qr	3rd qr	4th qr	1st qr	2nd qr	3rd qr	4th qr	1st qr
Evaluation and fine-tuning on the hardware, software and courseware of the 7 Arduino-based experiments							✓	✓	✓								
Main Study: Intervention of F.4 students in the 2015/16 cohort								✓	✓	✓							
Workshops followed by interview for six selected F.6 students in the 2015/16 cohort									✓								
Post-test on FCI and SPI for F.4 students in the 2015/16 cohort										✓							
Workshops conducted in the OEIR Programme 2016 for 131 Singaporean teachers											✓						
Workshops conducted for Hong Kong teachers and students in STEM Olympiad 2016											✓						
Interview of School teachers and technical assistant										✓	✓						
Interview of F.4 students in the 2015/2016 cohort										✓	✓						
Transcription of Interview records (teachers and students)											✓	✓	✓	✓			
Development of the CATEX Coding system													✓	✓	✓		
Thesis writing											✓	✓	✓	✓	✓	✓	✓

For students of the author's school

Appendix B1: Survey Form I

Questionnaire on Arduino based Science Activities

以 **Arduino** 為基礎而設計的科學實驗 **-** 學生問卷

(The data and information collected from this survey will be kept strictly confidential. They will only be used for the purposes of development and evaluation of course materials. Students are free to answer the questions in English or Chinese.) (本問卷所搜集的資料為絕對為保密資料，資料只會用作發展及評估教材用。學生可自由選擇以英文或中文作答。)

個人資料**:**

班級：	年齡:	性別 :男

Section A: Prior learning experiences with relevant IT skills (please circle the most appropriate number for the frequency of each item)
甲部份：本人在進行**Arduino** 相關實驗之前，對於**IT**技巧的學習經驗 **(**請就每項圈取合適的頻次)

題號		罕有 → 經常 1	2	3	4
1.	I use mobile device, tablet or PC to support my learning. e.g. web searching, reading, running educational Apps, simulation or virtual experiments, as a communication tools... 我使用無線設備、平板電腦或個人電腦輔助我的學習。例如上網溜覽、閱讀、運行教育軟件、模擬或虛擬實驗、作為通訊工具...	1	2	3	4
2.	I use data loggers for capturing physical data in my science practical classes. 我在科學實驗課中使用數據記錄儀去擷取物理數據。	1	2	3	4
3.	I conduct scientific investigations (or experiments) using sensors (e.g. light, motion, temperature, sound, acceleration...). 我利傳感器(例如光、運動、溫度、聲音、加速度傳感器...)進行科學探究或實驗。	1	2	3	4
4.	I use Excel for finding statistical results (calculating mean, maximum, minimum, number of counts...) 我利用Excel去查找統計結果 (如計算平均值、最高值、最低值、數數量...)	1	2	3	4
5.	I use Excel for graph plotting and curve fitting 我利用Excel作圖及配適直線。	1	2	3	4
6.	I use open source hardware and software in science learning 我運用開源硬件及軟件在我的科學學習上。	1	2	3	4

Circle the best answer for the questions in this section. The guideline is shown in the following table:

在這部份為每題圈取最合適的答案。指引如下圖所示：

Description 描述	Strongly Disagree 非常不同意	D isagree 不同意	Neutral 中性	Agree 同意	Strongly Agree 非常同意
Symbol 符號	1: ☹☹	2:☹	3: 😐	4: ☺	5: ☺☺

Section B:Attitudes and views on Arduino based Science Experiments

乙部份：你對以**Arduino** 為基礎的實驗的態度及看法

No. 題號	**Statement** 陳述	☹☹ **1**	☹ **2**	😐 **3**	☺ **4**	☺☺ **5**
1.	I am interested in applying Arduino technology in doing science experiments. 我對在科學實驗中運用 Arduino 科技是感興趣的。	1	2	3	4	5
2.	Arduino technology is useful in science investigation. Arduino 科技對於科學探究是有用的。	1	2	3	4	5
3.	Arduino technology is useful for supporting science learning within the school. Arduino 科技對於在校內支援科學學習是有用的。	1	2	3	4	5
4.	Arduino technology are useful for supporting science learning outside the school. Arduino 科技對於在校外支援科學學習是有用的。	1	2	3	4	5
5.	I prefer to use Arduino based devices instead of traditional equipment to conduct scientific investigation. 我較喜歡運用 Arduino 科技去進行科學探究多於傳統的方法。	1	2	3	4	5
6.	Every secondary school student should be able to apply Arduino technology for science learning. 每個中學生應懂得應用 Arduino 科技去學習科學。	1	2	3	4	5

Section C: Evaluation of experience after applying Arduino technology in various science activities

丙部份：對在實驗中應用**Arduino**科技的經驗評估

No. 題號	**Statement** 陳述	☹☹ **1**	☹ **2**	😐 **3**	☺ **4**	☺☺ **5**
1.	The activities as based on Arduino technology are interesting and stimulating to me. 我對以 Arduino 科技為基礎的實驗是有興趣的和具激發性的。	1	2	3	4	5
2.	I can carry out the Arduino-based activities as expected. 我能進行以 Arduino 科技為基礎的活動。	1	2	3	4	5
3.	The Arduino-based activities can enhance my learning of the course content as compared to the traditional one. 與傳統方法比較，以 Arduino 科技為基礎的活動能增加我對於課程內容的學習。	1	2	3	4	5
4.	The Arduino-based activities can enhance my motivation in learning the course. 以 Arduino 科技為基礎的實驗能增加我對於課程的學習動機。	1	2	3	4	5

No. 題號	Statement 陳述	☹☹ 1	☹ 2	😐 3	☺ 4	☺☺ 5
5.	I can apply similar Arduino technology in learning other science subjects. 我能運用類同的 Arduino 科技在其他科學學習上。	1	2	3	4	5
6.	The programmability of Arduino makes it a versatile tool in scientific investigation. 因為 Arduino 的可編程關係，令它在科學探究成為一件多用途的工具。	1	2	3	4	5

Section D: Write down your opinion(s) for each question in the boxes provided below.
丁部份：在以下方格寫下你對以下問題的意見。

1. Did you find any problem when using the Arduino devices in the course? If yes, please give brief description of the problem(s). 你對在課程中使用 Arduino 裝置會有困難嗎？如是，請簡單描述困難。

2. During the lesson, which Arduino-based experiment did you find most interesting? Why? 在課堂中，那個你最感興趣的 Arduino 基礎的實驗？為甚麼？

3. In what ways can the Arduino-based experiment be improved or modified? 以 Arduino 基礎的實驗如何可作改善或修訂？

4. What advantages/ disadvantages do you envisage in using Arduino-based device versus existing device in science learning? 與現有學習科學的裝置比較，你認為使用以 Arduino 基礎的實驗有何優點及缺點？

5. Other feedback or comments (if any) 其他回饋或評論

Thank you for completing this questionnaire survey

多謝完成此問卷

Appendix B2: Survey Form II

Questionnaire on Arduino based Science Activities

(For teachers / students other than the intervention group of the author's school)

☐ Teacher

☐ Student

Please tick.

(The data and information collected from this survey will be kept strictly confidential. They will only be used for the purposes of research, development and evaluation of course materials.)

Circle the answer you think most fit for the questions in this section. The guideline is shown in the following table:

Description	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Symbol	1: ☹☹	2:☹	3: 😐	4: ☺	5: ☺☺

Views on Arduino based Science Experiments

No.	Statement	☹☹ **1**	☹ **2**	😐 **3**	☺ **4**	☺☺ **5**
1.	It would be an interesting experience for students to apply Arduino technology in doing science experiments.	1	2	3	4	5
2.	The Arduino-based activities can arouse students' motivation in learning Science.	1	2	3	4	5
3.	Students would prefer using Arduino based-devices to traditional equipment in conducting scientific investigation.	1	2	3	4	5
4.	Students are capable of carrying out on their own the Arduino based experiments demonstrated.	1	2	3	4	5
5.	As compared to the traditional method, the Arduino-based activities can enhance students' learning of the course content.	1	2	3	4	5
6.	Arduino technology is useful for developing students-hand skills in science learning within the school.	1	2	3	4	5
7.	Arduino technology is useful for developing students-hand skills in science learning outside the school.	1	2	3	4	5
8.	The Arduino system is a powerful tool for enhancing students' ability in scientific investigation.	1	2	3	4	5
9.	Apart from physics, similar Arduino technology should be applied in learning other science subjects.	1	2	3	4	5
10.	For STEM education, every secondary school student should be able to apply Arduino technology for science learning.	1	2	3	4	5
11.	The Arduino-based activities can help to promote STEM education in schools.	1	2	3	4	5
12.	The relatively low cost of the Arduino systems would be conducive in promoting Science Education.	1	2	3	4	5
13.	The versatility (programmability, connection to different sensors, output device and wireless device...) the Arduino system makes it useful in Science teaching and learning.	1	2	3	4	5

(P.T.O)

Are there other education merits in using Arduino Technology? Please elaborate.

Any difficulties you may expect in implementation : (e.g. teachers' efficacy, students' readiness, technical support, integration to curriculum, students' readiness, financial support...)

Any other views and comments?

Thank you for completing this questionnaire survey

Appendix C1: Interview Questions in Main Study (for F.6 students of the 2015/16 cohort in the author's school)

Research: The use of an open source digital platform for practical work in science education

Time：13:30 to 15:30 Date：3 Mar. 2016

Place： Aberdeen Technical School Physics Laboratory
Interviewer: Mr. Wong shek nin (the researcher)
Interviewee: Six F.6 student in 2015/16 cohort

Brief description: Six F.6 students (3 chosen from English class and 3 from Chinese class) were invited for the interview. They have completed the whole Physics curriculum and were selected according to their academic performance. Two of the students were randomly selected from the lower achievers group, two from the medium and two from the high achievers groups. They were asked to compare two Physics experiments (listed below) that they have carried out in their previous study using conventional method with the two using the ArduinoTechnology.

1. Newton's 2nd Law in which the relationship between the acceleration of a trolley and the applied force acting on it was investigated.
2. Circular Motion in which the relationship of centripetal acceleration and the angular velocity was investigated.

Part I
Part I aimed at recalling students' memory in doing the above Physics experiments traditionally, which included:
1. the objectives and procedures of the experiments.
2. major sources of errors and how errors could be reduced.
3. difficulties encountered in the experiments.
4. suggestions for improvements.

Part II
Demonstrations on two Arduino-based experiments as mentioned above were carried out. Students were then given 30minutes to try out the experiments on their own.

Part III
Interview Questions:

1. Comparing the traditional experiments with that using Arduino technology, what are the advantages and disadvantages (learning effectiveness, arousing interest, ensuring accuracy, ease of use, time saving, cost, etc) of the two methods?
2. What do you think about the use of Excel (or open office) for data treatment in the new experiments?

3. Which methods do you prefer? (traditional or Arduino technology) Why?

*Attention：Student should respond to the questions on-site.

Remarks：*(unexpected events during interview, e.g. noises in the environment or interviewee's special reactions, please specify)*

Researcher：Wong shek nin

Name of voice file：20160303 six F6 students in 201415 cohort - 1
20160303 six F6 students in 201415 cohort - 2

Appendix C2: Interview questions in Main Study (for F.4 students of the 2015/16 cohort who had participated in the Intervention Program in the author's school)

Research: The use of an open source digital platform for practical work in science education

Starting time：__________________ Date：_______________________

Place： Aberdeen Technical School Physics Laboratory

Interviewer: Mr. Wong shek nin (the researcher)

Interviewee: All F.4 student in 2015/16 cohort who had participated in the Intervention Program in the author's School.

Brief description: After the students had completed the seven Arduino-based experiments, all students of the intervention group were invited for an interview to evaluate the effectiveness of the Arduino-based experiments on teaching and learning.

Interview questions:

1. How the Arduino-based experiments affect the effectiveness of teaching or learning of Physics? Why? (Hint: arouse motivation and interest; enhance the grasp of the content in the classroom, facilitate exploration, arouse critical thinking and enhance creativity, etc.) Why these are important in teaching and learning?
2. What are the advantages and disadvantages of using Arduino in Science teaching and learning?
3. How these IT skills used in the experiments (use of excel for data treatment, use of open source hardware and software) affect the teaching and learning of Physics? Why?
4. Do you think that the Arduino-based experiments could be used in learning outside school or in learning other Science subjects? How?

*Attention：Student should respond to the questions on-site.
Remarks：*(unexpected events during interview, e.g. noises in the environment or interviewee's special reactions, please specify)*

Researcher：Wong shek nin
Name of voice file：
Students:
Teachers:
Technical Assistant:

Appendix C3: Interview questions in Main Study (for teachers/technical assistant of author's school)

Research: The use of an open source digital platform for practical work in science education

Starting time：__________________ Date：_______________________

Place： Aberdeen Technical School Physics Laboratory

Interviewer: Mr. Wong shek nin (the researcher)

Interviewee: (i) Teachers ☐
(ii) Technical assistant ☐

Brief description: After the students had completed the seven Arduino-based experiments, teachers and technical assistant were invited for an interview to evaluate the effectiveness of the Arduino-based experiments on teaching and learning.

Interview questions for all:

5. How the Arduino-based experiments affect the effectiveness of teaching or learning of Physics? Why? (Hint: arouse motivation and interest; enhance the grasp of the content in the classroom, facilitate exploration, arouse critical thinking and enhance creativity, etc.) Why these are important in teaching and learning?
6. What are the advantages and disadvantages of using Arduino in Science teaching and learning?
7. How these IT skills used in the experiments (use of excel for data treatment, use of open source hardware and software) affect the teaching and learning of Physics? Why?
8. Do you think that the Arduino-based experiments could be used in learning outside school or in learning other Science subjects? How?
9. Discuss the advantages (if any) of the Arduino technology over the conventional method (including data logging system) in science education.
10. In the evaluation phase of DBR, what major comments or amendments you have made on the design of the seven Arduino-based experiments.
11. Could the Arduino-based experiments match the trend of STEM education in Hong Kong? Why?

Additional questions for the technical assistant and teachers who have conducted the intervention:

1. During the intervention, how would you describe the performance of the students in their learning process (including understanding the experiment procedures, performing the experiment, doing the report)?
2. Did students find the experiments useful and effective in learning Physics? How?
3. Comparing with the experiments that students have carried out in optics and thermal

Physics, how was students' performance different (if any)?
4. Did students learn more about science investigation after the intervention? How important was science investigation in the learning of Science?
5. How did students rate the level of difficulty in carrying out the Arduino-based experiments? What specific difficulties the students have come across in the experiments?
6. Which experiment(s) students were most interested in? Why?
7. How students with different learning ability (including SEN students) behaved in the intervention?
8. Would there be further improvement on the experiments after the intervention program?

Additional questions for the technical assistant:
1. Self-introduction: studies in the University, technical and IT background, the role in the Development and Evaluation phases of DBR, etc.
2. What major difficulties you have encountered in the development of the Arduino-based experiments and how they could be solved?
3. What you have done to simplify the use of Excel in data manipulation, and why it was important to students?
4. Comparing the Arduino-based experiments with the corresponding traditional experiments you have performed in secondary school, how were they different?
5. What type of experiments could Arduino best be used to maximize its performance?
6. Do you think that it was essential for students to know about programming the Arduino hardware in order to perform the experiment? Why?

*Attention：Student should respond to the questions on-site.

Remarks：*(unexpected events during interview, e.g. noises in the environment or interviewee's special reactions, please specify)*

Researcher：Wong shek nin

Name of voice file：
Students:
Teachers:
Technical Assistant:

Appendix D: Arduino based-Experiments - Evaluation Form Experiment No.: __

I. About the design of the experiments (Please tick appropriate box):

1: far below standard 2: below standard 3: appropriate 4: above standard 5.far above standard

	Item	1	2	3	4	5	N/A
1	Length of the experiment						
2	Level of difficulty level of the experiment						
3	Others (please specify) ____________________						

II. Meeting learning targets?

1: highly disagree 2: disagree 3: agree 4: highly agree

Meeting the targets of the HKDSE Assessment Framework (2018)?						
	Item	1	2	3	4	N/A
1	recall and show understanding of the facts, concepts, models and principles of physics, and the relationships between different topic areas in the curriculum framework;					
2	apply knowledge, concepts and principles of physics to explain phenomena and observations, and to solve problems;					
3	show an understanding of the use of apparatus in performing experiments;					
4	demonstrate an understanding of the method used in the study of physics;					
5	present data in various forms, such as tables, graphs, charts, diagrams, and transpose them from one form into another;					
6	analyse and interpret data, and draw appropriate conclusions;					
7	show an understanding of the treatment of errors;					
8	select, organize, and communicate information clearly, precisely and logically;					
9	demonstrate understanding of the applications of physics to daily life and its contributions to the modern world;					
10	show awareness of the ethical, moral, social, economic and technological implications of physics, and critically evaluate physics-related issues; and					

11	make suggestions, choices and judgments based on the examination of evidence using knowledge and principles of physics.					

Meeting other learning outcomes?

	Item	1	2	3	4	N/A
12	Catering for learner diversity					
13	Develop interest and arouse curiosity among students					
14	Develop the ability to think scientifically, critically and creatively					
15	Use of IT skills					
16	Develop Inquiry skills					
17	Others (please specify) ________________________________					

III. Amendments, comments and suggestions

Please feel free to mark on the worksheets with red pens.

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<<< End >>>

Appendix E1: Questions extracted from INTEGRATED PROCESS SKILLS TEST II (TIPS II) – English version (Burns, Okey, & Wise, 1985)

Pre-test / Pro-test

Instructions:
Please use a #2 pencil to complete this test. On your **answer sheet** mark the box below the letter of the best answer. Be careful that the answer number is the same as the question number you are answering. Darken each box completely, being careful not to color in any other boxes. Be sure to completely erase any stray marks.

A study of auto efficiency is done. The hypothesis tested is that a gasoline additive will increase auto efficiency. Five identical cars each receive the same amount of gasoline but different amounts of Additive A. They travel the same track until they run out of gasoline. The research team records the number of miles each car travels. How is auto efficiency measured in this study?

1.
A) The time each car runs out of gasoline.
B) The distance each car travels.
C) The amount of gasoline used.
D) The amount of Additive A used.

A class is studying the speed of objects as they fall to the earth. They design an investigation where bags of gravel weighing different amounts will be dropped from the same height. In their investigation which of the following is the hypothesis they would test about the speed of objects falling to earth?

2.
A) An object will fall faster when it is dropped further.
B) The higher an object is in the air the faster it will fall.
C) The larger the pieces of gravel in a bag the faster it will fall.
D) The heavier an object the faster it will fall to the ground.

A police chief is concerned about reducing the speed of autos. He thinks several factors may affect the automobile speed. Which of the following is a hypothesis he could test about how fast people drive?

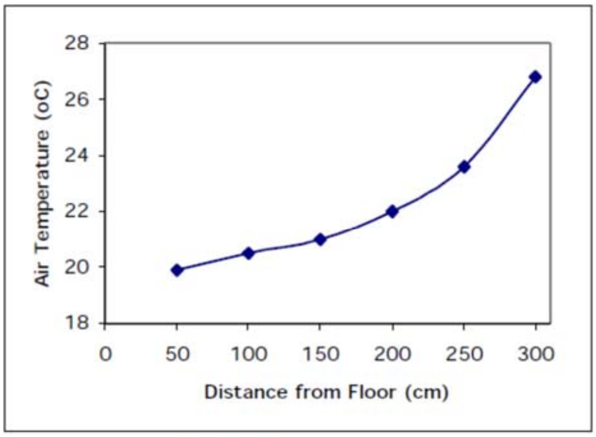
3.
A) The younger the drivers, the faster they are likely to drive.
B) The larger the autos involved in an accident, the less likely people are to get hurt.
C) The more policemen on patrol, the fewer the number of auto accidents.
D) The older the autos the more accidents they are likely to be in.

A science class is studying the effect of wheel width on ease of rolling. The class puts wide wheels onto a small cart and lets it roll down an inclined ramp and then across the floor. The investigation is repeated using the same cart but this time fitted with narrow wheels.
How could the class measure ease of rolling?

4.
A) Measure the total distance the cart travels.
B) Measure the angle of the inclined ramp.
C) Measure the width of each of the two sets of wheels.
D) Measure the weight of each of the carts.

5. A study is done of the temperature in a room at different distances from the floor. The graph of the data is shown below.

How are the variables related?



A) As distance from the floor increases, air temperature decreases.

B) As distance from the floor increases, air temperature increases.

C) An increase in air temperature means a decrease in distance from the floor.

D) The distance from the floor is not related to air temperature increases.

6. Jim thinks that the more air pressure in a basketball, the higher it will bounce. To investigate this hypothesis he collects several basketballs and an air pump with a pressure gauge.

How should Jim test his hypothesis?

A) Bounce basketballs with different amounts of force from the same height.

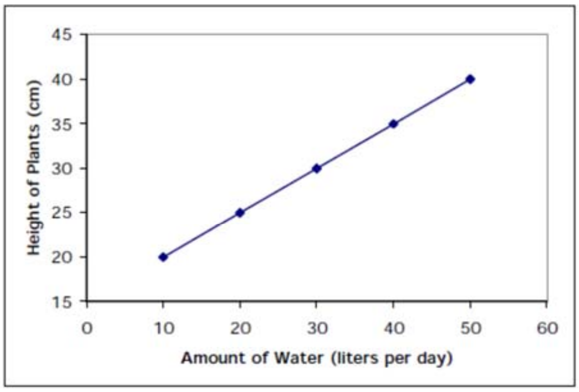
B) Bounce basketballs having different air pressures from the same height.

C) Bounce basketballs having the same air pressure at different angles from the floor.

D) Bounce basketballs having the same amount of air pressure from different heights.

7. A study is being done on the amount of water needed to grow plants. Five small garden plots are given different amounts of water. After two months the height of the plants is measured. The data are shown on the graph.

What is the relationship between the variables?



A) Increasing the amount of water increases the height of the plants.

B) Increasing the height of the plants increases the amount of water.

C) Decreasing the amount of water increases the height of the plants.

D) Decreasing the height of the plants decreases the amount of water.

Questions 8-11

Joe wanted to find out if the temperature of water affected the amount of sugar that would dissolve in it. He put 50 mL of water into each of four identical jars. He changed the temperatures of the jars of water until he had one at 0^{o}C, one at 50^{o}C, one at 75^{o}C, and one at 95^{o}C. He then dissolved as much sugar as he could in each jar by stirring.

8. What is the hypothesis being tested?

   A) The greater the amount of stirring, the greater the amount of sugar dissolved.
   B) The greater the amount of sugar dissolved, the sweeter the liquid.
   C) The higher the temperature, the greater the amount of sugar dissolved.
   D) The greater the amount of water used, the higher the temperature.

9. What is a controlled variable in Joe's study?

   A) Amount of sugar dissolved in each jar.
   B) Amount of water placed in each jar.
   C) Number of jars used to hold water.
   D) The temperature of the water.

10. What is the dependent or responding variable in Joe's study?

   A) Amount of sugar dissolved in each jar.
   B) Amount of water placed in each jar.
   C) Number of jars used to hold water.
   D) The temperature of the water.

11. What is the independent or manipulated variable in Joe's study?

   A) Amount of sugar dissolved in each jar.
   B) Amount of water placed in each jar.
   C) Number of jars used to hold water.
   D) The temperature of the water.

12. Lisa wants to measure the amount of heat energy a flame will produce in a certain amount of time. A burner will be used to heat a beaker containing a liter of cold water for ten minutes.
How will Lisa measure the amount of heat energy produced by the flame?

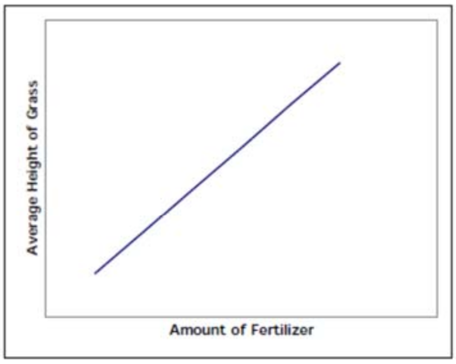
   A) Note the change in water temperature after ten minutes.
   B) Measure the volume of water after ten minutes.
   C) Measure the temperature of the flame after ten minutes.
   D) Calculate the time it takes for the liter of water to boil.

13. A researcher is testing a new fertilizer. Five small fields of the same size are used. Each field receives a different amount of fertilizer. One month later the average height of the grass in each is measured. The measurements are shown in the table below.

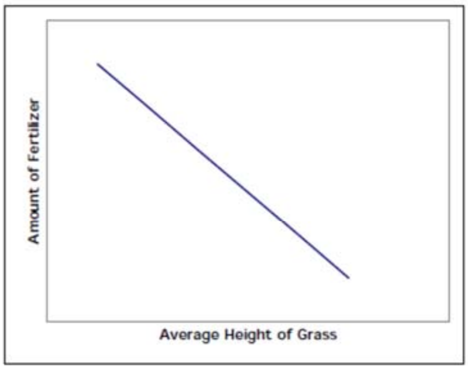
Amount of Fertilizer (kg)	Average Height of Grass (cm)
10	7
30	10
50	12
80	14
100	12

Which graph represents the data in the table?

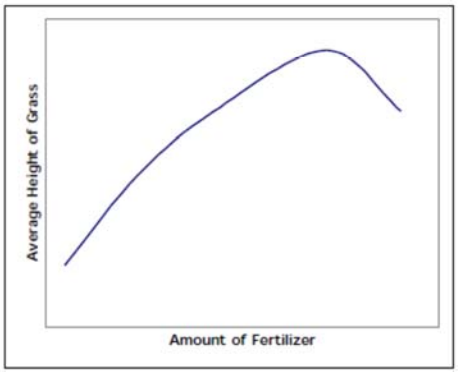
A)



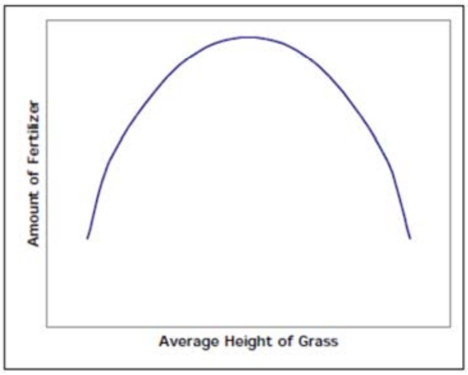
B)



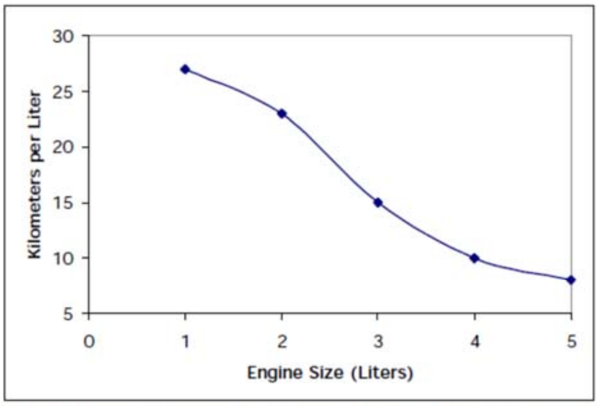
C)



D)



14. A consumer group measures the miles per gallon cars get with different size engines. The results are as follows:



Which of the following describes the relationship between the variables?

A) The larger the engine the more miles per gallon the car gets.

B) The fewer miles per gallon the car gets the smaller the engine.

C) The smaller the engine the more miles per gallon a car gets.

D) The more miles per gallon for a car the larger the engine.

Appendix E2: Mechanics Survey questions extracted from the Force Concept Inventory (FCI) – English version (Huffman, and Heller, 1995)

Pre-test / Pro-test

Put the right answer in the boxes below.

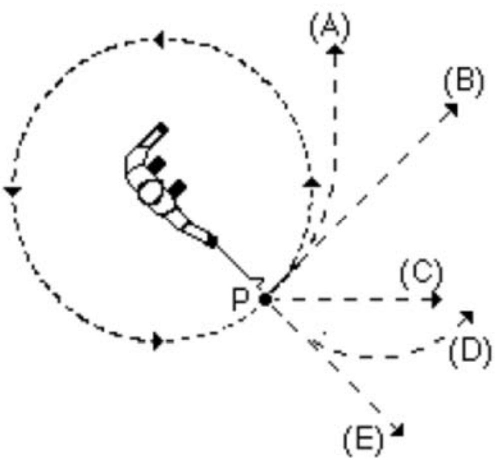
1	2	3	4	5	6	7	8	9	10	11	12

1. Two metal balls are the same size but one weighs twice as much as the other. The balls are dropped from the roof of a single story building at the same instant of time. The time it takes the balls to reach the ground below will be:
   (A) about half as long for the heavier ball as for the lighter one.
   (B) about half as long for the lighter ball as for the heavier one.
   (C) about the same for both balls.
   (D) considerably less for the heavier ball, but not necessarily half as long.
   (E) considerably less for the lighter ball, but not necessarily half as long.

2. A stone dropped from the roof of a single story building to the surface of the earth:
   (A) reaches a maximum speed quite soon after release and then falls at a constant speed thereafter.
   (B) speeds up as it falls because the gravitational attraction gets considerably stronger as the stone gets closer to the earth.
   (C) speeds up because of an almost constant force of gravity acting upon it.
   (D) falls because of the natural tendency of all objects to rest on the surface of the earth.
   (E) falls because of the combined effects of the force of gravity pushing it downward and the force of the air pushing it downward.

3. A large truck collides head-on with a small compact car. During the collision:
   (A) the truck exerts a greater amount of force on the car than the car exerts on the truck.
   (B) the car exerts a greater amount of force on the truck than the truck exerts on the car.
   (C) neither exerts a force on the other, the car gets smashed simply because it gets in the way of the truck.
   (D) the truck exerts a force on the car but the car does not exert a force on the truck.
   (E) the truck exerts the same amount of force on the car as the car exerts on the truck.

4. A steel ball is attached to a string and is swung in a circular path in a horizontal plane as illustrated in the accompanying figure.
   At the point P indicated in the figure, the string suddenly breaks near the ball.
   If these events are observed from directly above as in the figure, which path would the ball most closely follow after the string breaks?



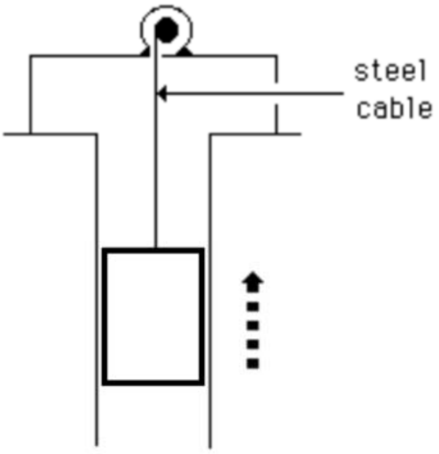
USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT TWO QUESTIONS (5 and 6).

A large truck breaks down out on the road and receives a push back into town by a small compact car as shown in the figure below.

5. While the car, still pushing the truck, is speeding up to get up to cruising speed:
   (A) the amount of force with which the car pushes on the truck is equal to that with which the truck pushes back on the car.
   (B) the amount of force with which the car pushes on the truck is smaller than that with which the truck pushes back on the car.
   (C) the amount of force with which the car pushes on the truck is greater than that with which the truck pushes back on the car.
   (D) the car's engine is running so the car pushes against the truck, but the truck's engine is not running so the truck cannot push back against the car. The truck is pushed forward simply because it is in the way of the car.
   (E) neither the car nor the truck exert any force on the other. The truck is pushed forward simply because it is in the way of the car.

6. After the car reaches the constant cruising speed at which its driver wishes to push the truck:
   (A) the amount of force with which the car pushes on the truck is equal to that with which the truck pushes back on the car.
   (B) the amount of force with which the car pushes on the truck is smaller than that with which the truck pushes back on the car.
   (C) the amount of force with which the car pushes on the truck is greater than that with which the truck pushes back on the car.
   (D) the car's engine is running so the car pushes against the truck, but the truck's engine is not running so the truck cannot push back against the car. The truck is pushed forward simply because it is in the way of the car.
   (E) neither the car nor the truck exert any force on the other. The truck is pushed forward simply because it is in the way of the car.

7. An elevator is being lifted up an elevator shaft at a constant speed by a steel cable as shown in the figure below. All frictional effects are negligible. In this situation, forces on the elevator are such that:
   (A) the upward force by the cable is greater than the downward force of gravity.
   (B) the upward force by the cable is equal to the downward force of gravity.
   (C) the upward force by the cable is smaller than the downward force of gravity.
   (D) the upward force by the cable is greater than the sum of the downward force of gravity and a downward force due to the air.
   (E) none of the above. (The elevator goes up because the cable is being shortened, not because an upward force is exerted on the elevator by the cable).

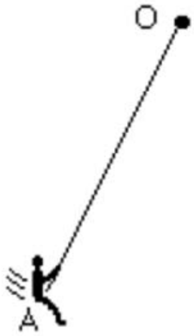


Elevator going up
at constant speed

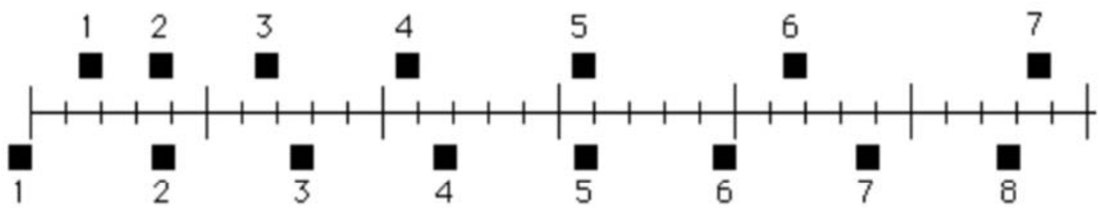
8. The figure below shows a boy swinging on a rope, starting at a point higher than A.
Consider the following distinct forces:
   1. A downward force of gravity.
   2. A force exerted by the rope pointing from A to O.
   3. A force in the direction of the boy's motion.
   4. A force pointing from O to A.

Which of the above forces is (are) acting on the boy when he is at position A?

(A) 1 only.
(B) 1 and 2.
(C) 1 and 3.
(D) 1, 2, and 3.
(E) 1, 3, and 4.



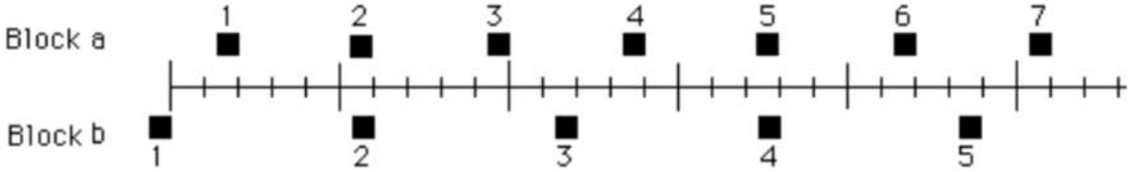
9. The positions of two blocks at successive 0.20-second time intervals are represented by the numbered squares in the figure below. The blocks are moving toward the right.



Do the blocks ever have the same speed?

(A) No.
(B) Yes, at instant 2.
(C) Yes, at instant 5.
(D) Yes, at instants 2 and 5.
(E) Yes, at some time during the interval 3 to 4.

10. The positions of two blocks at successive 0.20-second time intervals are represented by the numbered squares in the figure below. The blocks are moving toward the right.



The accelerations of the blocks are related as follows:

(A) The acceleration of "a" is greater than the acceleration of " b".

(B) The acceleration of "a" equals the acceleration of "b". Both accelerations are greater than zero.

(C) The acceleration of "b" is greater than the acceleration of "a".

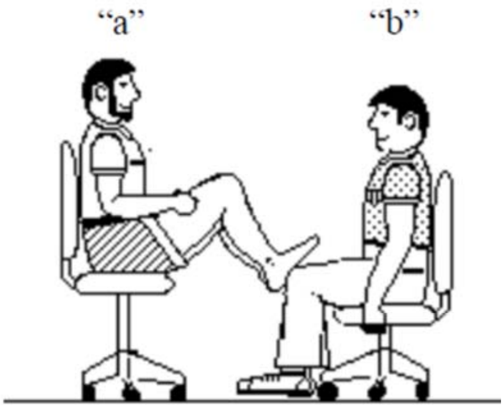
(D) The acceleration of "a" equals the acceleration of "b". Both accelerations are zero.

(E) Not enough information is given to answer the question.

11. In the figure at right, student "a" has a mass of 95 kg and student "b" has a mass of 77 kg. They sit in identical office chairs facing each other.

Student "a" places his bare feet on the knees of student "b", as shown. Student "a" then suddenly pushes outward with his feet, causing both chairs to move.

During the push and while the students are still touching one another:



(A) neither student exerts a force on the other.

(B) student "a" exerts a force on student "b", but "b" does not exert any force on "a".

(C) each student exerts a force on the other, but "b" exerts the larger force.

(D) each student exerts a force on the other, but "a" exerts the larger force.

(E) each student exerts the same amount of force on the other.

12. An empty office chair is at rest on a floor. Consider the following forces:

1. A downward force of gravity.
2. An upward force exerted by the floor.
3. A net downward force exerted by the air.

Which of the forces is (are) acting on the office chair?

(A) 1 only.

(B) 1 and 2.

(C) 2 and 3.

(D) 1, 2, and 3.

(E) none of the forces. (Since the chair is at rest there are no forces acting upon it.)

Appendix F1: Consent Form for Hong Kong participants

THE EDUCATION UNIVERSITY OF HONG KONG
Department of Science and Environmental Studies
CONSENT TO PARTICIPATE IN RESEARCH
The effectiveness of using open-source digital platform for practical work in the New Senior Secondary (NSS) Science education

I ______________________ hereby consent to my child participating in the captioned research supervised by Professor YEUNG Yau Yuen and conducted by Mr WONG Shek Nin, who is an EdD candidate of Department of Science and Environmental Studies in The Education University of Hong Kong.

I understand that information obtained from this research may be used in future research and may be published. However, our right to privacy will be retained, i.e., the personal details of my child will not be revealed.

The procedure as set out in the **attached** information sheet has been fully explained. I understand the benefits and risks involved. My child's participation in the project is voluntary.

I acknowledge that we have the right to question any part of the procedure and can withdraw at any time without negative consequences.

For participants of age above 18:

Name of participant ______________________

Signature of participant ______________________

Date ______________________

For participants of age below 18:

Name of participant ______________________

Signature of participant ______________________

Name of Parent or Guardian ______________________

Signature of Parent or Guardian ______________________

Date ______________________

INFORMATION SHEET

The effectiveness of using open-source digital platform for practical work in the New Senior Secondary (NSS) Science education

You are invited to participate with your child in a project supervised by Professor YEUNG Yau Yuen and conducted by Mr WONG Shek Nin, who is an EdD candidate of the Department of Science and Environmental Studies in The Education University of Hong Kong.

In this study, open-source hardware and software using the Arduino technology had been developed and the effectiveness of using this open-source digital platform for practical work in the New Senior Secondary (NSS) Science education would be investigated. Seven Arduino-based experiments on the topic of "Mechanics" have been developed and the experiments will be integrated into the existing NSS syllabus as an Intervention Programme. The objectives of this research aim at:

(a) investigating how the open source hardware and software can be put into good use in developing courseware for the learning and teaching of Physics at senior secondary level.
(b) searching for factors which would affect the effective use of the open source digital platform in students' learning of science.

The participation in the study is voluntary. The participants have every right to withdraw from the study at any time without negative consequences. All information related to the participants will remain confidential, and will be identifiable by codes known only to the researcher.

The summary of the results will be given to EdUHK as parts of the project completion report which is required by the funding body. Besides, some parts of conclusions will be published in conference papers, journals as well as books in order to make some contributions for teaching and learning in science education.

If you would like to obtain more information about this study, please contact Mr WONG Shek Nin at [redacted] or the Principal Investigator, Professor YEUNG Yau Yuen at 29487650.

If you have any concerns about the conduct of this research study, please do not hesitate to contact the Human Research Ethics Committee by email at hrec@eduhk.hk or by mail to Research and Development Office, The Education University of Hong Kong.

Thank you for your interest in participating in this study.
Professor Yeung, Yau Yuen
Principal Investigator

Appendix F2: Consent Form for Singaporean teachers in the OEIR Programme

Outstanding-Educator-In-Residence (OEIR) Master Class by Mr Wong Shek Nin
Questionnaire Survey on Arduino-Based Science Activities
CONSENT FORM

Dear teacher,

You are invited to complete a questionnaire survey on Arduino-based science activities from the Outstanding-Educator-In-Residence (OEIR) Master Class by Mr Wong Shek Nin.
The survey will be conducted after the segment on Arduino to collect feedback on the application of Arduino platform in secondary schools.
The data and information collected from this survey will be kept strictly confidential, and used in the OEIR's research thesis titled The Effectiveness of Using an Open Source Digital Platform for Practical Work in Senior Secondary Science Education, for the purposes of research, development and evaluation of course materials.

Consent

This is to certify that I, (name) ________________________, teacher at (school name) _________________________, hereby consent to participate in this survey.

Signature : ____________________ Date: ___________________

If you do NOT wish to give consent, sign here _______________________

Appendix G1: Revised worksheet on Arduino-based experiment – Chinese version

Arduino 實驗 #1

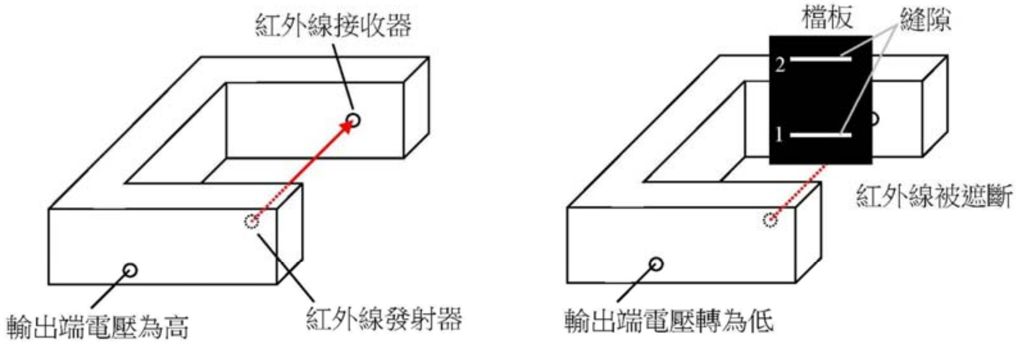
實驗	光閘實驗
姓名	
日期	
班別/班號	
分組	
積分	/10

1. **實驗儀器**：

Arduino 光閘實驗裝置	1
光閘 (4度縫隙、3度縫隙)	各1
吸震海綿或報紙球	1
紙箱	1
直尺(30cm)	1
Blu tack (寶貼萬用膠)	數片

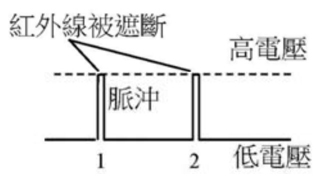
2. **甚麼是光閘 (Photo-gate)?**：

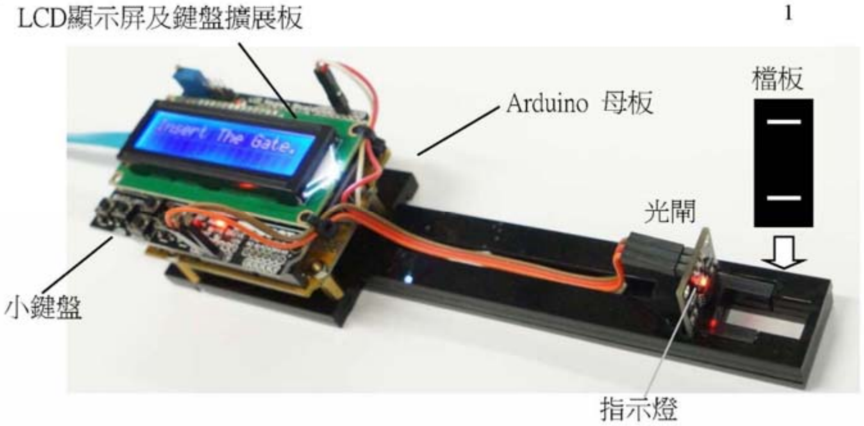
光閘是一個U形的電子零件，一端裝有紅外線發射器，其發出的光正好投射在另一面的紅外線接收器之上。當有物件遮檔著光線時，輸出電壓便會由低轉高。



3. **將光閘連接至 Arduino 微控制器**：

實驗用的光閘的輸出端已連接至 Arduino 微控制器的輸入端，而微控制器之上已加裝一塊LCD顯示屏及鍵盤擴展板。當一塊切割有多個縫隙的黑色檔板經過時，Arduino內置的程式便會記錄每次光線經過縫隙的一刻，時間以微秒 (μs, 1μs=10^{-6}s) 顯示。

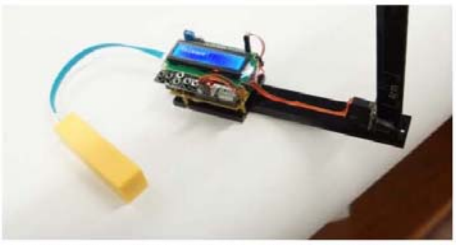


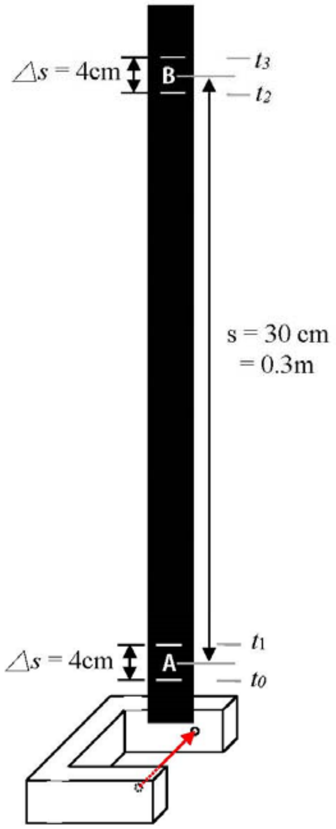


4. 實驗一：由兩點速度計算加速度

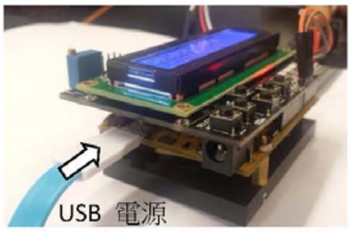
4.1 步驟：

- 用萬用寶貼將Arduino 裝置固定於桌面，光閘部份盡量伸延出桌面。





- 在光閘下的紙箱內放置一片吸震海綿，以防檔板摔碎。
- 檔板刻有兩組縫隙，每組縫隙間距為4cm，A、B分別為兩組縫隙的中點，而AB的距離為30cm。
- 如下圖所示插上USB電源，線路會發出「嘟-嘟」兩聲，表示程式已開始運作。



- 將檔板的其中一端插入光閘內，讓黑位遮擋著紅外線，光閘的指示燈應會立即熄滅，而線路會發出「嘟」一聲。暫時手持不釋放。
- 釋放檔板，讓其自由下墮，穿過光閘。注意不要讓檔板觸碰到光閘。
- 檔板經過光閘時，Arduino 已自動讀取四度縫隙經過的時間，時間分別是 t_0、t_1、t_2及t_3。
- 當檔板離開光閘後，可按下「UP」或 「DOWN」鍵分別查看t_0、t_1、t_2、t_3的數值。

"UP" & DOWN 上、下

"Select" 選擇

"RST" - 重置

4.2 記錄時間：錄得的時間是以秒(s)顯示，請取4個有效位。

時間(4個有效位)/ s	時間差 / s	平均時間 / s
t_0 =	$Q = (t_1 - t_0)$	$S=\left(\frac{t_1+t_0}{2}\right)$ = ________
t_1 =	= ________	
t_2 =	$P = (t_3 - t_2)$	$R=\left(\frac{t_3+t_2}{2}\right)$ = ________
t_3 =	= ________	

4.3 計算速度：

A及B點的平均速度可分別由兩組縫隙的間距(Δs)除以時間差(Δt)得出： $v = \frac{\Delta s}{\Delta t}$

A點平均初速 $u = \frac{0.04}{t_1 - t_0} = u = \frac{0.04}{Q}$ = ―――――――――― = ______ (m s^{-1})

(4cm轉為0.04m)

B點平均末速 $v = \frac{0.04}{t_3 - t_2} = v = \frac{0.04}{P}$ = ―――――――――― = ______ (m s^{-1})

4.4 計算加速度的實驗值：

加速度 a 是指每單位時間的速度變化，所以

$$a = \frac{v-u}{t} = \frac{v-u}{\left(\frac{t_3+t_2}{2}\right)-\left(\frac{t_1+t_0}{2}\right)} = \frac{v-u}{R-S}$$

B組兩縫隙經過光閘的平均時間

A組兩縫隙經過光閘的平均時間

= ―――――――――――――――― = ____________ (ms^{-2})

4.5 物件自由下墮的加速度，或稱引力加速度，以"**g**"表示，標準值為9.81 ms^{-2} 。實驗所得的數值與標準值相差多少個百份點?

誤差百份比 = $\frac{\text{實驗值}-\text{標準值}}{\text{標準值}}$x100% = $\frac{\quad - \quad}{\quad}$ x100%

= ____________ %

4.6 有甚麼原因會導致誤差? 應如何作出改善?

____

____

___

___

4.7 按下 "Select" 鍵重新開始實驗，但今次嘗試在檔板放入光閘後，稍為向下推壓檔板，讓它不是由靜止開始下墮。重新計算加速度，a_1。

時間(4個有效位)/ s	時間差 / s	平均時間 / s
t_0 =	$Q = (t_1 - t_0)$	$S=\left(\frac{t_1+t_0}{2}\right)$ = ________
t_1 =	= ________	
t_2 =	$P = (t_3 - t_2)$	$R=\left(\frac{t_3+t_2}{2}\right)$ = ________
t_3 =	= ________	

A點平均初速 $u = \frac{0.04}{t_1-t_0} = u = \frac{0.04}{Q} = \underline{\qquad\qquad\qquad} = \underline{\qquad}$ (m s^{-1})
(4cm轉為0.04m)

B點平均末速 $v = \frac{0.04}{t_3-t_2} = v = \frac{0.04}{P} = \underline{\qquad\qquad\qquad} = \underline{\qquad}$ (m s^{-1})

$$a_1 = \frac{v-u}{t} = \frac{v-u}{\left(\frac{t_3+t_2}{2}\right)-\left(\frac{t_1+t_0}{2}\right)} = \frac{v-u}{R-S}$$

$$= \underline{\qquad\qquad\qquad\qquad} = \underline{\qquad\qquad} \ (ms^{-2})$$

4.8 問4.7的與4.4 分別算得的 a_1 及 a 有沒有顯著的差別? 為甚麼?

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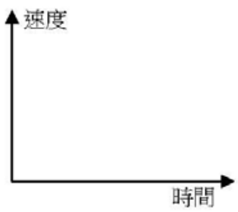
___

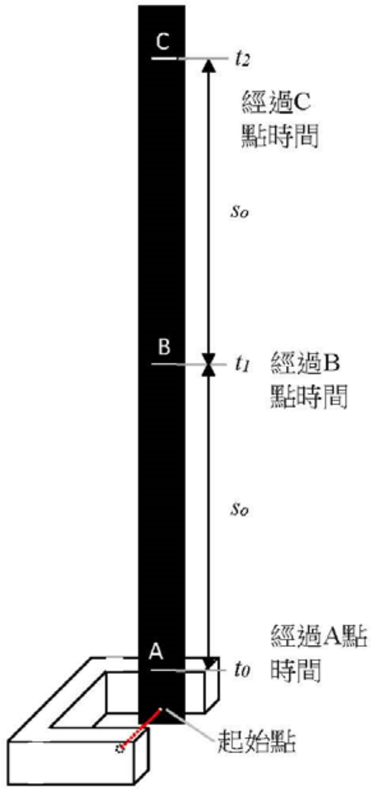
4.9 試在同一幅圖中簡繪 4.4 與 4.7 的「速度-時間關係圖」。在兩線加上標誌。



5. **挑戰實驗: 以三縫隙檔板計算加速度 (最高可額外取3分)**

5.1 步驟：

- 採用另一檔板重覆實驗，檔板刻有三度等距的縫隙，分別是A、B 及 C。
- 用直尺量度縫隙的間距，s_o
- 按下母板的 "Select"鍵以重置程式。
- 將檔板的其中一端插入光閘內，"嘟"一聲之後釋放檔板，讓其自由下墮，穿過光閘。
- 當檔板離開光閘後，可按下「UP」或 「DOWN」鍵查看三度縫隙經過的時間，分別記錄 t_0、t_1、t_2 的數值。



5.2 記錄：

s_o = ______________ (m)

t_0= ______________ (s)

t_1= ______________ (s)

t_2= ______________ (s)

5.3 算式推論：

假設在起始時，檔板放置在第一度縫隙下的任意一點，由靜止(u=0) 開始自由下墜，當經過第一度(A)、第二度(B)及第三度(C)縫隙時，時間分別為 t_0, t_1及t_2，而檔板的的速度分別增加至u_0, u_1及 u_2。

根據運動公式： $s = ut + \frac{1}{2} at^2$ ----- (1)
及 $v = u + at$ ----- (2)

其中 s = 位移; u = 初速; v = 未速;
g = 重力加速度; t = 時間 s_o = 兩條縫隙之間的距離

AB段： $s_o = u_o(t_1 - t_o) + \frac{1}{2} g(t_1 - t_o)^2$ ----(3)
$u_1 = u_o+g(t_1-t_o)$ ----(4)

BC段： $s_o = u_1(t_2 - t_1) + \frac{1}{2} g(t_2 - t_1)^2$ ----(5)

5.4 計算引力加速度的實驗值：：$g = \frac{2s_0(2t_1-t_2-t_0)}{(t_2-t_1)(t_1-t_0)(t_2-t_0)}$

$A = 2t_1 - t_2 - t_0 =$ ______________________________ = ______

$B = (t_2 - t_1) =$ ______________(s)

$C = (t_1 - t_0) =$ ______________(s)

$D = (t_2 - t_0) =$ ______________(s)

$$g = \frac{2 \times s_0 \times A}{B \times C \times D} = \frac{2 \times \qquad\qquad \times \qquad\qquad}{\qquad \times \qquad\qquad \times \qquad}$$

= ________________________________(m s^{-2})

實驗值比標準值(9.81 ms^{-2})誤差百份比 = ____

5.5 超級挑戰題：由公式(3)、(4)及(5)，證明：$g = \frac{2s_0(2t_1-t_2-t_0)}{(t_2-t_1)(t_1-t_0)(t_2-t_0)}$

____

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5.6 如何可以改善實驗的準確度？試簡述措施原因？

____

____

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<<< 實驗完 >>>

Appendix G2: Revised worksheet on Arduino-based experiment – Chinese version

實驗	**光閘探究實驗**
姓名	
日期	
班別/班號	
分組	
積分	/10

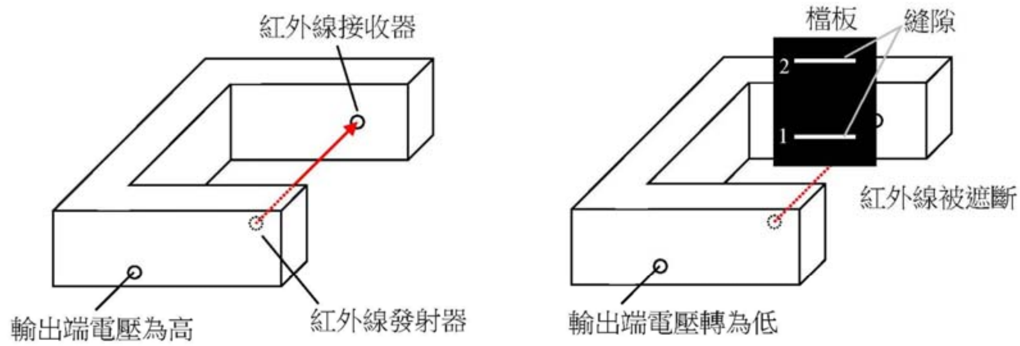
Arduino 實驗 #1B

1. **實驗儀器**：

Arduino 光閘實驗裝置	1
光閘 (2度縫隙)	1
吸震海綿或報紙球	1
紙箱	1
直尺(30cm)	1
Blu tack (寶貼萬用膠)	數片

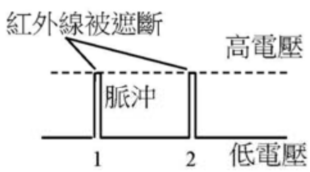
2. **甚麼是光閘 (Photo-gate)?**：

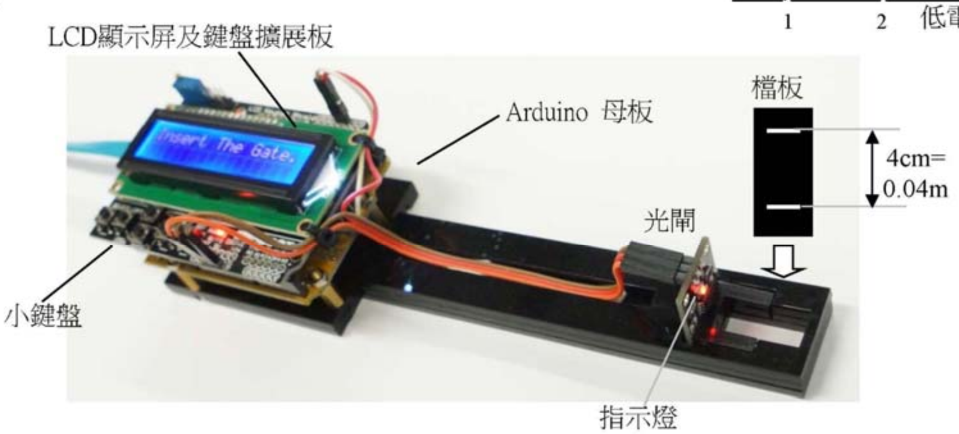
光閘是一個U形的電子零件，一端裝有紅外線發射器，其發出的光正好投射在另一面的紅外線接收器之上。當有物件遮檔著光線時，輸出電壓便會由低轉高。



3. **將光閘連接至 Arduino 微控制器**：

實驗用的光閘的輸出端已連接至 Arduino 微控制器的輸入端，而微控制器之上已加裝一塊LCD顯示屏及鍵盤擴展板。當一塊切割有多個縫隙的黑色檔板經過時，Arduino內置的程式便會記錄每次光線經過縫隙的一刻，時間以微秒 (μs, 1μs=10^{-6}s) 顯示。

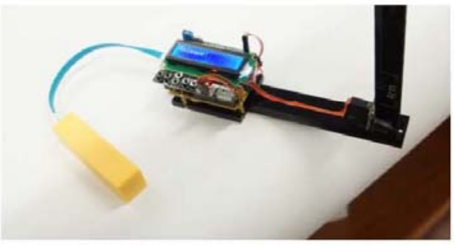


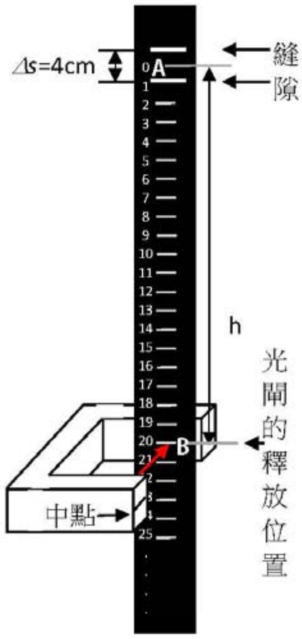


4. 實驗：物體的末速（v）與物體釋放的高度(h) 有何關係?

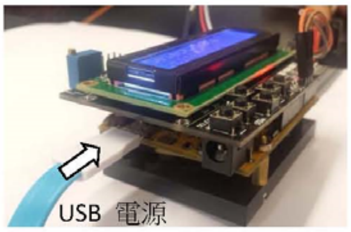
4.1 步驟：

- 用萬用寶貼將Arduino 裝置固定於桌面，光閘部份盡量伸延出桌面。





- 在光閘下的紙箱內放置一片吸震海綿，以防檔板摔碎。
- 檔板刻有一組縫隙，縫隙的間距為4cm，A為縫隙的中點，而檔板釋放的位置B點，是位於A點以下，距離A點 h cm。
- 如下圖所示插上USB電源，線路會發出「嘟-嘟」兩聲，表示程式已開始運作。



光閘中點

- 將檔板的其末端插入光閘內，讓黑位遮檔著紅外線，光閘的指示燈應會立即熄滅，而線路會發出「嘟」一聲。上下移動檔板直至光閘的中點(釋放紅線射的位置) 落在B點上。第一次將釋放距離調至 h = 30 cm 位置。
- 穩持檔板然後釋放，讓它由靜止開始自由下墮穿過光閘。注意不要讓檔板觸碰到光閘。
- 檔板經過光閘時，Arduino 已自動讀取兩度縫隙經過的時間，時間分別是 t_0及t_1。
- 當檔板離開光閘後，可按下「UP」或 「DOWN」鍵分別查看t_0及t_1的數值。

"UP" & DOWN 上、下

"Select" 選擇

"RST" - 重置

4.2 在不同釋放高度的情況下，記錄縫隙經過光閘的時間，LCD上的時間是以秒(s)顯示，請取**4個有效位**。計算A點的平均速度。以不同的釋放高度重覆實驗，將數據填入下表：

次數	釋放高度 h /m	t_o /s	t_1 /s	$(t_1 - t_0)$ /s	A點的平均速度 $v = 0.04/(t_1 - t_0)$ /m s^{-1}	v^2 / m^2 s^{-2}
1	0.30					
2	0.25					
3	0.20					
4	0.15					
5	0.10					
6	0.05					

4.3 (a) v 與 h 之中, 那項是獨立變項，那項是應變項?

____

(b) 繪製v與h的關係圖時，v 應放於 _______ (x或y?)軸；而h 應放於 _______ (x或y?)軸。

4.4 在下圖繪畫速度 v 與釋放高度 h 的關係圖。(需註明x,y軸代表甚麼變項及其單位；適當地在x,y軸上劃上刻度；盡用方格紙空間。)

4.5 從圖中所見，v 與 h 成正比關係嗎? 試解釋原因。

4.6 在4.2的表格中，計算末速的平方，v^2，取三個有效位。將 v^2 填入最右方一行。

4.7 在下圖繪畫速度 v^2 與釋放高度 h 的關係圖。

4.8 從以上線圖中，v 與 h 有甚麼關係?

4.9 以上實驗，有甚麼原因會導致誤差? 應如何作出改善?

<<< 實驗完結>>>

Appendix G3: Revised worksheet on Arduino-based experiment – Chinese version

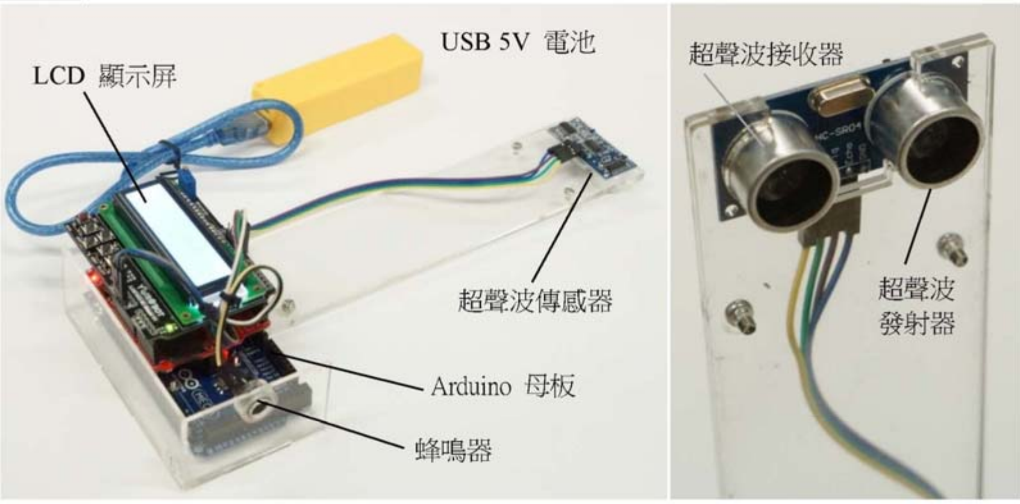
Arduino 實驗 #2

實驗	**彈跳球**
姓名	
日期	
班別/班號	
分組	
積分	

1. **實驗儀器**：

Arduino 運動感應器實驗裝置 (母板+SD咭+超聲波傳感器+USB電池) 1組
電腦 (內置 EXCEL 範本檔案) 1台
SD 咭讀咭器 1枚
彈跳球 (充滿氣之籃球或足球) 1個
萬寶貼 數片

2. **實驗裝置**：



2.1 測距及測速原理

超聲波發射器送出的聲波被物件反射後返回接收器，而Arduino 內置的程式量度聲波往返的時間，又已知上聲音在空氣傳播的速度為330ms^{-1}，便可計算傳感器與物件的距離。換能器能在1秒鐘內探測物件的位置超過100次，而每兩點之間的平均速度 v 可由兩點的位移差除以時間差計算得出。

2.2 擷取數據

- 以萬寶貼將實驗裝置固定在桌子邊旁，把傳感器向下伸出桌外， 如上圖所示。
- 開始實驗前，先在Arduino母板插入SD咭，不要將SD咭上鎖。
- 插上Arduino 母板USB電源，如已正常插入SD咭，LCD屏會顯示："Press Select ..."；否則LCD屏會提示："Please Insert SD"，此刻將咭插入便可。
- 將球放於超聲波傳感器正下方，距離約5cm的位置。
- 按下Select鍵後，LCD屏會顯示："Release after the 3rd beep"，你將會到三聲響鬧。

- LCD屏邊響鬧邊顯示："3"、"2"、"1"，三聲"必"聲過後，當看到"Release Now"出現便立即將球釋放。

- 大約在3秒後，母板便會自動停止收集數據。此時LCD屏會顯示儲存檔案的文件夾及檔名如下："BALL/BALLx, Press UP to continue"，示表資料已寫入SD 咭中。
- 按"UP"鍵可重覆實驗或關掉(拔掉)Arduino 母板電源停止實驗。
- 警告：資料寫入途中，切勿取出SD 咭，會嚴重損壞該咭。

2.3 <u>數據處理</u>

- 從Arduino 母板取出SD咭。
- 將SD咭插入電腦，SD咭儲存檔為原始檔，以Excel開啟SD咭內"Ball"文件夾的<u>最後</u>檔案，檔案名稱為 "ballxx.csv"；xx 為檔名順序，檔案越後，數字越大。
- 檔案記錄了兩欄資料，分別如下：
  (1) 欄A：Time, t, 以s (秒)表示；
  (2) 欄B：Distance , s, 球的頂點離開傳感器的距離，以 m (米)表示。
- 選取SD咭檔案內的A至B行資料，按Ctrl-C複製兩行資料。

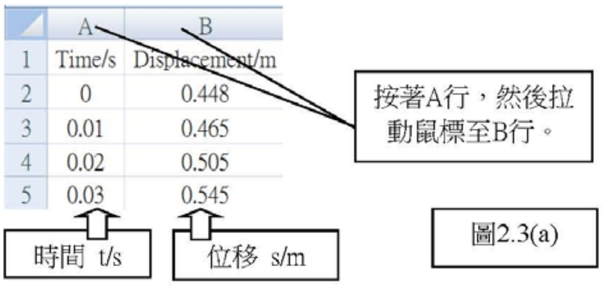
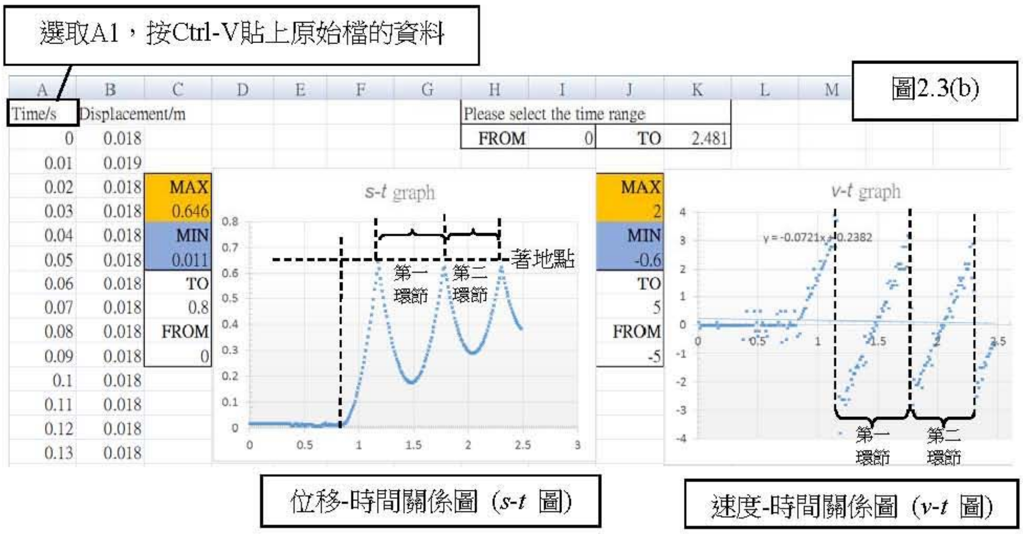
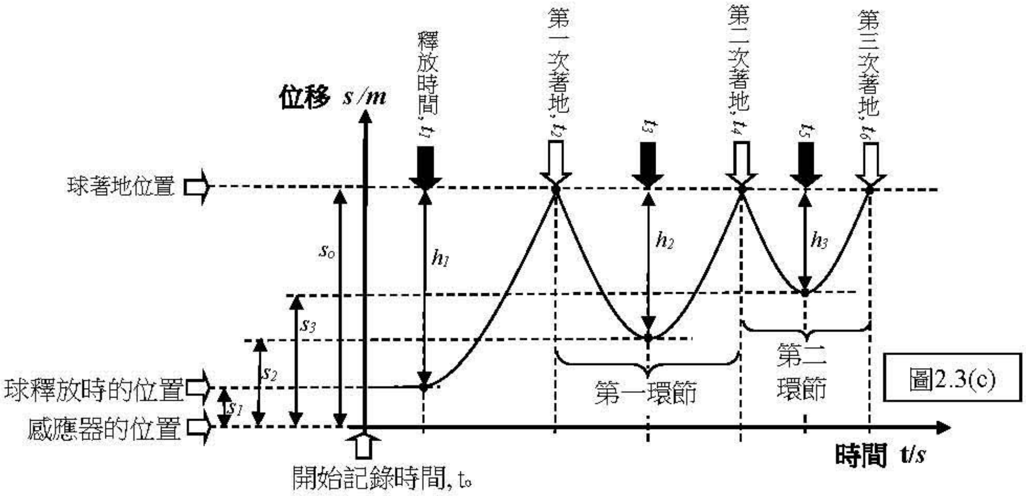


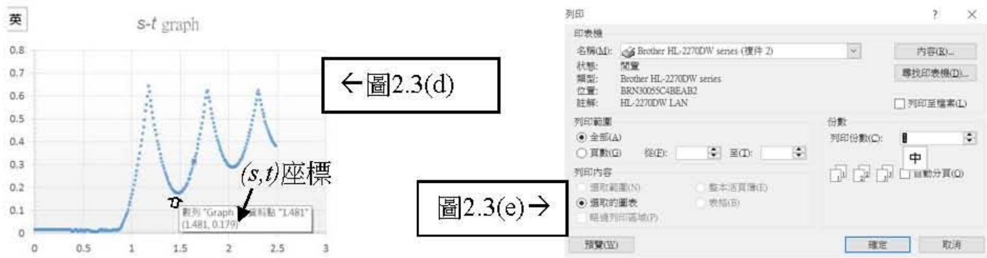
圖2.3(a)

- 開啟桌面上的Excel範本檔案 (Bouncing Ball_temp.xlsx)
- 選取方格A1，按Ctrl-V，在同一位置貼上**原**始檔的兩行資料。
- Excel 檔案內已預設兩圖，會按抄入的資料分別顯示：
  1. 位移-時間關係圖 (Displacement-time curve, ***s-t*** curve)
  2. 速度-時間關係圖 (Velocity-time curve, ***v-t*** curve)





- 在以上的**s–t** 圖中，**以"X"標示哪些點球是處於瞬間靜止的狀態**。
- 點擊excel表內的 ***s–t* 圖** 以選擇該圖，再按Ctrl-P鍵**以<u>橫印格式</u>打印選取的圖表**。



- 如你的電腦沒有連接打印機，請將此Excel檔另存新檔於SD咭內，再到另一電腦打印。要另存檔名，請按 "alt-F" 然後按"A"，改名為"class+class no"，如"4C_4_15_17 "。
- 以相同方法打印 *v-t* 圖表。**列印的圖表連同實驗報告一并呈交**。

2.4 實驗結果：

- 點擊圖2.3(d)的資料點，螢幕會顯示其(s,t)坐標讀數。利用坐標讀數量度以下數據的值：

s_o = ______ m　　s_1= ______ m　　s_2 = ______ m　　s_3 = ______ m

$h_1 = s_o\text{-}s_1$ = ______ m　　$h_2 = s_o\text{-}s_2$ = ______ m　　$h_3 = s_o\text{-}s_3$ = ______ m

- 請解釋為何h_1,h_2,h_3 的高度為何會遞減 ？

____

____

- 如圖3.3(a)及3.3(b)所示，按下下拉清單便可選擇圖線的開始及結束的時段。選擇合適的時段，令線圖**顯示其中一段球體凌空時段**。

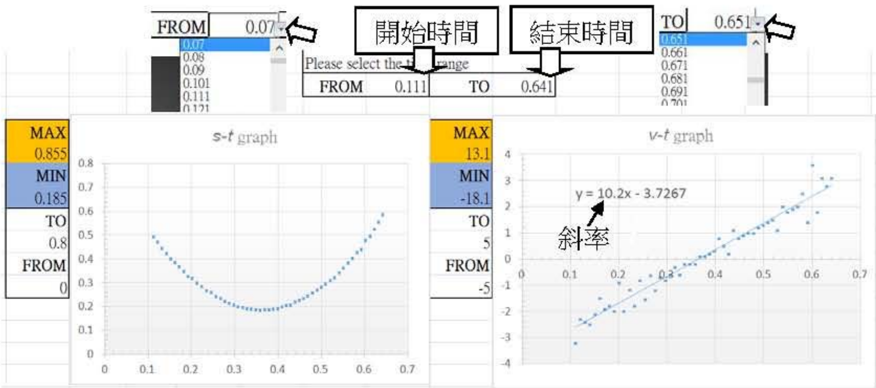


圖3.3(a)　　圖3.3(b)

- Excel會在圖3.3(b)的$v\text{-}t$圖上自動配適一條最佳直線，並計算其斜率。
- $v\text{-}t$圖中，直線的斜率代表自由下墮的引力加速度，acceleration, g 。揀選實驗的不同環節，從斜率計算引力加速度 。實驗值與標準值 9.81ms^{-2} 相差多少個百份點?

環節	斜率 ＝ 引力加速度 g / ms^{-2}	與標準值的誤差率/%
1		
2		

2.5 討論：

- 甚麼原因可能會導致誤差及應如何改善?

____

____

____

____

- 試在右圖簡繪反彈球的**加速度–時間** $(a\text{-}t)$ 關係圖。

- 建議如何稍為改動此實驗裝置，令你可進一步作不同的科學探究? (例：在球及地板之間加入一塊「滑鼠墊」，研究球騰空時的加速度有何不同?)

Appendix G4: Revised worksheet on Arduino-based experiment – Chinese version

Arduino 實驗 #3

P[實驗	**牛頓第二定律**
姓名	
日期	
班別/班號	
分組	
積分	

1. **實驗儀器**：

Arduino 牛頓第二定律實驗裝置 (母板+SD咭+ LCD顯示屏+力傳感器+加速度傳感器+USB電池)	1組
電腦 (內置 EXCEL 範本檔案)	1台
SD 咭讀咭器	1枚
2米軌道	1條
木板小車	1輛
G 鉗 / 海綿	1組
砝碼	100g 3個
電子磅	1台

2. **理論**

一塊木板上同時安裝了**力傳感器**(force sensor)和**加速度傳感器** (acceleration sensor)。木板由一條彈簧牽引，當彈簧釋放時，其長度縮短，作用在木板上的力(F)會隨之而改變，木板的加速度(a)也相應改變。實驗目的就是要得知力(F)與加速度(a)之間的關係。實驗一併研究作用於木板與軌道之間的摩擦力(f)對運動的影響。

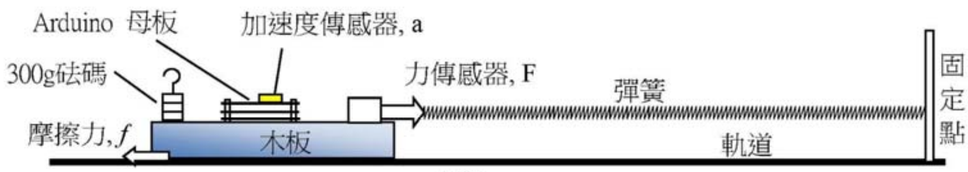


圖2

3 **實驗**

3.1 <u>實驗裝置</u>

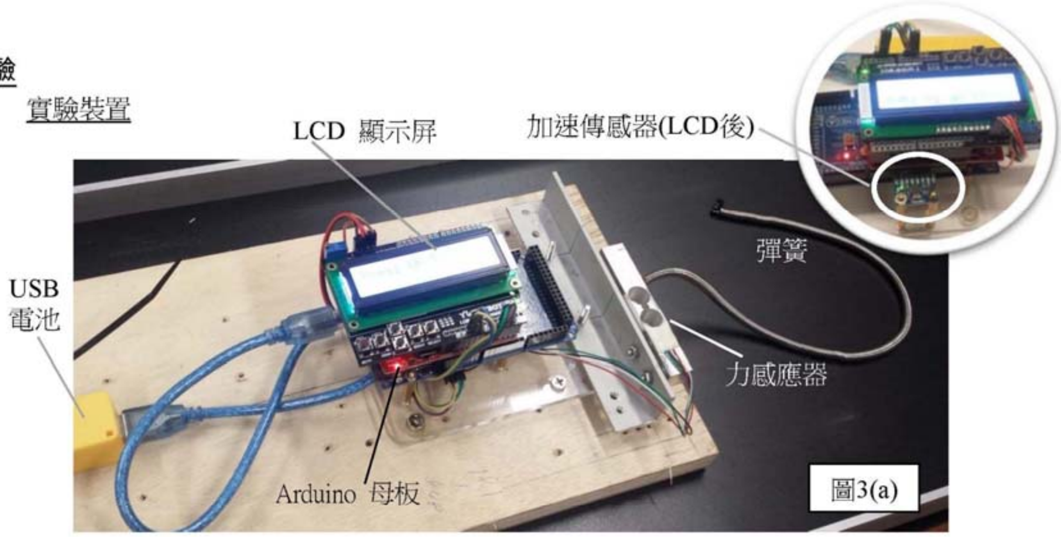


圖3(a)

Arduino裝置及300g砝碼已固定在一塊木板上。在軌道末端以G鉗繫緊彈簧的一端，而另一端則連接至裝置上的**力傳感器**。在軌道未端加上防撞海綿。釋放裝置時，請確保裝置以直線並與軌道平行移動，否則重做。

3.2 力傳感器(force sensor)置零

- 開始實驗前，先在Arduino母板插入SD咭，不要將SD咭上鎖。
- 插上Arduino 母板USB電源，程式會先要求你將力感應器置零(Tare)，彈簧**需保持在鬆弛狀態**(圖3c)，按下"UP"鍵一次置零(圖3d)，完成後LCD屏便會顯示"Done" (圖3e)。
- 如未插入SD咭，LCD屏會提示："Please Insert SD"，此刻請插回SD咭。

圖3(b)

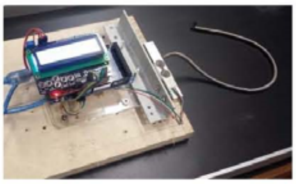


圖3(c)

圖3(d)

圖3(e)

4. **擷取數據**

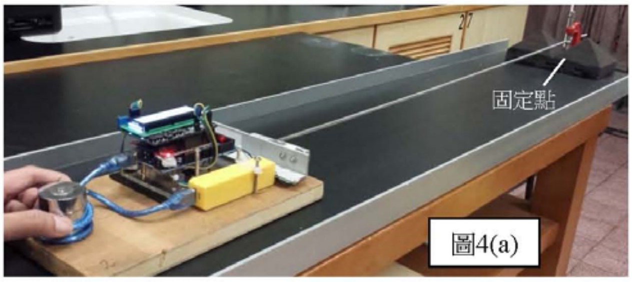
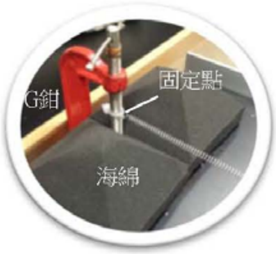


圖4(a)



- 將力傳感器置零後，LCD屏會顯示:"Save:Press DOWN", 及顯示即時力的數據。
- 如圖4(a)所示把木板往後拉，延長彈簧，直至LCD屏顯示的數據約為**8.0N**。
- 按下"Down"鍵，當LCD屏顯示:"Release now!!",便**立即**釋放裝置。

圖4(b)

- 此時裝置會自動收集數據並儲存於SD咭中。程式約在三數秒後停止。此時LCD屏會顯示儲存檔案的文件夾及檔名如下："Newton/Newtonxx.csv, Press UP to continue"，示表資料已寫入SD 咭中。
- 警告：資料寫入途中取出SD 咭，會嚴重損壞該咭。
- 按"UP"鍵可重覆實驗或關掉(拔掉)Arduino 母板電源停止實驗。(注意:重接電源需再次置零!)
- 以電子磅秤量木板小車連砝碼及裝置的質量，M = ____________________ kg

5 數據處理

- 從Arduino 母板取出SD咭。
- 將SD咭插入電腦，SD咭儲存的檔桉為原始檔，以Excel開啟SD咭內“Newton”文件夾的最後檔案，檔案名稱為 “NewtonXX.csv”；XX 為檔名順序，檔案越後，數字越大。
- 檔案記錄了三欄資料，分別如下：
  - (1) 欄A：Time, ***t***, 以s (秒)表示；
  - (2) 欄B：Force , ***F***, 以N (牛頓)表示；
  - (3) 欄C：Acceleration, ***a***, 以ms^{-2} (米每平方秒)表示。

- 選取SD咭檔案內的A至C行資料，按Ctrl-C複製兩行資料。

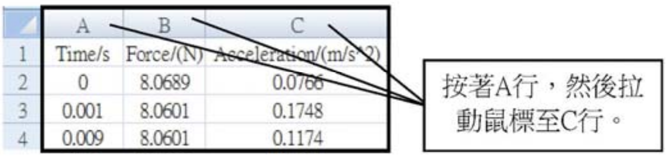


圖5(a)

- 開啟桌面上的Excel範本檔案 (Newon_template.xlsx)
- 選取方格A1，按Ctrl-V，在同一位置貼上原始檔的三行資料。

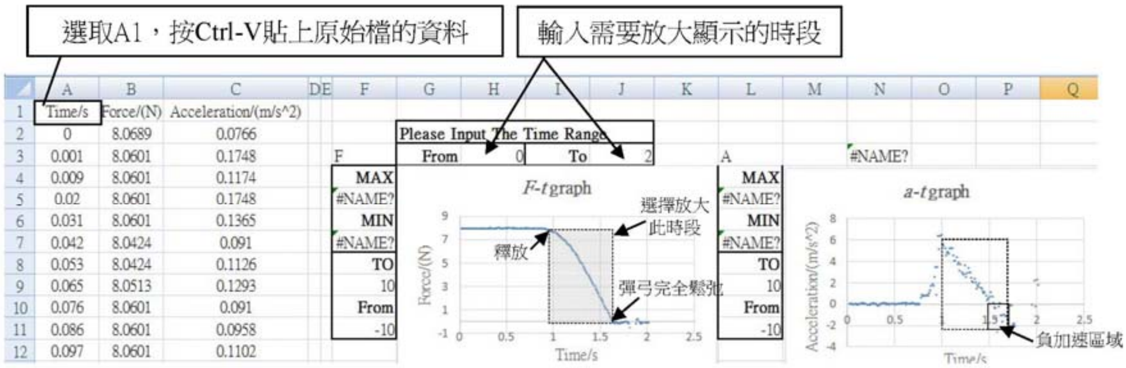


圖5(b) 圖5(c)

- Excel 檔案內已預設三圖，會按抄入的資料分別自動顯示：
  1. **力–時間** 關係圖 (Force-time curve, *F-t* curve), 圖5(b)
  2. **加速度–時間** 關係圖 (Acceleration-time curve, *a-t* curve), 圖5(c)
  3. **力–加速度** 關係圖 (Force-acceleration curve, ***F-a*** curve), 圖5(d)

- 在圖5(b) 輸入開始及結束時段，以**顯示彈簧被釋放後至物體停下前的時段** (*F-a*圖)。

- 點擊 *F-a* 圖以選取該表，**按 Ctrl-P 以橫印格式打印圖表，並連同實驗報告一并呈交**。
- 如你的電腦沒有連接打印機，請按 "alt-F,A" 將檔另存新檔於SD咭內，檔名為"class+class no"，如"4C_4_15_17"。移動SD咭到另一電腦打印。

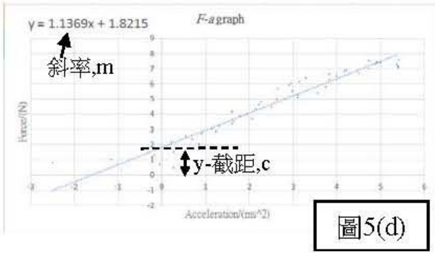


圖5(d)

6. <u>實驗結果</u>：

- Excel 會在*F-a*圖 (圖5d)上自動配適一條最佳直線，並顯示其斜率及y截距。
- 直線的格式為 $y = mx+c$，從圖表中讀出:

  (i) 斜率 $= m =$ ____________________ (ii) y截距 $= c =$ ____________________

7 <u>討論</u>：

(a) 圖5(d)的直線不會穿過原點是可能因為受到摩擦力的影響。試從圖5(d)估計摩擦力的量值。

____

(b) 如何改動實驗裝置，可令摩擦力減至最低或可補償摩擦力的作用?

____

____

(c) 如果真的能撇除摩擦力的影響，你對此實驗可作出甚麼結論?

____

____

(d) 你認為甚麼原因可能會導致誤差?

____

____

____

(e) 利用同相的實驗裝置，你可以改變實驗中那些變數，再作進一步科學探究?

____

____

8 <u>挑戰題</u>：

(a) 圖中的斜率有甚麼物理含意? 試簡單解釋。

____

____

(b) 圖5(c)出現「負加速區域」，試解釋此現象。

____

____

____

<<< 實驗完結>>>

Appendix G5: Revised worksheet on Arduino-based experiment – Chinese version

Arduino 實驗 #4

實驗	升降機 重力加速度實驗
姓名	
日期	
班別/班號	
分組	
積分	

1. **實驗儀器**：

Arduino 重力實驗裝置 1組
(母板+SD咭+ LCD顯示屏+加速度傳感器+USB電池)
電腦 (內置 EXCEL 範本檔案) 1台
SD 咭讀咭器 1枚
小膠盤 1個
電子磅 1台
10N 彈簧秤 1個
1kg 砝碼 1個
900 砝碼連吊架 1串

2 **實驗前體驗**

圖2(a)


圖2(b)


圖2(c)

- 將900g砝碼掛在彈簧秤的掛鈎上，彈簧秤靜止時的讀數 R = ____________N
- 將整組裝置帶進學校升降機內。同學也可使用圖2(c)的電子秤作測試，但注意電子秤並不是以N(牛頓)，而是以質量 g(克)作為力的量度單位，在物理學上，基本上是錯誤的概念。
- 按以下程序控制升降機，並注意在不同情況下(按下表) ，彈簧秤讀數的變化：
  - 關閉升降機門，上升最少**三樓層**(如由一樓到四樓)，然後停下。
  - 升降機打開門後，不要走出升降機，隨即關閉升降機門，返回原樓層。
- 填寫下表彈簧秤在各階段的讀數變化。

代號	階段		彈簧秤的讀數變化 (上升/下降/不變?)
(a)	升降機上升	關門，升降機向上加速	
(b)		保持恆速上升	
(c)		減速至停下	
(d)	升降機下降	關閉，升降機向下加速	
(e)		保持恆速下降	
(f)		減速至停下	

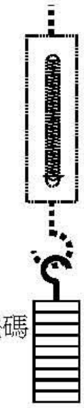
Q.1 在右圖的彈簧秤，繪劃作用於砝碼上的隔離力圖，以箭頭表示重力(W)及張力(T)。

Q.2 當升降機向上突然加速時，以下兩項有可變化? (上升/下降/不變?)

- 作用於砝碼的重力(W) : ____________________
- 彈簧作用於砝碼的張力(T) : ____________________

Q.3 彈簧秤的讀數，其實是量度砝碼的重力(W) 還是彈簧作用於砝碼的張力(T)?

____



3. **利用 Arduino 實驗裝置量度重力**

裝置主要由Arduino單片機及一枚**重力加速度傳感器** (gravitational acceleration sensor)組成。**傳感器**可理解為一個超細小型的內置電子秤，它可量度靜態和動態的重力場，***g*** 的變化。
。

圖2

4. **擷取數據**

- 開始實驗前，先在Arduino母板插入SD咭，不要將SD咭上鎖。
- 插上Arduino 母板USB電源後，蜂鳴器會發出「嗶」一聲響鬧，表示已正常運作，
- 將實驗裝置放入小膠盤內，移至學校的升降機中，水平放於升降機地面上，升降機關門前請按下啟動按鈕，蜂鳴器會發出「嗶-嗶」兩聲響鬧，如發出「嗶-嗶-嗶-嗶-嗶」五聲急促響鬧，表示你尚未插入SD咭，請入咭再按下按鈕。此時裝置會自動收集數據開始並儲存於SD咭中。
- 控制升降機：
  1. 啟動存儲程序後，關閉升降機門，上升**三樓層**(如由一樓到四樓)，然後停下。
  2. 升降機打開門後，不要走出升降機，隨即關閉升降機門，讓它返回原樓層。
  3. 當升降機返回原樓層後，再按下按鈕，蜂鳴器會再發出「嗶-嗶-嗶」三聲響鬧，表示裝置已完成數據儲存，資料寫入途中切勿取出SD 咭，否則會構成嚴重損壞。
- 如果要重新擷取數據，再按下按鈕兩次便可分別啟動及停止實驗，不需拔掉電源。

5 數據處理

- 從Arduino 母板取出SD咭。
- 將SD咭插入電腦，SD咭儲存的檔桉為原始檔，以Excel開啟SD咭內"Lift"文件夾的最後檔案，檔案名稱為 "LiftXX.csv"；XX 為檔名順序，檔案越後，數字越大。
- 檔案記錄了三欄資料，分別如下：

  (1) 欄A：Time, *t*, 以s (秒)表示；

  (2) 欄B：Acceleration, *a*, 以$m\,s^{-2}$ 或m/s^2 (米每平方秒)表示。
- 選取SD咭檔案內的A至B行資料，按Ctrl-C複製兩行資料。

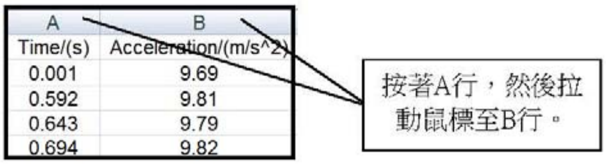


圖4(a)

- 開啟桌面上的Excel範本檔案 (Lift_template.xlsx)
- 選取方格A1，按Ctrl-V，在同一位置貼上原始檔的兩行資料。

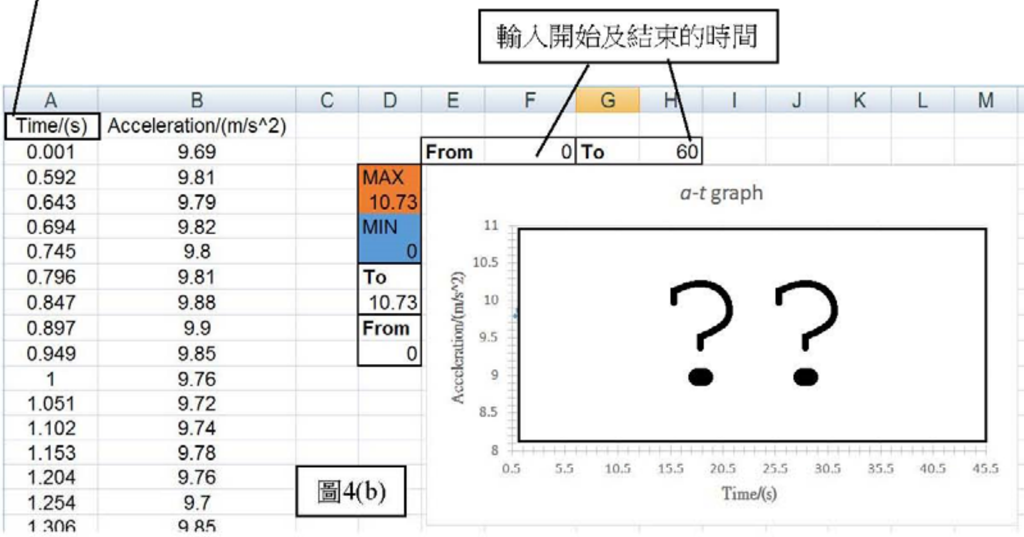


圖4(b)

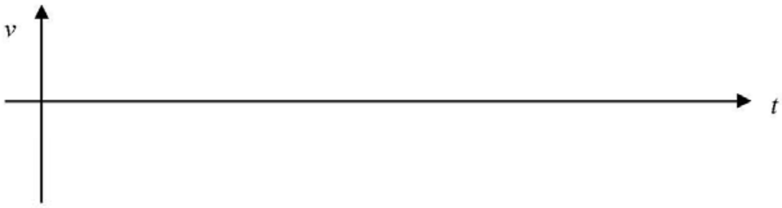
- Excel 檔案內已內置加速度-時間 關係圖 (acceleration-time curve, a-t curve)，會按抄入的資料分別自動顯示, 圖4(b)。
- 輸入顯示圖表的開始及結束的時間。
- 點擊 *a-t* 圖以選取該表，**按 Ctrl-P 以橫印格式打印圖表，並連同實驗報告一并呈交**。
- 在呈交的圖表上，**以代號(a),(b)(c),(d),(e),(f) 標誌下表顯示的各階段**。
- 如你的電腦沒有連接打印機，請按 "alt-F,A" 將檔另存新檔於SD咭內，檔名為"class+class no"，如"4C_4_15_17 "。移動SD咭到另一電腦打印。

代號	階段		記下此段最高或最低 **g** 的數值
(a)	升降機上升	關門，升降機向上加速	
(b)		保持恆速上升	
(c)		減速至停下	
(d)	升降機下降	關閉，升降機向下加速	
(e)		保持恆速下降	
(f)		減速至停下	

Q.4: 在升降機處於靜止狀態時，錄得的重力加速度平均值約為多少?

Q.5: 升降機除了處於靜止狀態外，在其他甚麼運動狀態時，錄得的重力加速度與 Q.1 的相同?

Q.6: 簡繪整個過程中，物件的速度-時間圖 (*v-t* curve)，假設向上為「正」。**以代號(a),(b)(c),(d),(e),(f) 標誌各階段**。



6 **討論**：

(a) 你認為甚麼原因可能會導致誤差?應如何解決?

(b) 試利用同相的實驗裝置，構思如何可再作其他科學探究? (提示: 裝置放在不同場地或場景下量度加速度、擺設裝置的方向和方法、裝置與地面間加一些物料…)

<<< 實驗完結>>>

Appendix G6: Revised worksheet on Arduino-based experiment – Chinese version

Arduino 實驗 #5

實驗	**非彈性撞碰**
姓名	
日期	
班別/班號	
分組	
積分	

1. **實驗儀器**：

Arduino 運動感應器實驗裝置 (母板+SD咭+超聲波傳感器+USB電池)	1組
電腦 (內置 EXCEL 範本檔案)	1台
SD 咭讀咭器	1枚
膠片(安置在車頭，反射超聲波用)	1塊
軌道	1條
吸震海綿/G鉗	1 片
萬寶貼/魔術貼	數片
電子磅	1個

2. **實驗裝置**：

超聲波發射器送出的聲波被物件反射後返回接收器，而Arduino 內置的程式量度聲波往返的時間，從而計算傳感器與物件的距離。

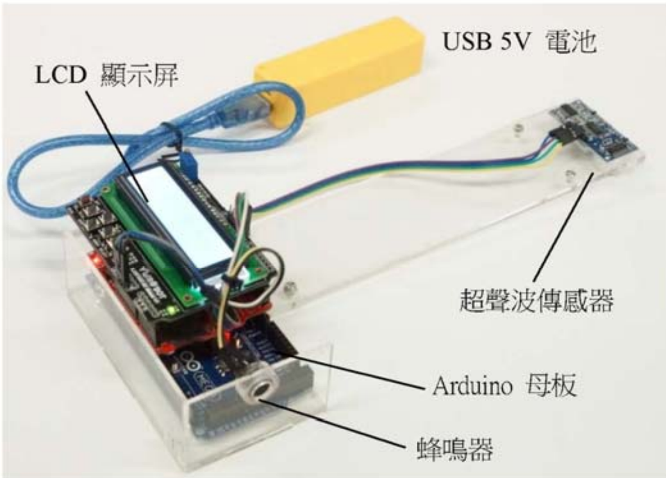


圖2(a)

圖2(b)

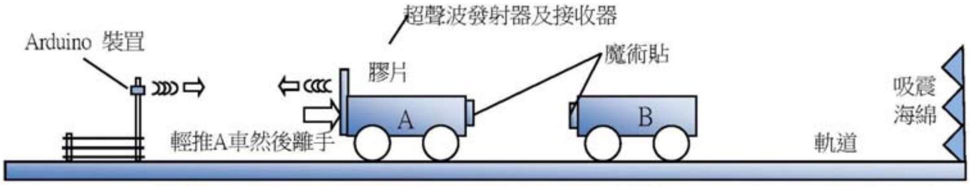


圖2(c)

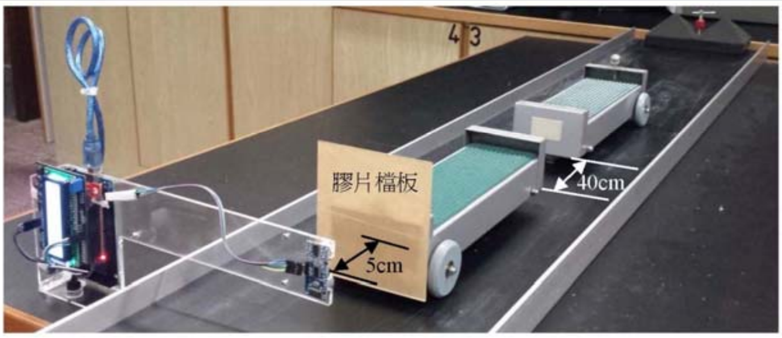


圖2(d)

3. **擷取數據：**

- 以萬寶貼將Arduino裝置固定在桌面，如圖2(d)所示，超聲波傳感器面向小車。
- 將膠片檔板以萬寶貼固定在小車A，面向傳感器的一面，如圖2(d)所示
- 將兩小車A及B放置於軌道之上，A車離開超聲波傳感器約5cm，而兩車距離40cm。
- 開始實驗前，先在Arduino母板插入SD咭，不要將SD咭上鎖。
- 插上Arduino 母板USB電源，如已正常插入SD咭，LCD屏會顯示："Press Select ..."；否則LCD屏會提示："Please Insert SD"，此刻將咭插入便可。
- 按下Select鍵後，LCD屏會顯示："Release after the 3rd beep"，你將會到三聲響鬧。

圖3(a)

圖3(b)

- 裝置會邊響鬧邊顯示："3"、"2"、"1"，三聲"嗶"聲過後，當看到"Release Now" 出現便立即將小車A輕推一下，然後離手，讓它與B車發生碰撞。碰撞後，兩車應扣在一起以相同的末速, ***v*** 移動。
- 注意身體要遠離傳感器，以免聲波被反射。
- 大約在3秒後，母板便會自動停止收集數據。此時LCD屏會顯示儲存檔案的文件夾及檔名如下："BALL/BALLx, Press UP to continue"，示表資料已寫入SD 咭中。

圖3(c)

- 按"UP"鍵可重覆實驗或關掉(拔掉)Arduino 母板電源停止實驗。
- 警告：資料寫入途中，切勿取出SD 咭，會嚴重損壞該咭。

4 **數據處理**

- 從Arduino 母板取出SD咭。
- 將SD咭插入電腦，SD咭儲存檔為原始檔，以Excel開啟SD咭內"Ball"文件夾的<u>最後</u>檔案，檔案名稱為 "ballxx.csv"；xx 為檔名順序，檔案越後，數字越大。
- 檔案記錄了兩欄資料，分別如下：
  - (1) 欄A：Time/s, 以s (秒)表示；
  - (2) 欄B：Displacement/m, 木板離開傳感器的距離，以 m (米)表示。
- 選取SD咭檔案內的A至B行資料，按Ctrl-C複製兩行資料。

A	B
Time/s	Displacement/m
0	0.027
0.01	0.028
0.02	0.029
0.03	0.028

按著A行，然後拉動鼠標至B行。

時間 t/s　　位移 s/m

圖4(a)

- 開啟桌面上的Excel範本檔案 (Inelastic collision_template.xlsx)
- 選取方格A1，按Ctrl-V，在同一位置貼上原始檔的兩行資料。
- Excel檔案會按抄入的資料顯示**速度−時間**關係圖(Velocity-time curve, *v-t* curve) 及 位移時間關係圖(*s-t* curve)。
- 如圖4(b)所示，輸入合適的時段，令線圖**顯示整個碰撞過程的速度改變**。
- 分別點擊Excel表內的 *v-t* 圖及 *s-t*圖表，再按Ctrl-P鍵**以橫印格式打印圖表，圖表連同實驗報告一并呈交**。
- 如你的電腦沒有連接打印機，請將此Excel檔另存新檔於SD咭內，再到另一電腦打印。要另存檔名，請按 "alt-F" 然後按"A"，改名為"class+class no"，如"4C_4_15_17 "。

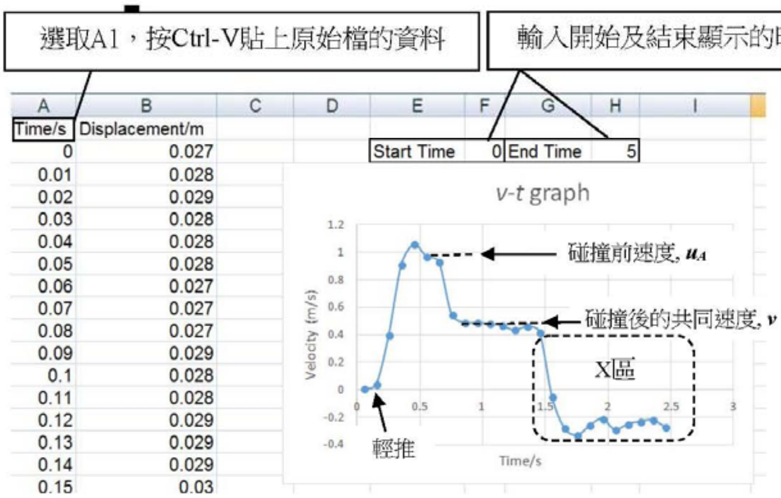


圖4(b) 速度-時間關係圖 (*v-t* 圖)

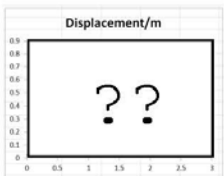


圖4(c)位移時間關係圖(*s-t* 圖)

Q.1 上圖虛線所示的X區域，其實代表小車在碰撞後發生了甚麼事?

---

5. **實驗結果：**

- 點擊圖4(b)的資料點，螢幕會顯示其(*v,t*)坐標讀數。量度以下數據的值：

碰撞前A車的速度, u_A = ________ (ms^{-1})

碰撞前B車的速度, u_B = ________ (ms^{-1})

碰撞後的共同速度, v = ________ (ms^{-1})

- 量度小車質量：

小車A(連檔板)的總質量 = m_A = ________ kg 小車B 的質量 = m_B = ________ kg

- 動量的變化：

狀態	動量和 ($kg\ ms^{-1}$)
碰撞前	$p_1 = m_A u_A + m_B u_B =$
碰撞後	$p_2 = (m_A + m_B) v =$

- 動能的變化：

狀態	能量和 (J)
碰撞前	$E_1 = {}^1/_2 m_A u_A^2 + {}^1/_2 m_B u_B^2 =$
碰撞後	$E_2 = {}^1/_2 (m_A + m_B) v^2 =$

6. **結論與討論**：

Q.2 碰撞前、後的**動量**是否守恆? (是/否?) ____________________ (誤差不超過10%可視作守恆)

Q.3 碰撞前、後的**動能**是否守恆? 如否，請說明原因?

____

____

____

Q.4 這種碰撞是彈性碰撞還是非彈性碰撞? ______________________________

Q.5 甚麼原因可能會導致誤差及應如何改善?

____

____

____

Q.6 有同學建議在兩車的車頭裝上極性相同的磁石，令兩車相撞後不會扣在一起，而是以不同速度反彈。試以簡圖輔助說明你如何改動實驗裝置，令其可以同時分別量度兩車相撞前後的速度?假設你可採用多於一組的Arduino裝置。

____

____

____

<<< 實驗完結>>>

Appendix G7: Revised worksheet on Arduino-based experiment – Chinese version

Arduino 實驗 #6

p實驗	向心運動
姓名	
日期	
班別/班號	
分組	
積分	

1. **實驗儀器：**

Arduino向心加速度實驗裝置	1
(直尺+Arduino母板+SD咭+傳感器+外置電源)	1
電腦	1台
SD 咭及SD 咭讀咭器	1
EXCEL Template 範本檔	1

2. **實驗目的及原理**

- 此實驗要求學生在圓周運動中，尋找向心加速度(a)與運動週期(T)之間的關係。
- 實驗裝置主要由Arduino單片機及一枚傳感晶片MPU-6050組成，內置三軸(x,y,z軸)的加速度(acceleration, a)和角速度(angular velocity,ω)的傳感器，以每秒100次擷取數據。
- 運動週期可由 $T = \frac{2\pi}{\omega}$ 得出。

MPU-6050晶片
(黑色方塊)

3. **實驗設定**

3.1 實驗裝置

- Arduino 裝置已固定在木尺的一端， L是由轉軸至模黑色晶片中點的距離。

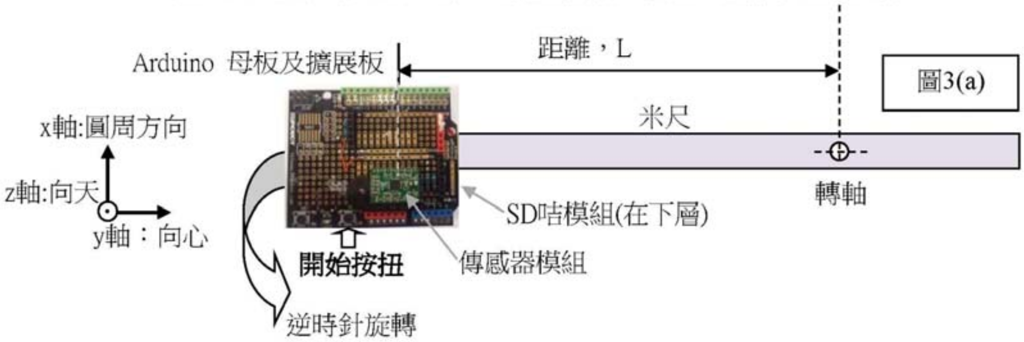


圖3(a)

3.2 擷取數據

- 將手柄上的絲桿穿過木尺的小孔作為支點。
- 插上電源前，記緊在Arduino母板上的SD咭模組插入SD咭，不要將SD咭上鎖。
- 插上電源，此刻如SD咭尚未插妥，母板會發出"嗶-嗶-嗶-嗶"急促聲響，請穩固或重新插入SD咭，如正常啟動，母板會發出"嗶"一聲表示已進入預備狀態。
- 此實驗裝置會在15秒內分三階段(按下表指示)自動擷取數據。
- 完成後關掉(拔掉)Arduino 母板電源，取出SD咭。

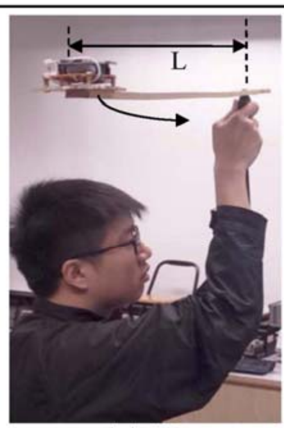


圖3(b)

時段	聲響提示	動作	儲存數據
0-5s	**按下開始按扭**，母板會發出"嗶-嗶-嗶"三聲表示開始。	如圖3(b)所示手持裝置，以水平方向啟動裝置繞著轉軸以箭頭方向旋轉。保持約每秒1圈相對慢的恆速，等待響鬧提示。	預備階段，未開始儲存數據。
5-10s	到5s時，母板會發出"嗶-嗶"兩聲提示加快轉速。	**漸漸增加轉速**至約每秒3至4圈，直至響鬧提示出現。(警告：勿超此轉速上限!)	在5s時開始儲存數據。
10-15s	到10s時，母板會發出"嗶"一聲提示減慢轉速。	在5s內，**漸漸減低轉速**至停下，完成後裝置會發出3秒長"嗶"聲響，表示結束。	在15s時停止儲存數據。

4 **數據處理**

- 將SD咭插入電腦，以Excel 開啟SD咭內檔案，檔案名稱為 "centXX.csv"。XX代表檔案編號，數字越大，表示檔案越後。
- 檔案A記錄了三項資料，按時序排列：

  (1) Time/s：時間，單位為 s

  (2) a (m/s^2)：向心加速度，單位為 ms^{-2}

  (3) w (rad/s)：角速度 (向天，ω)，單位為 rad s^{-1}

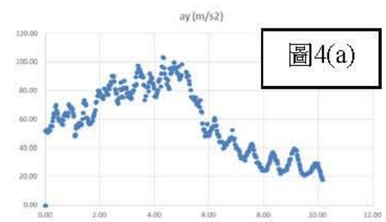
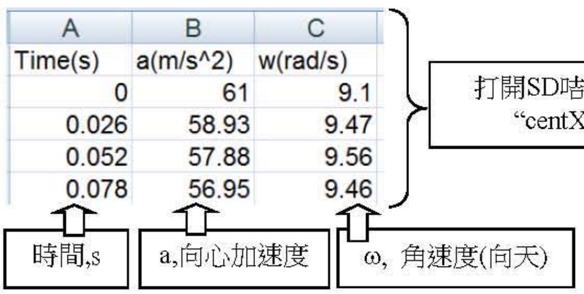


圖4(a)

向心加速度隨轉速漸漸由低轉高，再漸漸由高漸漸轉低。

- ω = 角速度

  =感應器轉動時每秒所張開的弧度 θ，$\boxed{\omega=\theta/t}$ 。
- $\boxed{\omega=2\pi/T}$ 或 $\boxed{T=\omega/(2\pi)}$ ，T：轉動週期，單位為 s
- 學生需利用 Excel 自行找出向心加速度 a 與週期 T 有甚麼關係?
- 選取原始檔案 "centXX.csv" 內的 A至C行資料，按 **Ctrl-C** 複製



A	B	C
Time(s)	a(m/s^2)	w(rad/s)
0	61	9.1
0.026	58.93	9.47
0.052	57.88	9.56
0.078	56.95	9.46

圖4(b)

- 開啟Excel範本檔案，圖4(c), 檔名為 centripetal_template.xlsx
- 選取方格A1，按Ctrl-V，在同一位置貼上原始檔的3行原始資料。T是經由ω 轉換得出的週期，單位為 s。

圖4(c)

a 與 *T* 關係的可能性

(1)：$T(s)$ (2):$T^2(s^2)$ (3):$1/T(s^{-1})$ (4):$1/T^2(s^{-2})$

Ctrl-V 在此貼上原始數據

A	B	C	D	E	F	G	H
Time(s)	a(m/s^2)	w(rad/s)		T	square (T)	1/T	1/square(T)
0	61	9.1		0.6905	0.47674	1.45	2.10
0.026	58.93	9.47		0.6635	0.44021	1.51	2.27
0.052	57.88	9.56		0.6572	0.43196	1.52	2.32
0.078	56.95	9.46		0.6642	0.44114	1.51	2.27

5 **關係驗證**

- 範本已在E,F,G,H各行內，置設四條可能的方程式，分別是 T，T^2, $1/T$ 及 $1/T^2$，

  以下是 *a*與 *T* 的關係的其中一些可能性：

  (1) 如 *a*與 *T* 成正比，則 *a*對 *T* 圖線為一直線

  (2) 如 *a* 與 T^2 成正比，則 *a*對 T^2 圖線為一直線

  (3) 如 *a*與 *T* 成反比，(或 *a*與 $1/T$ 成正比），則 *a*對 $1/T$ 圖線為一直線，

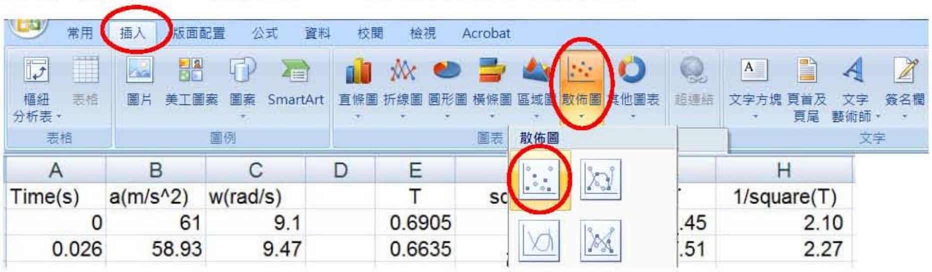
  (4) 如 *a* 與 T^2 成正比，(或 *a* 與 $1/T^2$ 成正比)，則 *a*對 $1/T^2$ 圖線為一直線。

- 按以下步驟驗證其中關係，以第一種可能性為例，以滑鼠選取 B 及 E 的資料 (先點擊 B 行，再Ctrl-點擊 E 行)

點擊　　Ctrl-點擊

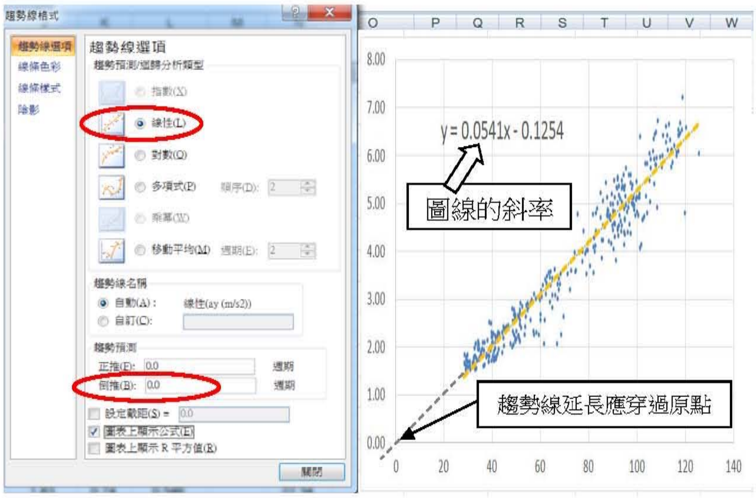
A	B	C	D	E	F	G	H
Time(s)	a(m/s^2)	w(rad/s)		T	square (T)	1/T	1/square(T)
0	61	9.1		0.6905	0.47674	1.45	2.10
0.026	58.93	9.47		0.6635	0.44021	1.51	2.27
0.052	57.88	9.56		0.6572	0.43196	1.52	2.32
0.078	56.95	9.46		0.6642	0.44114	1.51	2.27

- 選取「插入」→「散佈圖」→「帶有資料標記的散佈圖」



- 如T與a真的成正比關係，圖線趨勢應為一條穿原點的直線。你認為 <T-a> 圖線是直線嗎?

- 如否，**請繼續逐一測試不同的可能性**，直至一條穿原點的直線趨勢圖出現。
- 當直線趨勢圖出現而且是穿越原點，代表該種關係成正比。此時請按滑鼠右鍵，選擇「加上趨勢線」，再勾選「線性」及「圖表上顯示公式」。



6 **<u>實驗結果</u>**：

(a) 旋轉半徑

L = ___________ m

(b) 經多輪驗證後，你認為 a 與 T 最有可能是跟隨何種關係?為甚麼?

____

____

____

(c) 為你揀選的關係配適一條直線，並找出圖線的斜率 = ______________________

(d) 你認為甚麼原因可能會導致誤差及應如何改善?

____

____

____

____

(e) **打印 Excel 表格及圖表，連同此實驗報告呈交**。

7 **<u>挑戰題</u>**：

(a) 圖線的斜率與L(支點與傳感器的距離)你認為有何關係? 試以實驗數據支持你的說法。

____

____

____

____

(b) 你認為有甚麼因素會影響向心加速度有?如何影響? 利用此實驗裝置，你如可作出改動，令它可證明你的假設?

____

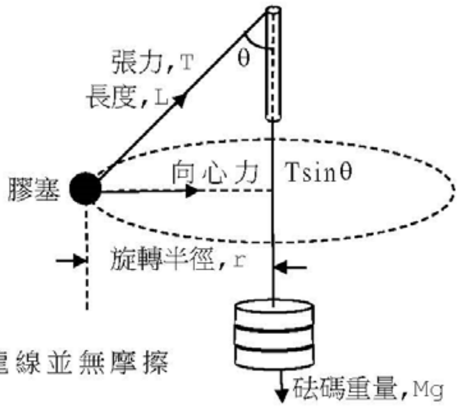
____

____

<<<實驗完結>>>

附件：傳統方法

1. 理論：



膠塞的向心力= T 的分量= $T\sin\theta$

張力 T = 砝碼重量 = Mg

向心力= $T\sin\theta = m\omega^2 r$ --- (1)

但 $\sin\theta = r/L$, $r = L\sin\theta$

r 代入(1) $Mg\sin\theta = m\omega^2 r\sin\theta$， 得出

$\boxed{Mg = m\omega^2 L}$. 假定玻璃管口和尼龍線並無摩擦

2. 步驟：

1. 把 1.5 m 長尼龍線的一端縛緊膠塞，將另一端穿過玻璃管和紙標記並縛於一串有槽砝碼，如圖所示。
2. 首先將紙標記的位置調至距玻璃管口 1 cm 處，而玻璃管另一端與膠塞之間的尼龍線長度 L 為 0.8 m。如有需要可用膠紙固定紙標記。開始時取 M = 0.10 kg (即 100 g) 進行實驗。
3. 豎直地拿著玻璃管並使膠塞在頭頂沿水平圓周旋轉。使膠塞的速率逐漸增加並向外移 (即讓 L 增加) 直至紙標記約在玻璃管下端 1 cm 處。
4. 保持角速率穩定使紙標記一直位於玻璃管下端 1 cm 處。另一組員則用秒表量度膠塞旋轉 20 週的時間。重複實驗以確定數據並求 20 週旋轉的平均需時。
5. 選取不同的 L 值或 M 值，重複實驗，驗證以下公式的有效性。

3. 實驗結果：

取 g = 9.81ms^{-2}， L = 0.8 m

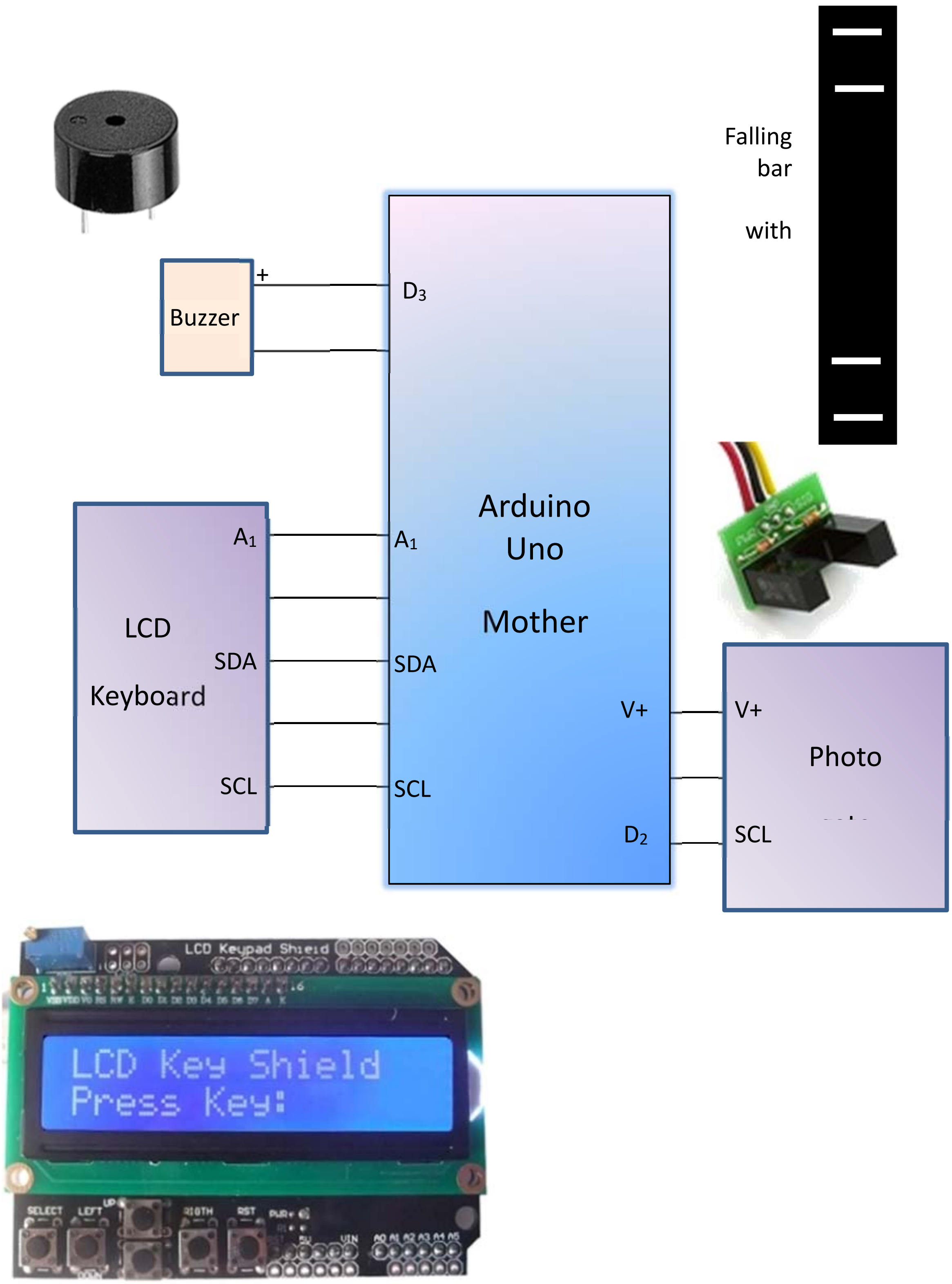
(i) 驗證 M 與 ω^2 成正比, 保持 L 不變 (如時間不足，請只完成第一列資料)

M / kg	Mg / N (A)	20 週旋轉所需時間 20 T / s			週期 T/s	角速率 $\omega = \frac{2\pi}{T}$ / rad s^{-1}	$m\omega^2 L$ / N (B)	誤差百份比/% (B-A)/Ax100%
		第一次	第二次	平均				
0.1								
0.15								
0.2								

(ii) L 與 ω^2 成反比 (或 1/L 與 ω^2 成正比)，保持 M 不變

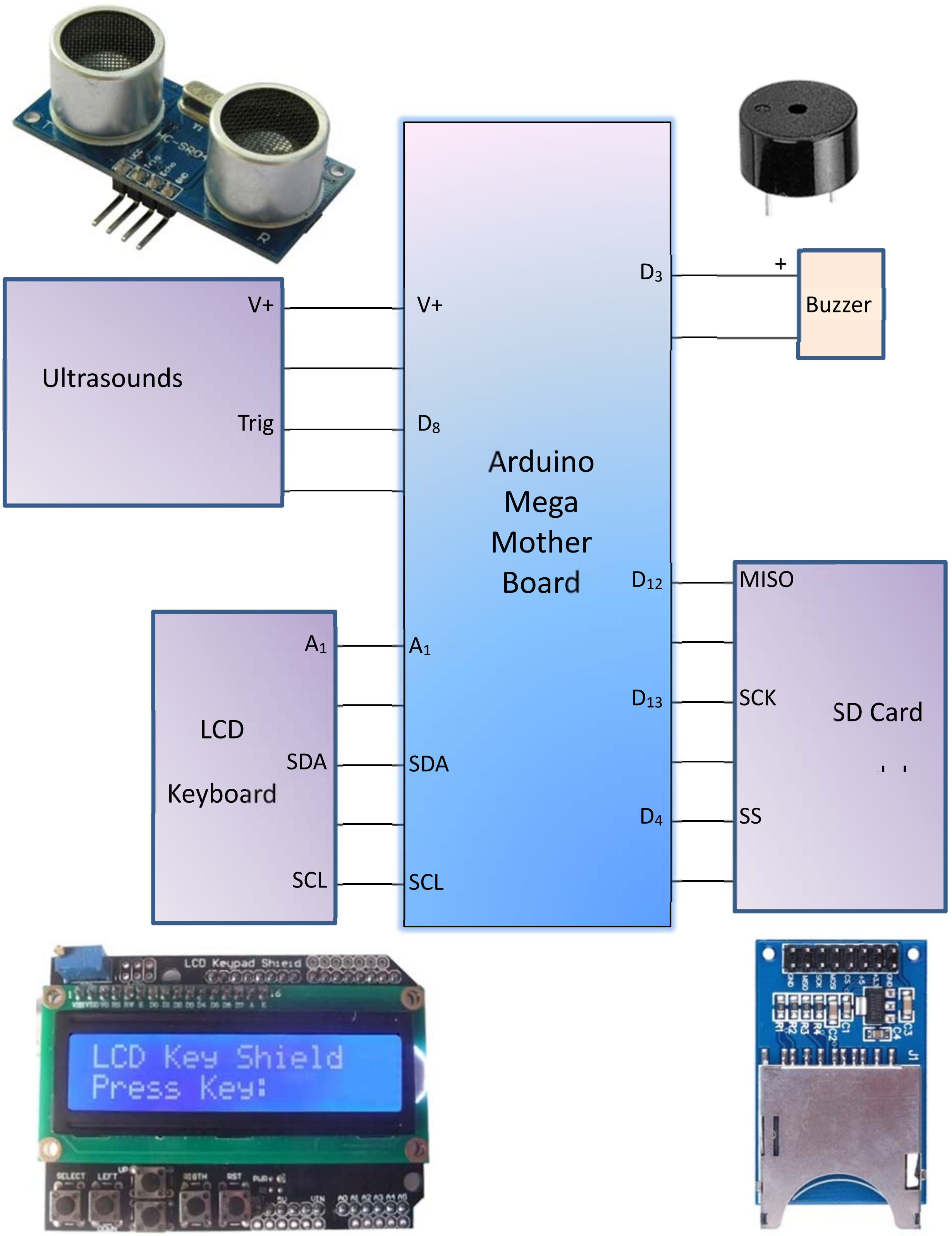
Appendix H1: Circuit diagrams for the Arduino devices

Circuits for Arduino-based Experiment 1A and 1B
Free falling experiment with photo gate



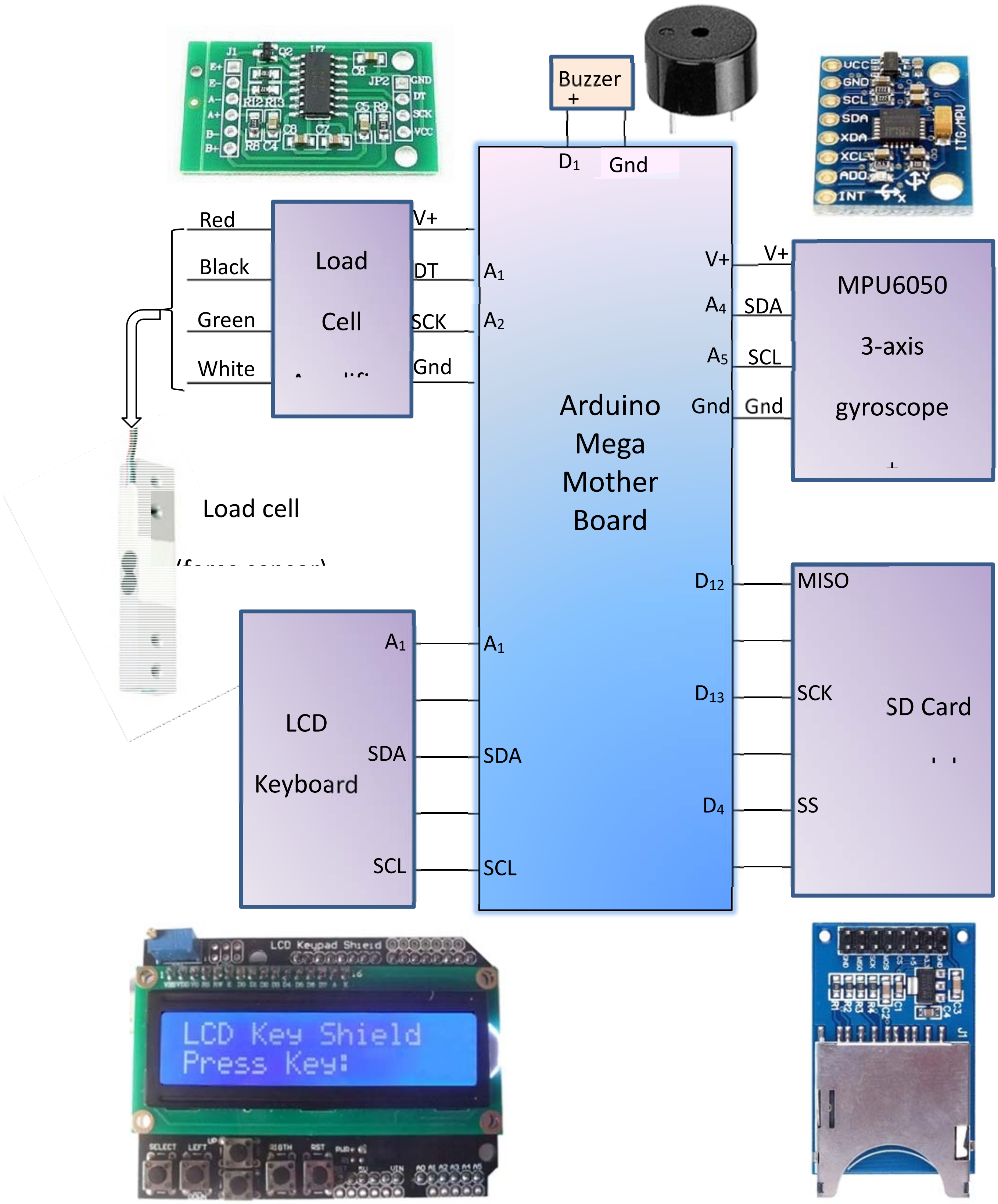
Appendix H2: Circuit diagrams for the Arduino devices

Circuits for Arduino-based Experiment 2
Bouncing Ball Experiment



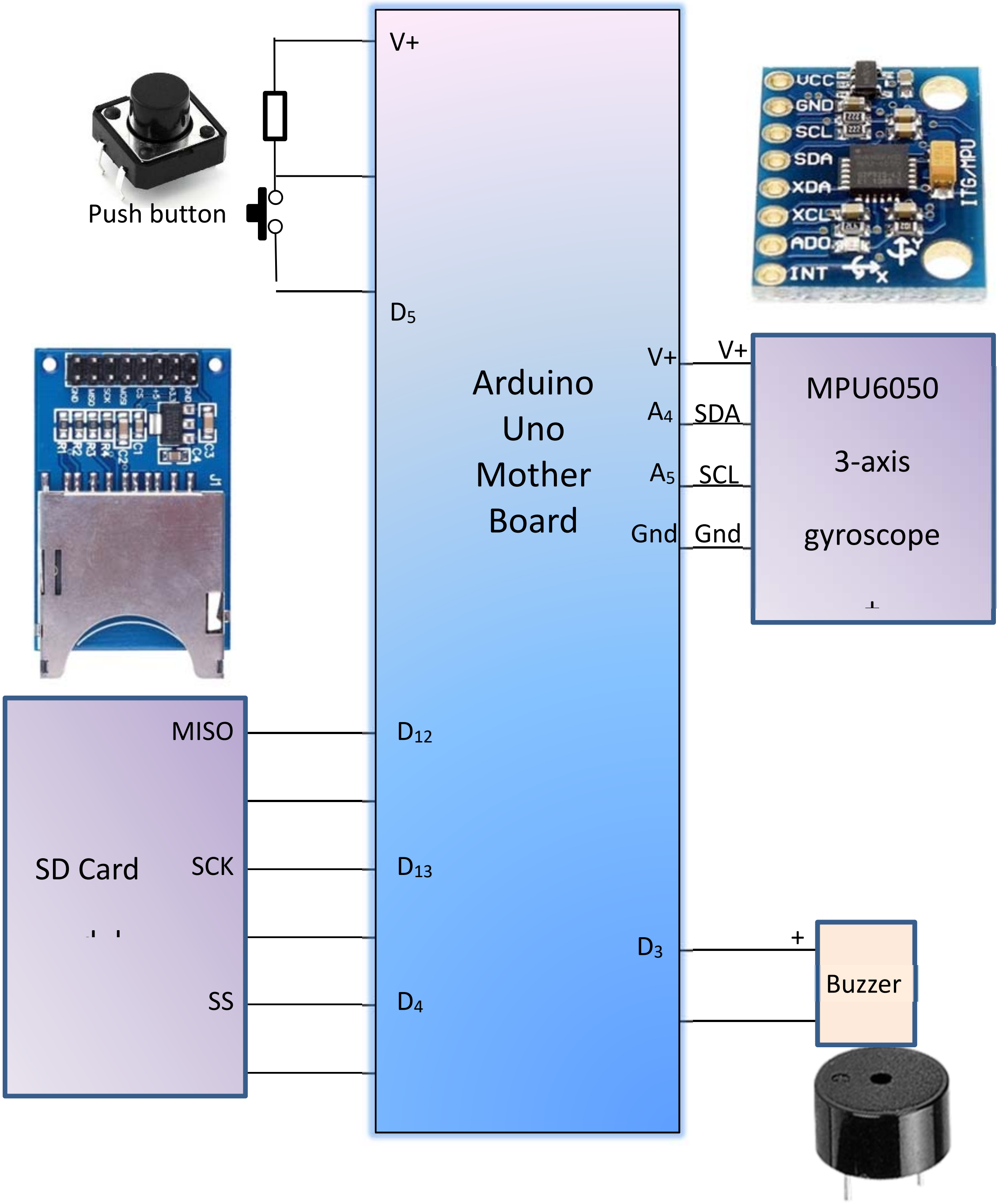
Appendix H3: Circuit diagrams for the Arduino devices

Circuits for Arduino-based Experiment 3
Newton's second Law



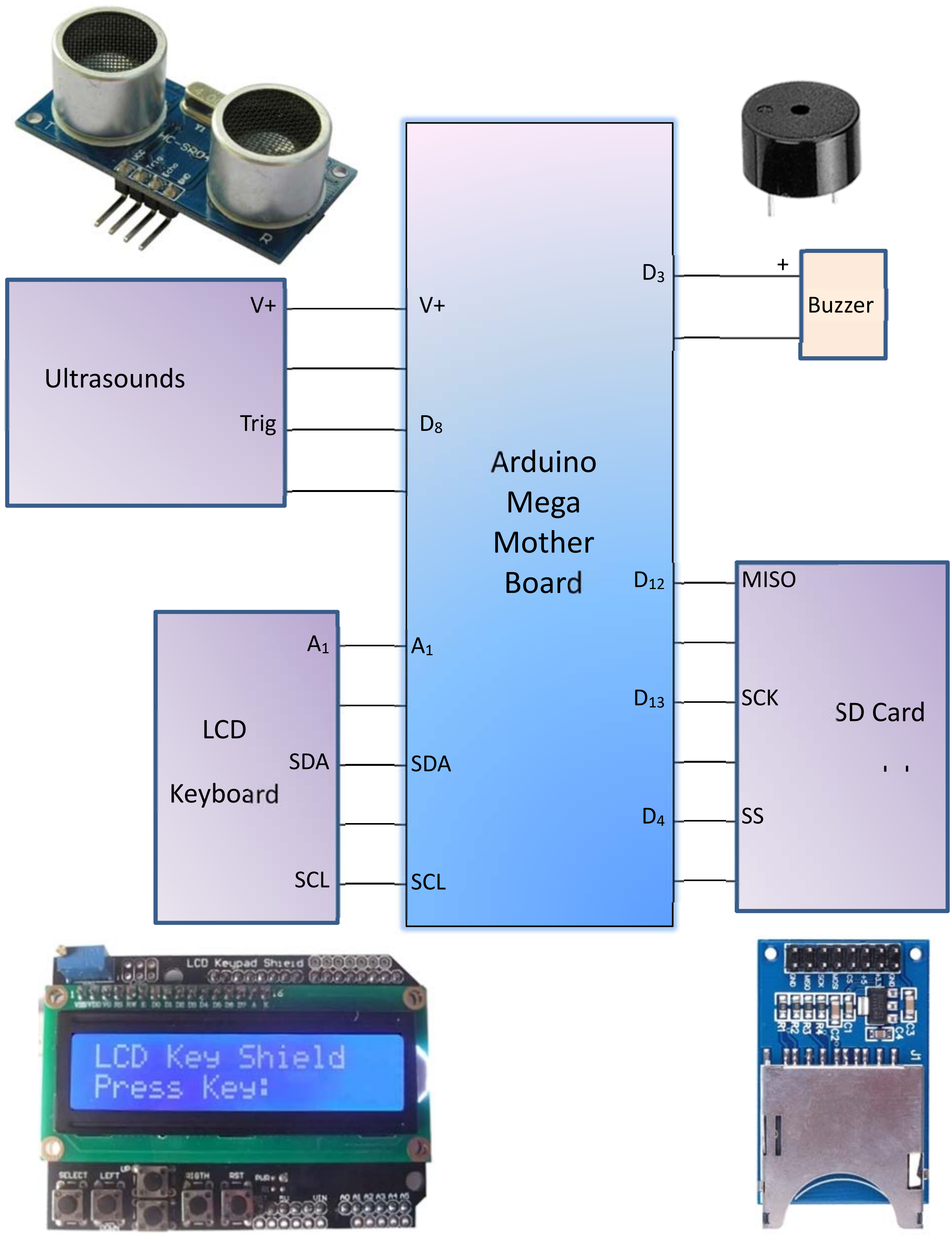
Appendix H4: Circuit diagrams for the Arduino devices

Circuits for Arduino-based Experiment 4
Acceleration in a Lift



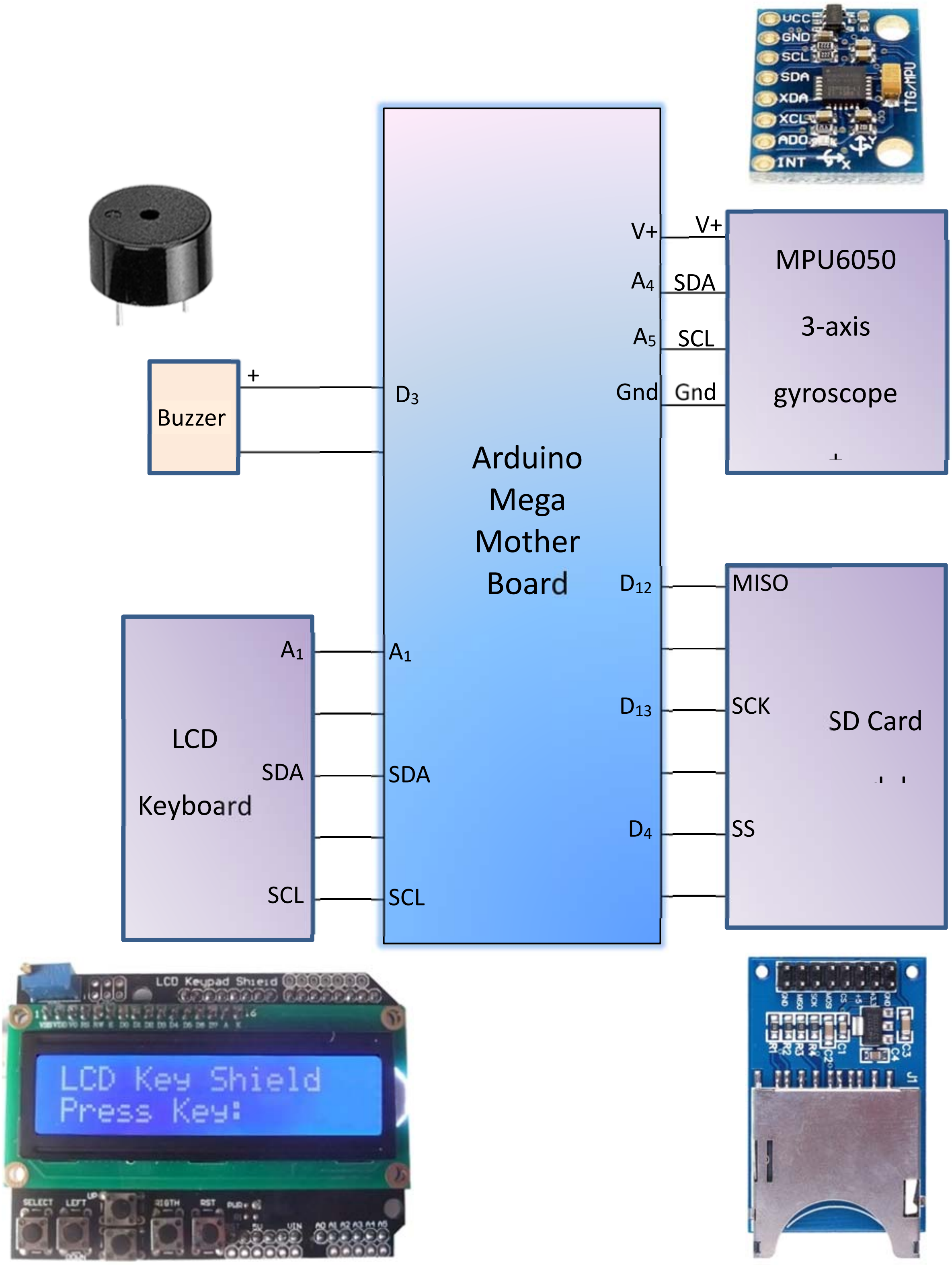
Appendix H5: Circuit diagrams for the Arduino devices

Circuits for Arduino-based Experiment 5
Inelastic Collision



Appendix H6: Circuit diagrams for the Arduino devices

Circuits for Arduino-based Experiment 6
Circular Motion



Appendix I: Statistics on the Arduino-based experiments in the Evaluation Phase of DBR

(53 records collected in seven experiments)

7 Expt. | 7 expt

Qno	Evaluation Items	total	"1"	"2"	"3"	"4"	Average
I1	Length of the experiment	53	0.0%	5.7%	73.6%	20.8%	3.15
I2	Difficulty level of the experiment	53	0.0%	1.9%	71.7%	26.4%	3.25

Qno	Evaluation Items	Total	"1"	"2"	"3"	"4"	"3"+"4"	Average
II1	recall and show understanding of the **facts, concepts, models and principles** of physics, and the relationships between different topic areas in the curriculum framework;	53	0.0%	1.9%	86.8%	11.3%	98.1%	3.09
II2	apply knowledge, concepts and principles of physics to **explain phenomena and observations**, and to **solve problems**;	53	0.0%	3.8%	73.6%	22.6%	96.2%	3.19
II3	show an understanding of the **use of apparatus** in performing experiments;	53	0.0%	3.8%	60.4%	35.8%	96.2%	3.32
II4	demonstrate an **understanding of the method** used in the study of physics;	53	0.0%	1.9%	69.8%	28.3%	98.1%	3.26
II5	**present data in various forms**, such as tables, graphs, charts, diagrams, and transpose them from one form into another;	53	0.0%	1.9%	56.6%	41.5%	98.1%	3.40
II6	**analyse and interpret data**, and draw appropriate conclusions;	53	0.0%	3.8%	56.6%	39.6%	96.2%	3.36
II7	show an understanding of the **treatment of errors**;	53	0.0%	5.7%	73.6%	20.8%	94.3%	3.15
II8	**select, organize, and communicate information** clearly, precisely and logically;	52	0.0%	3.8%	61.5%	34.6%	96.2%	3.31
II9	demonstrate understanding of the applications of **physics to daily life** and its contributions to the modern world;	53	0.0%	13.2%	56.6%	30.2%	86.8%	3.17
II10	show **awareness of the ethical, moral, social, economic and technological implications** of physics, and critically evaluate physics-related issues; and	50	4.0%	22.0%	68.0%	6.0%	74.0%	2.76
II11	**make suggestions, choices and judgments** based on the examination of evidence using knowledge and principles of physics.	51	3.9%	7.8%	70.6%	17.6%	88.2%	3.02
II12	Catering for **learner diversity**	52	0.0%	17.3%	67.3%	15.4%	82.7%	2.98
II13	Develop **interest** and arouse **curiosity** among students	51	0.0%	3.9%	62.7%	33.3%	96.1%	3.29
II14	Develop the ability to **think scientifically, critically and creatively**	51	0.0%	3.9%	54.9%	41.2%	96.1%	3.37
II15	Use of **IT skills**	48	0.0%	12.5%	37.5%	50.0%	87.5%	3.38
II16	Develop **Inquiry skills**	50	0.0%	6.0%	76.0%	18.0%	94.0%	3.12

Appendix J: Results of pre-test and post-test of FCI and TIPS II

Test	Question number	Intervention Group Pre-test	Intervention Group Post-test	Control Group Pre-test	Control Group Post-test
TIPSII	1	52.9%	53.3%	62.5%	60.0%
TIPSII	2	58.8%	86.7%	81.3%	66.7%
TIPSII	3	35.3%	60.0%	50.0%	53.3%
TIPSII	4	52.9%	60.0%	75.0%	46.7%
TIPSII	5	94.1%	86.7%	93.8%	80.0%
TIPSII	6	82.4%	80.0%	87.5%	93.3%
TIPSII	7	82.4%	73.3%	75.0%	86.7%
TIPSII	8	88.2%	80.0%	81.3%	86.7%
TIPSII	9	35.3%	13.3%	50.0%	26.7%
TIPSII	10	41.2%	60.0%	81.3%	80.0%
TIPSII	11	29.4%	40.0%	43.8%	53.3%
TIPSII	12	76.5%	66.7%	37.5%	26.7%
TIPSII	13	70.6%	73.3%	81.3%	86.7%
TIPSII	14	70.6%	46.7%	50.0%	66.7%
FCI	1	70.6%	66.7%	53.3%	78.6%
FCI	2	35.3%	40.0%	46.7%	35.7%
FCI	3	29.4%	26.7%	40.0%	64.3%
FCI	4	47.1%	60.0%	46.7%	78.6%
FCI	5	17.6%	26.7%	13.3%	35.7%
FCI	6	29.4%	40.0%	33.3%	42.9%
FCI	7	17.6%	13.3%	20.0%	21.4%
FCI	8	5.9%	20.0%	20.0%	21.4%
FCI	9	11.8%	20.0%	53.3%	35.7%
FCI	10	11.8%	13.3%	46.7%	28.6%
FCI	11	58.8%	66.7%	73.3%	57.1%
FCI	12	35.3%	60.0%	60.0%	50.0%

Appendix K1: Survey Results - Form I

(Intervention group of F.4 students of the 2012/16 cohort in the author's School)

			Percentage of choices							
No	Questions	Total	""	"1"	"2"	"3"	"4"	"5"	"4"+"5"	Average
A1	I use mobile device, tablet or PC to support my learning. e.g. web searching, reading, running educational Apps, simulation or virtual experiments, as a communication tools.	15	0.0%	20.0%	6.7%	33.3%	40.0%	0.0%	40.0%	2.93
A2	I use data loggers for capturing physical data in my science laboratory classes.	15	0.0%	20.0%	13.3%	46.7%	20.0%	0.0%	20.0%	2.67
A3	I conduct scientific investigations (or experiments) using sensors (e.g. light, motion, temperature, sound, acceleration…)	15	0.0%	26.7%	13.3%	46.7%	13.3%	0.0%	13.3%	2.47
A4	I use Excel for finding statistical results (calculating mean, maximum, minimum, number of counts…)	15	0.0%	33.3%	40.0%	20.0%	6.7%	0.0%	6.7%	2.00
A5	I use Excel for graph plotting, curve fitting.	15	0.0%	46.7%	13.3%	33.3%	6.7%	0.0%	6.7%	2.00
A6	I use open source hardware and software in science learning.	15	0.0%	40.0%	13.3%	46.7%	0.0%	0.0%	0.0%	2.07
B1	I am interested in applying Arduino technology in doing science experiments.	15	0.0%	0.0%	6.7%	20.0%	40.0%	33.3%	73.3%	4.00
B2	Arduino technology is useful in science investigation.	15	0.0%	0.0%	0.0%	13.3%	40.0%	46.7%	86.7%	4.33
B3	Arduino technology is useful for supporting science learning within the school.	15	0.0%	0.0%	0.0%	20.0%	40.0%	40.0%	80.0%	4.20
B4	Arduino technology is useful for supporting science learning outside the school.	15	0.0%	0.0%	0.0%	20.0%	66.7%	13.3%	80.0%	3.93
B5	I prefer to use Arduino based devices instead of traditional equipment to conduct scientific investigation.	15	0.0%	6.7%	6.7%	13.3%	53.3%	20.0%	73.3%	3.73
B6	Every secondary school student should be able to apply Arduino technology for science learning.	15	0.0%	6.7%	0.0%	26.7%	60.0%	6.7%	66.7%	3.60
C7	The activities as based on Arduino technology are interesting and stimulating to me.	15	0.0%	0.0%	0.0%	33.3%	46.7%	20.0%	66.7%	3.87
C8	I can carry out the Arduino based activities as expected	15	0.0%	0.0%	0.0%	13.3%	60.0%	26.7%	86.7%	4.13
C9	The Arduino based activities can enhance my learning of the course content as compared to the traditional one.	15	0.0%	6.7%	6.7%	26.7%	40.0%	20.0%	60.0%	3.60
C10	The Arduino based activities can enhance my motivation in learning the course.	15	0.0%	6.7%	6.7%	26.7%	26.7%	33.3%	60.0%	3.73
C11	I can apply similar Arduino technology in learning other science subjects.	15	0.0%	13.3%	13.3%	6.7%	40.0%	26.7%	66.7%	3.53
C12	The programmability of Arduino made it a versatile tool in scientific investigation.	15	0.0%	6.7%	0.0%	13.3%	46.7%	33.3%	80.0%	4.00

Appendix K2A: Survey Results - Form II

(Teachers + Technical Assistant + Laboratory Technician in the author's School)

No	Questions	Total	""	"1"	"2"	"3"	"4"	"5"	"4"+"5"	Average
1	It would be an interesting experience for students to apply Arduino technology in doing science experiments.	9	0.0%	0.0%	0.0%	11.1%	66.7%	22.2%	88.9%	4.11
2	The Arduino-based activities can arouse students' motivation in learning Science.	9	0.0%	0.0%	0.0%	11.1%	66.7%	22.2%	88.9%	4.11
3	Students would prefer using Arduino based-devices to traditional equipment in conducting scientific investigation.	9	0.0%	0.0%	0.0%	11.1%	77.8%	11.1%	88.9%	4.00
4	Students are capable of carrying out on their own the Arduino based experiments demonstrated.	9	0.0%	0.0%	0.0%	55.6%	33.3%	11.1%	44.4%	3.56
5	As compared to the traditional method, the Arduino-based activities can enhance students' learning of the course content.	9	0.0%	0.0%	0.0%	11.1%	77.8%	11.1%	88.9%	4.00
6	Arduino technology is useful for developing students-hand skills in science learning within the school.	9	0.0%	0.0%	11.1%	11.1%	55.6%	22.2%	77.8%	3.89
7	Arduino technology is useful for developing students-hand skills in science learning outside the school.	9	0.0%	0.0%	11.1%	0.0%	55.6%	33.3%	88.9%	4.11
8	The Arduino system is a powerful tool for enhancing students' ability in scientific investigation.	9	0.0%	0.0%	0.0%	11.1%	55.6%	33.3%	88.9%	4.22
9	Apart from physics, similar Arduino technology should be applied in learning other science subjects.	9	0.0%	0.0%	0.0%	22.2%	55.6%	22.2%	77.8%	4.00
10	For STEM education, every secondary school student should be able to apply Arduino technology for science learning.	9	0.0%	0.0%	11.1%	55.6%	22.2%	11.1%	33.3%	3.33
11	The Arduino-based activities can help to promote STEM education in schools.	9	0.0%	0.0%	0.0%	22.2%	66.7%	11.1%	77.8%	3.89
12	The relatively low cost of the Arduino systems would be conducive in promoting Science Education.	9	0.0%	0.0%	0.0%	22.2%	33.3%	44.4%	77.8%	4.22
13	The versatility (programmability, connection to different sensors, output device and wireless device...) the Arduino system makes it useful in Science teaching and learning.	9	0.0%	0.0%	0.0%	33.3%	44.4%	22.2%	66.7%	3.89

Appendix K2B: Survey Results - Form II

(Singaporean Teachers in OEIR 2016)

No	Questions	Total	""	"1"	"2"	"3"	"4"	"5"	"4"+"5"	Average
1	It would be an interesting experience for students to apply Arduino technology in doing science experiments.	130	0.8%	0.0%	0.0%	2.3%	64.6%	33.1%	97.7%	4.31
2	The Arduino-based activities can arouse students' motivation in learning Science.	131	0.0%	0.0%	0.8%	5.3%	61.8%	32.1%	93.9%	4.25
3	Students would prefer using Arduino based-devices to traditional equipment in conducting scientific investigation.	130	0.8%	0.0%	2.3%	26.9%	47.7%	23.1%	70.8%	3.92
4	Students are capable of carrying out on their own the Arduino based experiments demonstrated.	131	0.0%	0.8%	11.5%	32.1%	44.3%	11.5%	55.7%	3.54
5	As compared to the traditional method, the Arduino-based activities can enhance students' learning of the course content.	131	0.0%	0.0%	0.0%	17.6%	69.5%	13.0%	82.4%	3.95
6	Arduino technology is useful for developing students-hand skills in science learning within the school.	131	0.0%	0.0%	0.0%	7.6%	69.5%	22.9%	92.4%	4.15
7	Arduino technology is useful for developing students-hand skills in science learning outside the school.	130	0.8%	0.0%	0.8%	11.5%	64.6%	23.1%	87.7%	4.10
8	The Arduino system is a powerful tool for enhancing students' ability in scientific investigation.	131	0.0%	0.0%	0.0%	4.6%	61.8%	33.6%	95.4%	4.29
9	Apart from physics, similar Arduino technology should be applied in learning other science subjects.	130	0.8%	0.0%	0.8%	11.5%	56.9%	30.8%	87.7%	4.18
10	For STEM education, every secondary school student should be able to apply Arduino technology for science learning.	131	0.0%	0.0%	3.1%	15.3%	58.0%	23.7%	81.7%	4.02
11	The Arduino-based activities can help to promote STEM education in schools.	130	0.8%	0.0%	0.8%	10.0%	57.7%	31.5%	89.2%	4.20
12	The relatively low cost of the Arduino systems would be conducive in promoting Science Education.	131	0.0%	0.0%	0.0%	6.9%	54.2%	38.9%	93.1%	4.32
13	The versatility (programmability, connection to different sensors, output device and wireless device...) the Arduino system makes it useful in Science teaching and learning.	131	0.0%	0.0%	0.0%	6.1%	55.7%	38.2%	93.9%	4.32

Appendix K2C: Survey Results - Form II

(Hong Kong Teachers in STEM Olympiad 2016)

No	Questions	Total	""	"1"	"2"	"3"	"4"	"5"	"4"+"5"	Average
1	It would be an interesting experience for students to apply Arduino technology in doing science experiments.	14	0.0%	0.0%	0.0%	0.0%	50.0%	50.0%	100.0%	4.50
2	The Arduino-based activities can arouse students' motivation in learning Science.	14	0.0%	0.0%	0.0%	7.1%	50.0%	42.9%	92.9%	4.36
3	Students would prefer using Arduino based-devices to traditional equipment in conducting scientific investigation.	14	0.0%	0.0%	0.0%	35.7%	35.7%	28.6%	64.3%	3.93
4	Students are capable of carrying out on their own the Arduino based experiments demonstrated.	14	0.0%	0.0%	0.0%	14.3%	42.9%	42.9%	85.7%	4.29
5	As compared to the traditional method, the Arduino-based activities can enhance students' learning of the course content.	14	0.0%	0.0%	0.0%	28.6%	42.9%	28.6%	71.4%	4.00
6	Arduino technology is useful for developing students-hand skills in science learning within the school.	14	0.0%	0.0%	0.0%	7.1%	71.4%	21.4%	92.9%	4.14
7	Arduino technology is useful for developing students-hand skills in science learning outside the school.	14	0.0%	0.0%	0.0%	7.1%	64.3%	28.6%	92.9%	4.21
8	The Arduino system is a powerful tool for enhancing students' ability in scientific investigation.	14	0.0%	0.0%	0.0%	0.0%	57.1%	42.9%	100.0%	4.43
9	Apart from physics, similar Arduino technology should be applied in learning other science subjects.	14	0.0%	0.0%	0.0%	7.1%	57.1%	35.7%	92.9%	4.29
10	For STEM education, every secondary school student should be able to apply Arduino technology for science learning.	14	0.0%	0.0%	0.0%	21.4%	57.1%	21.4%	78.6%	4.00
11	The Arduino-based activities can help to promote STEM education in schools.	14	0.0%	0.0%	0.0%	0.0%	64.3%	35.7%	100.0%	4.36
12	The relatively low cost of the Arduino systems would be conducive in promoting Science Education.	14	0.0%	0.0%	0.0%	0.0%	42.9%	57.1%	100.0%	4.57
13	The versatility (programmability, connection to different sensors, output device and wireless device...) the Arduino system makes it useful in Science teaching and learning.	14	0.0%	0.0%	0.0%	14.3%	42.9%	42.9%	85.7%	4.29

Appendix K2D: Survey Results - Form II

(Students in STEM Olympiad 2016)

No	Questions	Total	""	"1"	"2"	"3"	"4"	"5"	"4"+"5"	Average
1	It would be an interesting experience for students to apply Arduino technology in doing science experiments.	24	0.0%	0.0%	0.0%	4.2%	54.2%	41.7%	95.8%	4.38
2	The Arduino-based activities can arouse students' motivation in learning Science.	24	0.0%	0.0%	0.0%	8.3%	54.2%	37.5%	91.7%	4.29
3	Students would prefer using Arduino based-devices to traditional equipment in conducting scientific investigation.	24	0.0%	0.0%	0.0%	29.2%	37.5%	33.3%	70.8%	4.04
4	Students are capable of carrying out on their own the Arduino based experiments demonstrated.	24	0.0%	0.0%	4.2%	20.8%	45.8%	29.2%	75.0%	4.00
5	As compared to the traditional method, the Arduino-based activities can enhance students' learning of the course content.	24	0.0%	0.0%	4.2%	12.5%	41.7%	41.7%	83.3%	4.21
6	Arduino technology is useful for developing students-hand skills in science learning within the school.	24	0.0%	0.0%	0.0%	4.2%	58.3%	37.5%	95.8%	4.33
7	Arduino technology is useful for developing students-hand skills in science learning outside the school.	24	0.0%	0.0%	0.0%	25.0%	37.5%	37.5%	75.0%	4.13
8	The Arduino system is a powerful tool for enhancing students' ability in scientific investigation.	23	4.3%	0.0%	0.0%	8.7%	43.5%	47.8%	91.3%	4.39
9	Apart from physics, similar Arduino technology should be applied in learning other science subjects.	24	0.0%	0.0%	0.0%	16.7%	45.8%	37.5%	83.3%	4.21
10	For STEM education, every secondary school student should be able to apply Arduino technology for science learning.	24	0.0%	4.2%	0.0%	20.8%	33.3%	41.7%	75.0%	4.08
11	The Arduino-based activities can help to promote STEM education in schools.	24	0.0%	0.0%	0.0%	29.2%	41.7%	29.2%	70.8%	4.00
12	The relatively low cost of the Arduino systems would be conducive in promoting Science Education.	24	0.0%	0.0%	0.0%	12.5%	41.7%	45.8%	87.5%	4.33
13	The versatility (programmability, connection to different sensors, output device and wireless device...) the Arduino system makes it useful in Science teaching and learning.	24	0.0%	0.0%	0.0%	8.3%	33.3%	58.3%	91.7%	4.50

Appendix K2E: Survey Results - Form II

HK Teacher Group = (Teachers in STEM Olympiad 2016) + (Teachers + Technical Assistant + Laboratory Technician in the author's School)

No	Questions	Total	""	"1"	"2"	"3"	"4"	"5"	"4"+"5"	Average
1	It would be an interesting experience for students to apply Arduino technology in doing science experiments.	23	0.0%	0.0%	0.0%	4.3%	56.5%	39.1%	95.7%	4.35
2	The Arduino-based activities can arouse students' motivation in learning Science.	23	0.0%	0.0%	0.0%	8.7%	56.5%	34.8%	91.3%	4.26
3	Students would prefer using Arduino based-devices to traditional equipment in conducting scientific investigation.	23	0.0%	0.0%	0.0%	26.1%	52.2%	21.7%	73.9%	3.96
4	Students are capable of carrying out on their own the Arduino based experiments demonstrated.	23	0.0%	0.0%	0.0%	30.4%	39.1%	30.4%	69.6%	4.00
5	As compared to the traditional method, the Arduino-based activities can enhance students' learning of the course content.	23	0.0%	0.0%	0.0%	21.7%	56.5%	21.7%	78.3%	4.00
6	Arduino technology is useful for developing students-hand skills in science learning within the school.	23	0.0%	0.0%	4.3%	8.7%	65.2%	21.7%	87.0%	4.04
7	Arduino technology is useful for developing students-hand skills in science learning outside the school.	23	0.0%	0.0%	4.3%	4.3%	60.9%	30.4%	91.3%	4.17
8	The Arduino system is a powerful tool for enhancing students' ability in scientific investigation.	23	0.0%	0.0%	0.0%	4.3%	56.5%	39.1%	95.7%	4.35
9	Apart from physics, similar Arduino technology should be applied in learning other science subjects.	23	0.0%	0.0%	0.0%	13.0%	56.5%	30.4%	87.0%	4.17
10	For STEM education, every secondary school student should be able to apply Arduino technology for science learning.	23	0.0%	0.0%	4.3%	34.8%	43.5%	17.4%	60.9%	3.74
11	The Arduino-based activities can help to promote STEM education in schools.	23	0.0%	0.0%	0.0%	8.7%	65.2%	26.1%	91.3%	4.17
12	The relatively low cost of the Arduino systems would be conducive in promoting Science Education.	23	0.0%	0.0%	0.0%	8.7%	39.1%	52.2%	91.3%	4.43
13	The versatility (programmability, connection to different sensors, output device and wireless device...) the Arduino system makes it useful in Science teaching and learning.	23	0.0%	0.0%	0.0%	21.7%	43.5%	34.8%	78.3%	4.13

Appendix K2F: Survey Results - Form II

(Singaporean Teachers in OEIR versus Hong Kong Teachers)

No	Questions	OEIR Total	OEIR "4"+"5"	OEIR Average	HKT Total	HKT "4"+"5"	HKT Average
1	It would be an interesting experience for students to apply Arduino technology in doing science experiments.	130	97.7%	4.31	23	95.7%	4.35
2	The Arduino-based activities can arouse students' motivation in learning Science.	131	93.9%	4.25	23	91.3%	4.26
3	Students would prefer using Arduino based-devices to traditional equipment in conducting scientific investigation.	130	70.8%	3.92	23	73.9%	3.96
4	Students are capable of carrying out on their own the Arduino based experiments demonstrated.	131	55.7%	3.54	23	69.6%	4.00
5	As compared to the traditional method, the Arduino-based activities can enhance students' learning of the course content.	131	82.4%	3.95	23	78.3%	4.00
6	Arduino technology is useful for developing students-hand skills in science learning within the school.	131	92.4%	4.15	23	87.0%	4.04
7	Arduino technology is useful for developing students-hand skills in science learning outside the school.	130	87.7%	4.10	23	91.3%	4.17
8	The Arduino system is a powerful tool for enhancing students' ability in scientific investigation.	131	95.4%	4.29	23	95.7%	4.35
9	Apart from physics, similar Arduino technology should be applied in learning other science subjects.	130	87.7%	4.18	23	87.0%	4.17
10	For STEM education, every secondary school student should be able to apply Arduino technology for science learning.	131	81.7%	4.02	23	60.9%	3.74
11	The Arduino-based activities can help to promote STEM education in schools.	130	89.2%	4.20	23	91.3%	4.17
12	The relatively low cost of the Arduino systems would be conducive in promoting Science Education.	131	93.1%	4.32	23	91.3%	4.43
13	The versatility (programmability, connection to different sensors, output device and wireless device...) the Arduino system makes it useful in Science teaching and learning.	131	93.9%	4.32	23	78.3%	4.13

Appendix L1: Mind-map – ALL data collected in the study

SID		No
SAI41	✓	95
SAI42	✓	90
SAI43	✓	92
SAI44	✓	53
SAI45	✓	91
SAI46	✓	104
SAI6	✓	191
SAC4	✓	69
SOCS	✓	15
TAIB	✓	95
TAID	✓	59
TAIE	✓	63
TAIF	✓	52
TAIT	✓	104
TAC	✓	16
TOCO	✓	346
TOCS	✓	9
		1544

Total 1544 100.0%

A	218	14.1%
E	321	20.8%
T	545	35.3%
C	297	19.2%
X	155	10.0%
NA	8	0.5%

A-	19	8.7%
A+	183	83.9%
A=	16	7.3%
Atotal	218	100.0%
E-	33	10.3%
E+	267	83.2%
E=	21	6.5%
Etotal	321	100.0%
T-	17	3.1%
T+	503	92.3%
T=	25	4.6%
Ttotal	545	100.0%
C-	243	81.8%
C+	34	11.4%
C=	20	6.7%
Ctotal	297	100.0%
X-	13	8.4%
X+	132	85.2%
X=	10	6.5%
Xtotal	155	100.0%
NA	8	

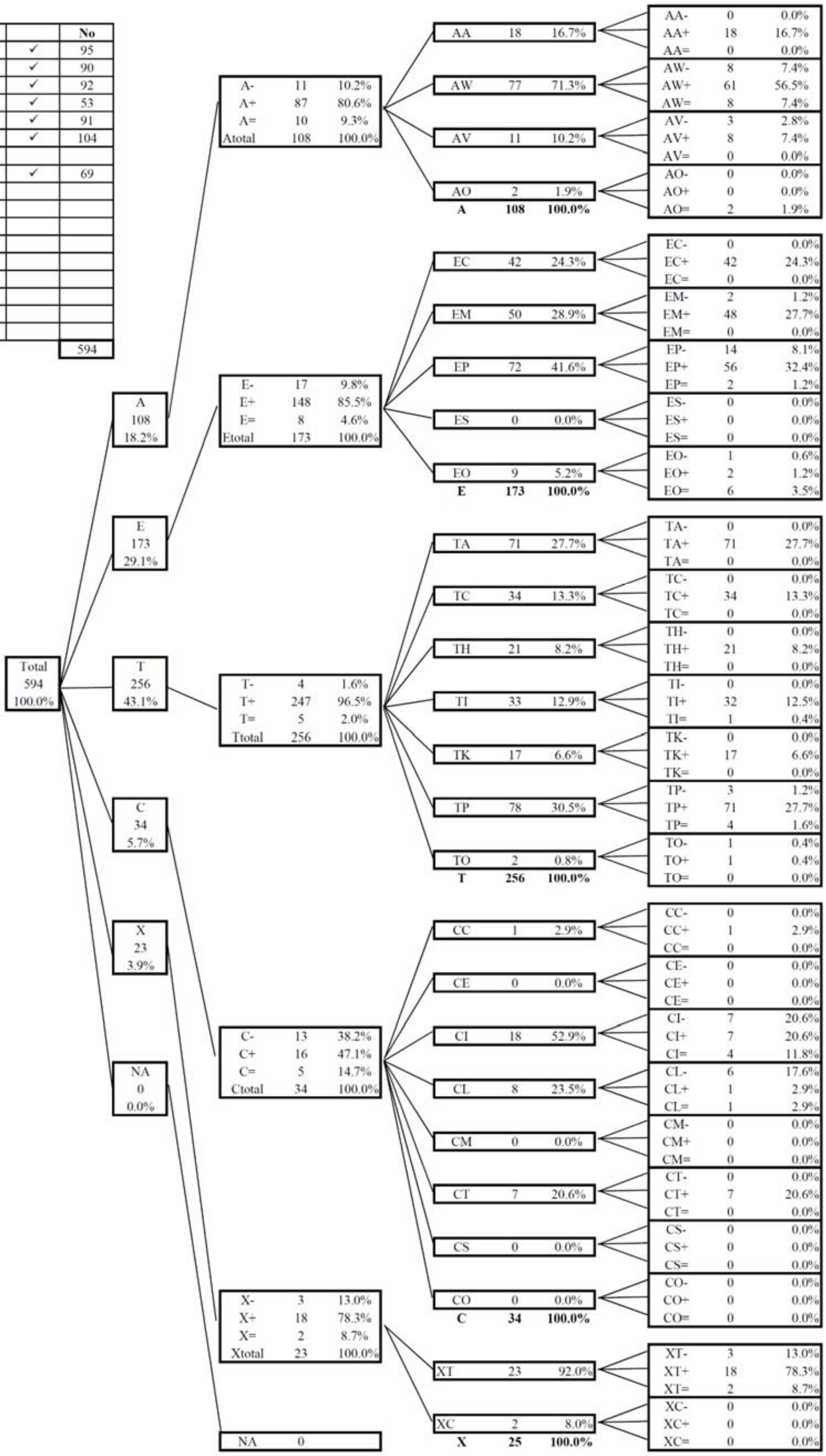
AA	42	19.3%
AW	134	61.5%
AV	37	17.0%
AO	5	2.3%
A	**218**	**100.0%**
EC	75	23.4%
EM	91	28.3%
EP	137	42.7%
ES	0	0.0%
EO	18	5.6%
E	**321**	**100.0%**
TA	128	23.5%
TC	58	10.6%
TH	57	10.5%
TI	88	16.1%
TK	59	10.8%
TP	149	27.3%
TO	6	1.1%
T	**545**	**100.0%**
CC	17	5.7%
CE	15	5.1%
CI	58	19.5%
CL	50	16.8%
CM	29	9.8%
CT	61	20.5%
CS	52	17.5%
CO	15	5.1%
C	**297**	**100.0%**
XT	76	49.0%
XC	79	51.0%
X	**155**	**100.0%**

AA-	0	0.0%
AA+	42	19.3%
AA=	0	0.0%
AW-	15	6.9%
AW+	108	49.5%
AW=	11	5.0%
AV-	3	1.4%
AV+	33	15.1%
AV=	1	0.5%
AO-	1	0.5%
AO+	0	0.0%
AO=	4	1.8%
EC-	2	0.6%
EC+	73	22.7%
EC=	0	0.0%
EM-	6	1.9%
EM+	83	25.9%
EM=	2	0.6%
EP-	22	6.9%
EP+	108	33.6%
EP=	7	2.2%
ES-	0	0.0%
ES+	0	0.0%
ES=	0	0.0%
EO-	3	0.9%
EO+	3	0.9%
EO=	12	3.7%
TA-	5	0.9%
TA+	122	22.4%
TA=	1	0.2%
TC-	0	0.0%
TC+	58	10.6%
TC=	0	0.0%
TH-	0	0.0%
TH+	54	9.9%
TH=	3	0.6%
TI-	0	0.0%
TI+	86	15.8%
TI=	2	0.4%
TK-	1	0.2%
TK+	57	10.5%
TK=	1	0.2%
TP-	9	1.7%
TP+	122	22.4%
TP=	18	3.3%
TO-	2	0.4%
TO+	4	0.7%
TO=	0	0.0%
CC-	10	3.4%
CC+	6	2.0%
CC=	1	0.3%
CE-	13	4.4%
CE+	2	0.7%
CE=	0	0.0%
CI-	44	14.8%
CI+	8	2.7%
CI=	6	2.0%
CL-	43	14.5%
CL+	3	1.0%
CL=	4	1.3%
CM-	29	9.8%
CM+	0	0.0%
CM=	0	0.0%
CT-	52	17.5%
CT+	8	2.7%
CT=	1	0.3%
CS-	49	16.5%
CS+	1	0.3%
CS=	2	0.7%
CO-	3	1.0%
CO+	6	2.0%
CO=	6	2.0%
XT-	6	7.9%
XT+	65	85.5%
XT=	5	6.6%
XC-	7	8.9%
XC+	67	84.8%
XC=	5	6.3%

Appendix L1: Mind-map – Phase I

(Intervention Group of F.4 students in 2015/16 cohort in the author's school)

SID		No
SAI41	✓	95
SAI42	✓	90
SAI43	✓	92
SAI44	✓	53
SAI45	✓	91
SAI46	✓	104
SAI6		
SAC4	✓	69
SOCS		
TAIB		
TAID		
TAIE		
TAIF		
TAIT		
TAC		
TOCO		
TOCS		
		594



Appendix L2: Mind-map – Phase I – F.6 students in 2015/16 cohort in the author’s School

SID		No
SAI41		
SAI42		
SAI43		
SAI44		
SAI45		
SAI46		
SAI6	✓	191
SAC4		
SOCS		
TAIB		
TAID		
TAIE		
TAIF		
TAIT		
TAC		
TOCO		
TOCS		
		191

Total	191	100.0%

A	8	4.2%
E	27	14.1%
T	38	19.9%
C	6	3.1%
X	104	54.5%
NA	8	4.2%

A-	0	0.0%
A+	8	100.0%
A=	0	0.0%
Atotal	8	100.0%

AA	4	50.0%	AA-	0	0.0%
			AA+	4	50.0%
			AA=	0	0.0%
AW	2	25.0%	AW-	0	0.0%
			AW+	2	25.0%
			AW=	0	0.0%
AV	2	25.0%	AV-	0	0.0%
			AV+	2	25.0%
			AV=	0	0.0%
AO	0	0.0%	AO-	0	0.0%
			AO+	0	0.0%
			AO=	0	0.0%
A	**8**	**100.0%**			

E-	4	14.8%
E+	18	66.7%
E=	5	18.5%
Etotal	27	100.0%

EC	4	14.8%	EC-	0	0.0%
			EC+	4	14.8%
			EC=	0	0.0%
EM	9	33.3%	EM-	1	3.7%
			EM+	6	22.2%
			EM=	2	7.4%
EP	14	51.9%	EP-	3	11.1%
			EP+	8	29.6%
			EP=	3	11.1%
ES	0	0.0%	ES-	0	0.0%
			ES+	0	0.0%
			ES=	0	0.0%
EO	0	0.0%	EO-	0	0.0%
			EO+	0	0.0%
			EO=	0	0.0%
E	**27**	**100.0%**			

T-	1	2.6%
T+	29	76.3%
T=	8	21.1%
Ttotal	38	100.0%

TA	2	5.3%	TA-	0	0.0%
			TA+	2	5.3%
			TA=	0	0.0%
TC	0	0.0%	TC-	0	0.0%
			TC+	0	0.0%
			TC=	0	0.0%
TH	4	10.5%	TH-	0	0.0%
			TH+	4	10.5%
			TH=	0	0.0%
TI	11	28.9%	TI-	0	0.0%
			TI+	11	28.9%
			TI=	0	0.0%
TK	1	2.6%	TK-	0	0.0%
			TK+	1	2.6%
			TK=	0	0.0%
TP	20	52.6%	TP-	1	2.6%
			TP+	11	28.9%
			TP=	8	21.1%
TO	0	0.0%	TO-	0	0.0%
			TO+	0	0.0%
			TO=	0	0.0%
T	**38**	**100.0%**			

C-	4	66.7%
C+	0	0.0%
C=	2	33.3%
Ctotal	6	100.0%

CC	0	0.0%	CC-	0	0.0%
			CC+	0	0.0%
			CC=	0	0.0%
CE	0	0.0%	CE-	0	0.0%
			CE+	0	0.0%
			CE=	0	0.0%
CI	0	0.0%	CI-	0	0.0%
			CI+	0	0.0%
			CI=	0	0.0%
CL	3	50.0%	CL-	3	50.0%
			CL+	0	0.0%
			CL=	0	0.0%
CM	0	0.0%	CM-	0	0.0%
			CM+	0	0.0%
			CM=	0	0.0%
CT	0	0.0%	CT-	0	0.0%
			CT+	0	0.0%
			CT=	0	0.0%
CS	3	50.0%	CS-	1	16.7%
			CS+	0	0.0%
			CS=	2	33.3%
CO	0	0.0%	CO-	0	0.0%
			CO+	0	0.0%
			CO=	0	0.0%
C	**6**	**100.0%**			

X-	8	7.7%
X+	91	87.5%
X=	5	4.8%
Xtotal	104	100.0%

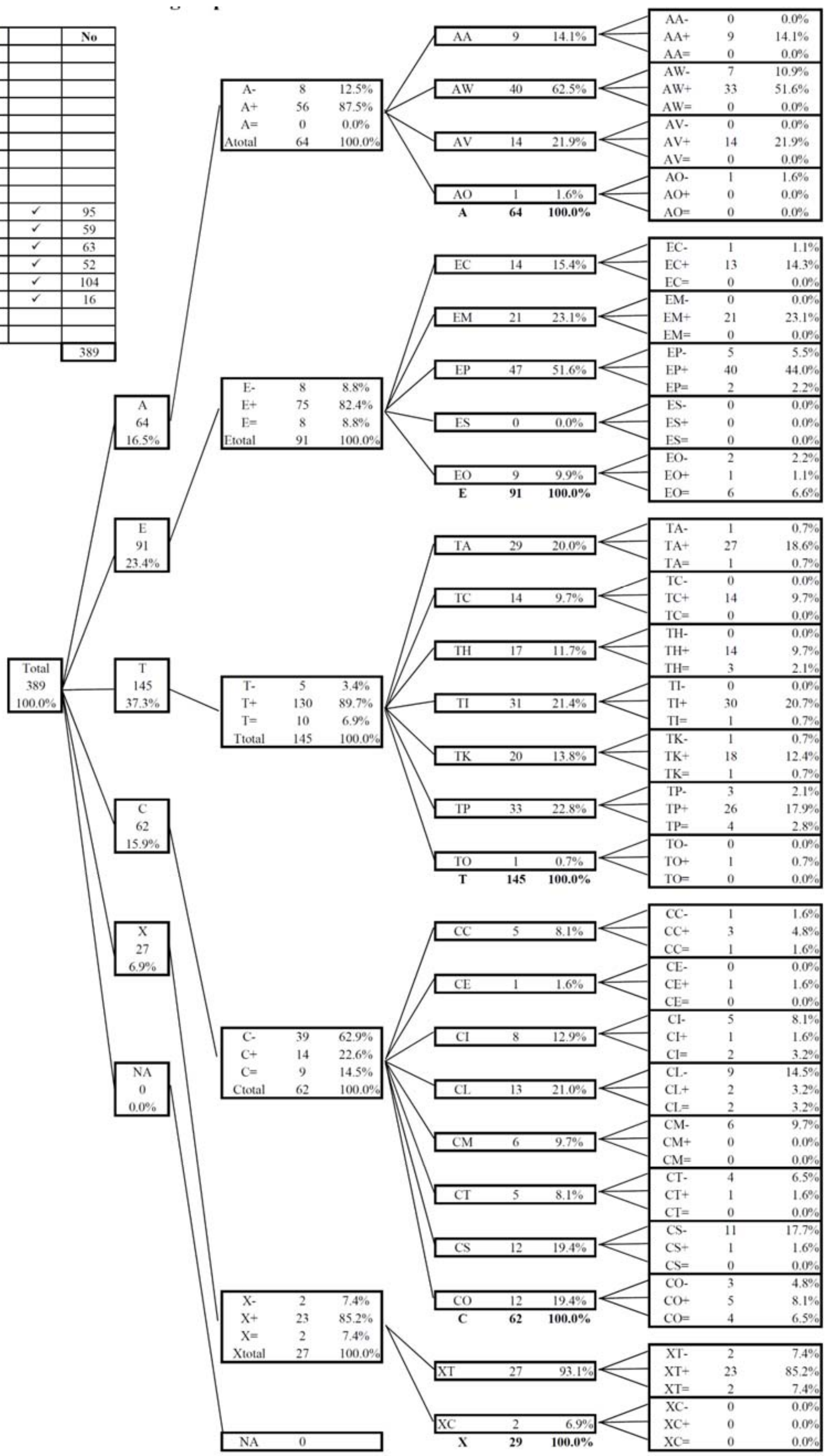
XT	25	25.3%	XT-	1	4.0%
			XT+	24	96.0%
			XT=	0	0.0%
XC	74	74.7%	XC-	7	9.5%
			XC+	67	90.5%
			XC=	5	6.8%
X	**99**	**100.0%**			

NA	8

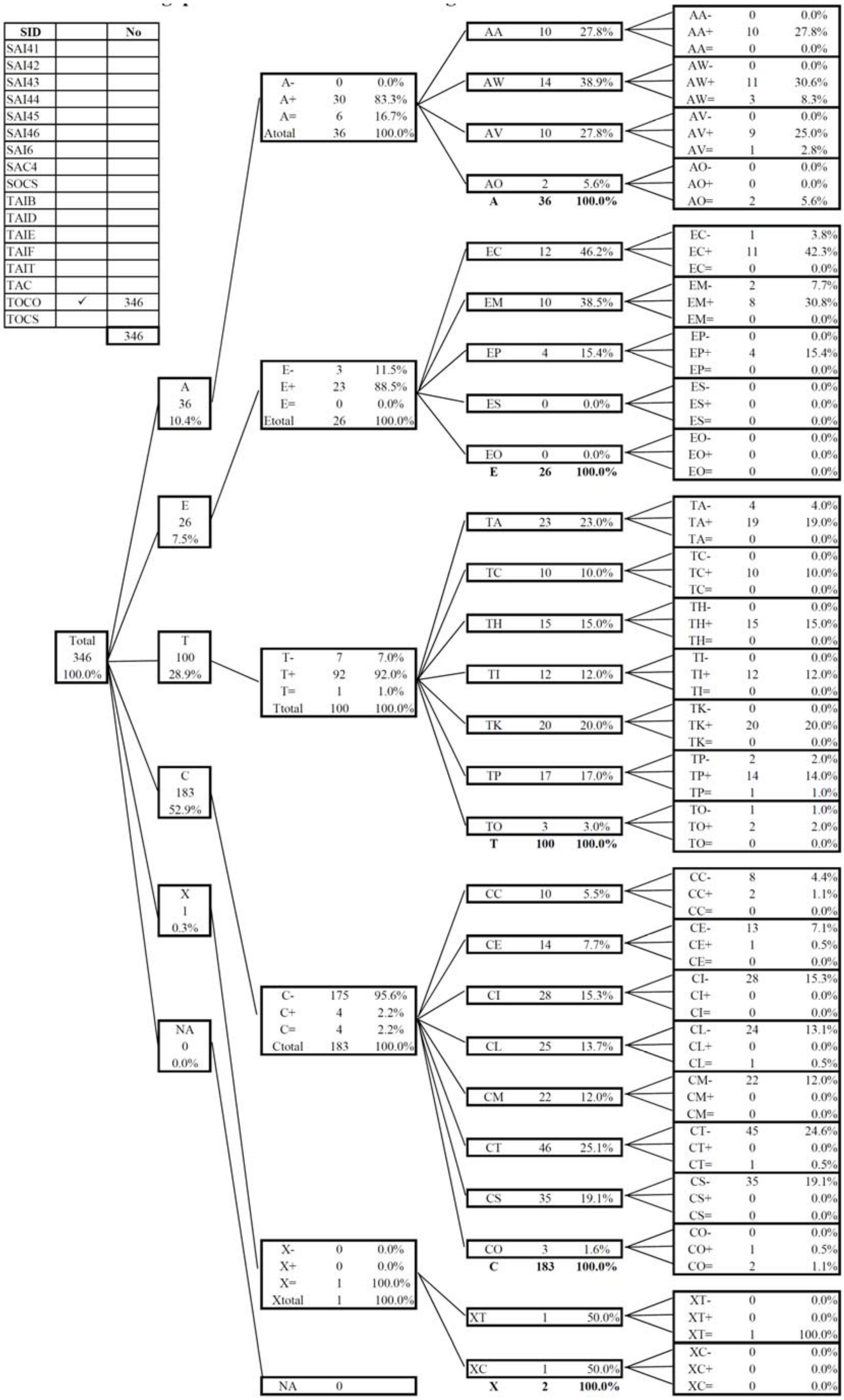
Appendix L3: Mind-map – Phase I

(Teacher + laboratory technician + technical assistant in the author's school)

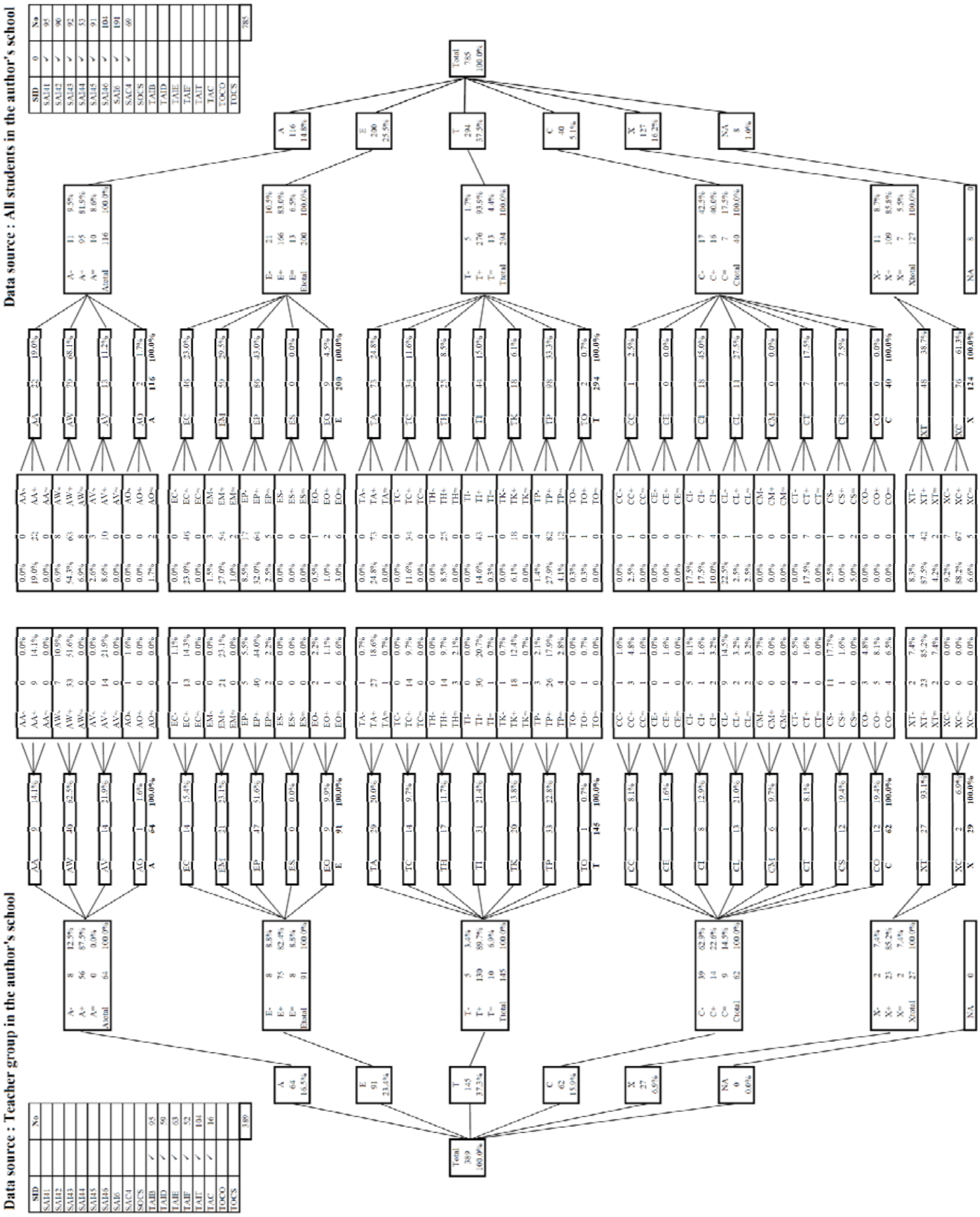
SID		No
SAI41		
SAI42		
SAI43		
SAI44		
SAI45		
SAI46		
SAI6		
SAC4		
SOCS		
TAIB	✓	95
TAID	✓	59
TAIE	✓	63
TAIF	✓	52
TAIT	✓	104
TAC	✓	16
TOCO		
TOCS		
		389



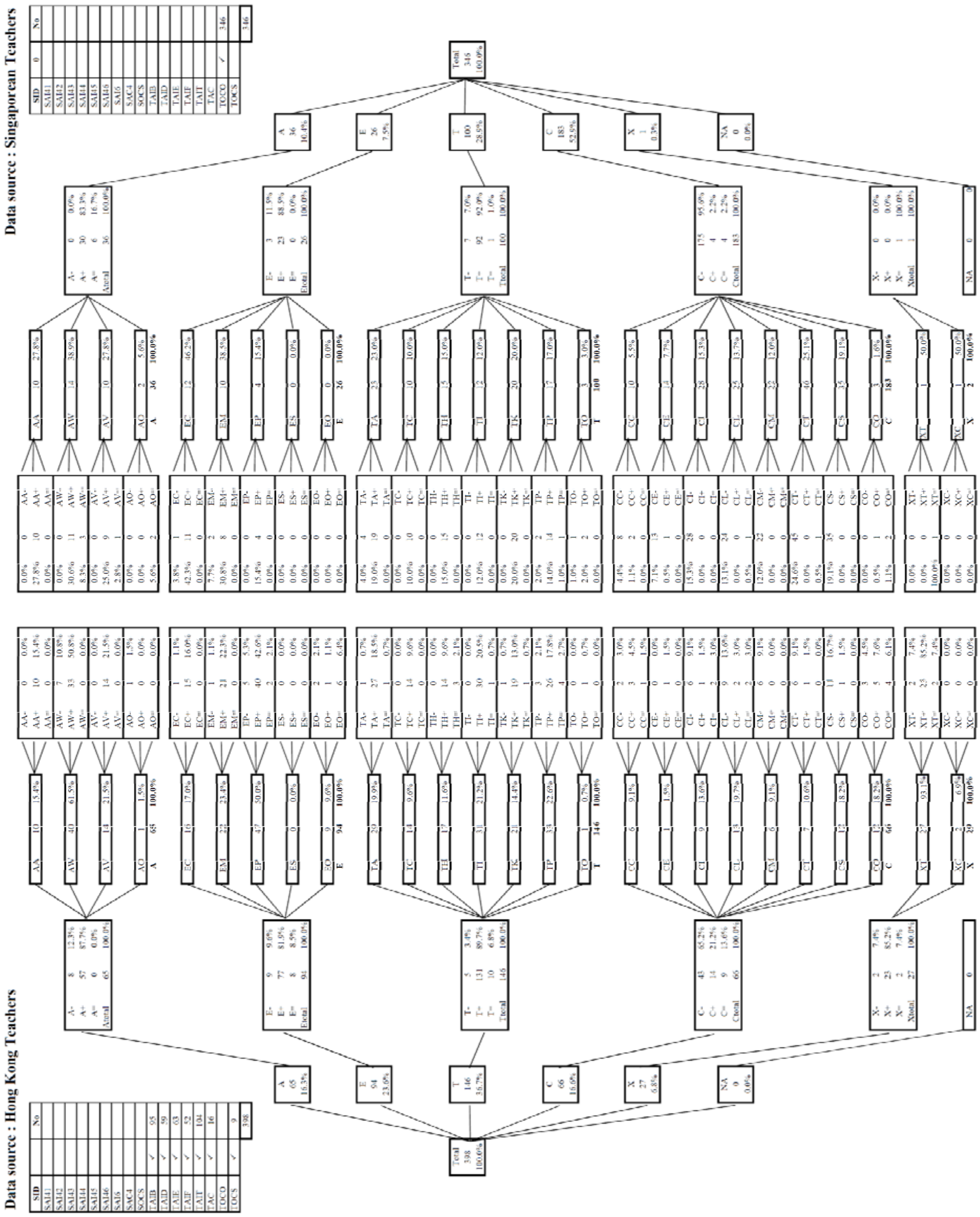
Appendix L4: Mind-map – Phase II – Singaporean teachers in OEIR Progromme 2016



Appendix L5: Mind map – Teacher group versus student group in the author's school



Appendix L6: Mind map – Hong Kong teachers versus Singaporean teachers



Appendix M: Sample of codes in the CATEX coding system

Code	Comment/ Feedback/ Opinion	SID-No
AA+	F4S7: The cost of ownership is low. Even if the Arduino device were broken, they would not cost much.	SAI43-22
AA+	Cheap and low cost. Therefore more sets could be given to each class.	TOCO-59
AO-	If user friendly interface can be developed for student use, it is better for students to use other software.	TAC-11
AO=	F4S14: The label on the Arduino keypad was a bit small to read.	SAI45-73
AO=	Arduino may not be for everyone.	TOCO-225

Code	Comment/ Feedback/ Opinion	SID
AV-	F4S12: However, some experiments cannot not be replaced by the Arduino-based experiments.	SAI45-69
AV-	F4S13: The Arduino-based experiments may not be useful for simple experiments.	SAI45-70
AV+	F4S16: The same Arduino mother board could be used to perform many other different experiments only by changing the sensors (or program).	SAI46-69
AV+	The flexibility to build almost anything for own experiment is highly valued.	TOCO-85
AV=	Could accelerometers and GPS functionality in smart phone be used?	TOCO-345

Code	Comment/ Feedback/ Opinion	SID
AW-	F4S7: The single board computer was a bit slow.	SAI43-88
AW-	F4S16: The Arduino device got no protection. They were fragile and might easily be damaged.	SAI46-101
AW+	Arduino apparatus was highly portable (or wearable) to carry around to do experiments. e.g. g-sensors in measuring acceleration in a lift.	TAID-33
AW+	(Arduino is) powerful and effective tool…in obtaining experimental data…and analyzing the data collected.	TOCO-50
AW=	F4S3, F4S2, F4S1: We knew that the Arduino apparatus had to be driven by a program.	SAI41-11
AW=	F4S16: The size of the Arduino apparatus could further be reduced.	SAI46-99
Code	Comment/ Feedback/ Opinion	SID
CC-	There may not be enough time in our curriculum to do this.	TOCO-183
CC-	May have to re-teach to align it to the syllabus	TOCO-192
CC+	The experiments were well designed and matched the requirement of the NSS syllabus.	TAIE-26

CC+	….even further programming applications (computer science, robotics, electrical engineering, app creation) can also be considered to be taught at the secondary level.	TOCO-33
CC=	… and curriculum development is also a must so that the applications are within students' learning curriculum.	TAC-13

Code	Comment/ Feedback/ Opinion	SID
CE-	(difficulty in) acquisition of equipment as well.	TOCO-156
CE-	In an education system with high-stakes testing like Singapore, teachers may feel such innovative processes have limited returns compared to tried and tested, drill and practice.	TOCO-168
CE+	The class size in the school was small so that individual needs could be entertained.	TAID-42
CE+	will look forward to the ministry providing support for such tools in our classrooms.	TOCO-341

Code	Comment/ Feedback/ Opinion	SID
CI-	More time could be spent to provide step-by-step guidance for students to use Excel, plot out and print out the graphs, etc.	TAIE-5
CI-	There is a high barrier with regards to ICT skills for both teachers and students	TOCO-253
CI+	Students nowadays can manage to use computer well and quickly, e.g. skills in plotting graph and verifying data with Excel.	TAID-2
CI+	F4S5: Arduino motivated me in learning Arduino programming.	SAI42-71
CI=	Grasp of IT skills could facilitate students to carry out the Arduino-based experiments.	TAIE-6
CI=	F4S2: Some students thought that knowing how to write program would help do the experiment better.	SAI41-14

Code	Comment/ Feedback/ Opinion	SID
CL-	Some students of the School were weak in mathematics so that before each laboratory session, the teacher had to spend extra time to brief them.	TAIE-33
CL-	Students may also find the large quantity of data gathered overwhelming…	TOCO-305
CL+	Mr TF thought that students with average ability or high achievers were able to accept the new technology better and could learn a lot from the experiments…	TAIF-16
CL+	F4S11: Even without the guidance from the teachers, we can follow the instructions and complete the experiments and worksheets.	SAI44-53
CL=	If students had acquired relevant IT skills in their junior classes, they could apply the skills in learning NSS Science. It is not necessary to revise with them the IT skills.	TAIE-2

CL=	However, for junior secondary or primary school students, the technology might be too difficult for them to master.	SAI42-52

Code	Comment/ Feedback/ Opinion	SID
CM-	Teachers do not have time to prepare so many teaching materials and preparation.	SOCS-5
CM-	Lots of time and resources should have been spent in developing the seven experiments.	TAIB-71

Code	Comment/ Feedback/ Opinion	SID
CO-	As there were inadequate tools in the market which could facilitate the implementation of Science investigation, teachers very often ignore Science investigation in the school based assessment (SBA) and would replace it with a long report instead.	TAIB-39
CO-	Different Excel templates were tailor-made to manipulate data for different experiments. If the Arduino-based experiments were further promoted to other schools, it would be better to have a universal interface (like those provided by the data logger vendor) so that the users could manipulate the data more easily.	TAIE-39
CO+	In fact, in designing the (Arduino-based) experiments, some uncommon method was employed. Data was first saved in the RAM and after the experiment was completed, the data stored in the RAM was transferred and saved in the SD card. That solved the problem of (slow) saving speed.	TAIT-61
CO+	After students had selected the area of data, I created an additional page in the EXCEL table in which the data out of the area would be automatically deleted. …Inserting this step enabled students who did not have much knowledge on the application of EXCEL to use EXCEL for (data) manipulation.	TAIT-94
CO=	The first experiment developed was that on the centripetal force. At that time, different methods had been tried, e.g. control the experiment with a mobile phone. However, in order to simplify the procedure, push buttons were used for the control.	TAIT-56
CO=	A community of teachers of like-mindedness will help in growing teachers who are interested.	TOCO-334

Code	Comment/ Feedback/ Opinion	SID
CS-	Technicians needed to be trained in order provide technical support. In case the device broke down, teachers might not know how to fix it.	TAID-36
CS-	Trouble shooting will be a big issue if lesson is conducted big groups of students.	TOCO-202
CS+	I think that what we are doing now is a better method, e.g. students could be given the open source program that can be found on the web, so that students could use the sensors and do not need to understand programming.	TAIT-77

CS=	Author: If you came across hardware failure, you just had to replace it with another set, as if in the case when you got a broken multi-meter, what would you do? Student: Replace another one…	SAI6-136
CS=	Author: Students were not expected to know about maintenance. We could prepare more spare parts. If it was damages, just replaced one. Is the problem solved? Students: Yes.	SAI6-137

Code	Comment/ Feedback/ Opinion	SID
CT-	The difficulties may come from teacherefficacy...	TAC-5
CT-	This is an initial learning curve that teachers must be willing to invest in.	TOCO-323
CT+	F4S11: …but the teachers had given us appropriate advice and guidance, and helped us finish it (report writing) in time.	SAI44-44
CT+	F4S4: Teacher's guidance was very important to lead us to understand the whole process.	SAI42-59
CT=	The focus of teachers should focus on ideation and testing the feasibility.	TOCO-326

Code	Comment/ Feedback/ Opinion	SID
EC-	Some students might not be able to visualize how data was generated from the instrument and how these data was related to the experiment.	TAIF-13
EC-	too many raw data	TOCO-218
EC+	With the Arduino technology, data collection could be collected within a few seconds to 15 minutes.	TAIB-56
EC+	More reliable measurement instead of basing on human observation and measurement using normal laboratory equipment.	TOCO-113

Code	Comment/ Feedback/ Opinion	SID
EM-	F4S2: There could be many possible relationships between the data of the two columns, but various types of relationships made it a bit confusing.	SAI41-23
EM-	F4S15: I preferred more calculations on our own to that done by Excel.	SAI46-100
EM+	F4S8: Sometimes the data obtained (e.g, in Newton's 2^{nd} Law Expt) were very scattered. If the average on hundreds or thousands of data points was taken, the random error could be reduced.	SAI43-18
EM+	F4S4: I preferred using Excel in graph plotting than free hand, as it was more convenient and accurate.	SAI42-60
EM=	Author: Follow me to where the computer is. Put (the SD card) into the card reader and read data into EXCEL.	SAI6-105
EM=	Author: Yes, there are hundreds of samples (collected). Would all hundred points fall onto the straight line? Students: No.	SAI6-154

Code	Comment/ Feedback/ Opinion	SID
EO-	The bars were not rigid enough so that they would be easily broken if they unfortunately hit onto the ground.	TAID-27
EO-	F4S15: In the falling bar experiment, the bar would easily touch the light gate and the bar was easily broken…	SAI46-92
EO+	F4S6: I preferred to working the experiments on my own, but sometimes I needed to cooperate with others so that I could discuss with them and had better understanding.	SAI42-31
EO+	(Improvement?) Can increase more sessions in which students can participate more, e.g. calculations.	SAC4-40
EO=	A tablet or a lap-top computer can be used in classroom to illustrate the phenomenon instantly and this match with the trendy e-learning.	TAIB-59
EO=	F4S16: It would be better if the accuracy of the experiments could be further increased.	SAI46-104

Code	Comment/ Feedback/ Opinion	SID
EP-	F4S11: For the circular motion experiment, it was a bit difficult to control the rotation smoothly.	SAI44-46
EP-	F4S2: The worksheet seemed to be a bit lengthy, with more texts in the worksheet (than the experiments we had done before).	SAI41-78
EP+	F4S11: I encountered some difficulties when performing the first two experiments. After that, the procedures were more or less the same and I became adapted to it.	SAI44-42
EP+	F4S3: The experiments were time saving so that the experiments could be repeated many times to obtain more accurate results.	SAI41-51
EP=	F4S15: It is necessary to keep the track horizontal.	SAI46-25
EP=	F4S3: experiments 4 and 5 still needed some improvements in the settings.	SAI41-93

Code	Comment/ Feedback/ Opinion	SID
NA	Author: The English group performs the experiment on the Newton's 2nd Law first, while the Chinese group performs the experiment on circular motion.	SAI6-125
NA	Author: Please compare the merits and demerits between the traditional method and the new method with Arduino technology. Do you need more time for discussion? Students: No need.	SAI6-126

Code	Comment/ Feedback/ Opinion	SID
TA-	On the other hand, some students might be scared by high-ended technology they were not familiar with.	TAIF-8
TA-	Students may not be very excited to see data as compared to animation or video.	TOCO-242

TA+	F4S8: I always look forward to these lessons, in which we can play with different types of Arduino device to do different experiments.	SAI43-63
TA+	Great attempt to push more students to learn Science in a more engaging way.	TOCO-339
TA=	Whether these (Arduino-based) experiments could motivate students in learning Physics depended on individual students.	TAIE-12
Code	Comment/ Feedback/ Opinion	SID
TC+	F4S10: If sensors could be small enough, they could be mounted onto basketball, lead ball in shot put, javelin, and running shoes to capture data of motion.	SAI44-37
TC+	F4S6: Real-life experience would be very important in learning Physics.	SAI42-63

Code	Comment/ Feedback/ Opinion	SID
TH+	Able to stretch students' imagination to invent new things that are useful.	TOCO-37
TH+	It sparks creativity and innovation	TOCO-72
TH=	If the students could be involved in the design of the experiment, it would be a very good chance of providing them with high order thinking skills.	TAIF-44
TH=	In order to distinguish their abilities, Mr TE suggested not to introduce briefing session and observed whether they could perform the experiments after self-study.	TAIE-61

Code	Comment/ Feedback/ Opinion	SID
TI+	Science Investigation is very important in learning Science and it is the drive for learning Science.	TAIE-17
TI+	It also helps to generate questions themselves, learn how to investigate and explore.	TOCO-58
TI=	F4S12: I remembered that in an investigative study of a falling bar (Expt. 2), the relationship between the velocity (v) and the height of released (h) was investigated.	SAI45-16
TI=	If students have resistance in doing Science investigation, they would not like this subject.	TAIE-18

Code	Comment/ Feedback/ Opinion	SID
TK-	Data treatment such as measuring pH values, would be less demanding. The Chemistry or Biology syllabuses are a bit alienated from high technology.	TAIB-45
TK+	Besides, the future is probably in computing and technology, hence learning computing and modifying programs for Arduino is useful as well.	TOCO-10

TK+	The experiments well echoed with the ideas in STEM education. In producing the Arduino-based device¸ mathematics, electronics, coding and even laser-cutting technology were involved.	TAIF-32
TK=	Applying Arduino technology in other subjects would not be as easy as in Physics. Many Chemistry experiments like titration would usually be based on very traditional and fundamental experimental techniques such as using pipet and burette.	TAIB-44

Code	Comment/ Feedback/ Opinion	SID
TO-	The demerit (of using Arduino) may reduce the chance of students' participation.	SAC4-49
TO-	Students not as engaged.	TOCO-278
TO+	The students could have a chance to understand the design of the electronics.	TAIF-42
TO+	(Arduino technology) could connect students with the latest advanced technology and make them easier to enter the workforce.	SAC4-52

Code	Comment/ Feedback/ Opinion	SID
TP-	F4S7: … even though I didn't learn much about Physics.	SAI43-46
TP-	and it was quite difficult to understand that friction and mass of the trolley could be retrieved from the slope and the y-intercept, respectively.	TAID-51
TP+	F4S15: In the bouncing ball experiment, I understood the meaning of the signs +/- in velocities (up/down).	SAI46-7
TP+	Allowing students to use technology to make their thinking more visible.	TOCO-97
TP=	F4S16: I was not quite sure what the slope represented.	SAI46-12
TP=	Students might not easily relate the concepts to the course content but if they understood the principle behind, they were able to grasp the ideas.	TAIE-29

Code	Comment/ Feedback/ Opinion	SID
XC-	Author: The experiment on circular motion was an experiment on investigative study…. Who remember what Newton's Second Law said? F6S6：about action and reaction... (wrong answer)	SAI6-1
XC-	Author: How to pull (the cart)? F6S3：with a piece of string (wrong answer)	SAI6-7
XC+	Author: How should the rubber band be pulled? F6S5：to keep the length (of rubber band) unchanged.	SAI6-11
XC+	Author: …Do you remember what does the slope of the velocity-time graph stand for? Students: Acceleration.	SAI6-21

XC=	Author: … please show me how to achieve "friction compensated". (Students raised the angle of inclination until the cart just started to move and was stopped by the Author.)	SAI6-50
XC=	Author: Who can tell how the experiment was carried out? (Student discussing among them…) Author: F6S6, please tell me… F6S6：The method we used in school ...	SAI6-62

Code	Comment/ Feedback/ Opinion	SID
XT-	F4S14: In some traditional experiments, many pieces of equipment were involved. Students had to follow many steps to collect data and data were not accurate. Students would easily lose interest in doing the experiments.	SAI45-31
XT-	Only a few sets of data could be collected in the whole lesson and there was no time left for further discussion (in conducting the traditional experiment).	TAID-57
XT+	Some students might feel more comfortable working with some primitive and simple apparatus, e.g. using a timer to measure the number of revolutions per second.	TAIF-9
XT+	F4S4: I preferred using free hand to plot graph as it would be more realistic. When plotting the graph, if some data deviated from the main trend, the data could be deleted and removed (manually).	SAI42-13
XT=	(Most interested experiment)…as it is different from the traditional experiment.	SAC4-31
XT=	Arduino may results in students' decrease exposure to traditional experiments since many things can be done electronically	TOCO-271