# THE EFFECTIVENESS OF REMOTE-CONTROLLED LABORATORY SYSTEM FOR SECONDARY SCIENCE EDUCATION

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by

THO, SIEW WEI

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## STATEMENT OF ORIGINALITY

I, THO, Siew Wei, hereby declare that I am the sole author of the thesis and the material presented in this thesis in my original work except those indicated in the acknowledgement. I further declare that I have followed the Institute's policies and regulations on Academic Honesty, Copy Right and Plagiarism in writing the thesis and no material in this thesis has been published or submitted for a degree in this or other universities.

THO, Siew Wei

May 2015

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# ABSTRACT

## THE EFFECTIVENESS OF REMOTE-CONTROLLED LABORATORY SYSTEM FOR SECONDARY SCIENCE EDUCATION

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This paper proposes a novel remote-controlled laboratory (RCL) system, which was developed by using innovative ideas and methods for applying technology-enhanced learning to secondary school science education (grade 7-9 or ages 12-14) through three iterative cycles of design-based research. This Internet-based RCL system enables learners to control and observe the server side of the laboratory equipment and to perform real-time remote scientific investigations at distant places.

In this study, three iterative cycle trials and refinements were performed. First, a newly developed RCL system involving four remote experiments was initially tested by 64 undergraduate students who studied science education and web technology and were enrolled in teacher training courses. Then, a refined RCL system involving eight remote experiments were then evaluated by 32 secondary school students from a local public school as a second iterative cycle (selected electricity, plants, light and sound topics). After the refined RCL system was further refined, it was again evaluated by 35 secondary school students from another local public school as a third iterative cycle. The evaluation of these three iterative cycles was performed using a mixed

research method that included achievement tests (for the second and third iterative cycles only), questionnaire survey, open-ended questions and interviews specifically developed to collect data on student understanding, perception, and implementation of the use of the RCL system.

The results of the achievement tests revealed that the secondary students more comprehensively understood the related science topics. In addition, the survey results indicated that the participants believed that the RCL system and methods for conducting the experiments were appropriate and educational. Nevertheless, negative comments and suggestions for improvement were identified. Accordingly, the researcher refined the RCL system and its design principles (integration with science education curriculum, interactive learning, learner engagement, a wide-range of learner ability, collaboration in learning, and RCL instruction). Thus, the novel RCL system can be used in laboratory activities and demonstrations for science learning and teaching.

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| ADCs | Analog-to-Digital Converters |
| ANCOVA | Analysis of Covariance |
| ANOVA | Analysis of Variance |
| CBL | Computer-based Laboratory |
| CDC | Curriculum Development Council |
| DAQ | Data Acquisition |
| DBR | Design-based Research |
| DIO | Digital Input or Output |
| EdB | Education Bureau |
| FTP | File Transfer Protocol |
| GS | Graduate School |
| HKIEd | The Hong Kong Institute of Education |
| ICT | Information and Communication Technology |
| IP | Internet Protocol |
| IR | Infrared |
| LabVIEW | Laboratory Virtual Instrument Engineering Workbench |
| MBL | Microcomputer-based Laboratory |
| MCQ | Multiple-choice Question |
| NI | National Instruments |
| PC | Personal Computer |
| RCL | Remote-controlled Laboratory |
| RLs | Remote Laboratories |
| SD | Secure Digital |

| | |
|---|---|
| SPSS | Statistical Package for the Social Sciences |
| STEM | Science, Technology, Engineering, and Mathematics |
| TEL | Technology-enhanced Learning |
| WoS | Web of Science |

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# CHAPTER 1

# INTRODUCTION

This chapter discusses the background, rationale, and scope of the study. In addition, the study aim and research objectives, and significance of the study are presented. Finally, definitions of terms are introduced.

## 1.1 Background

The manner of conducting scientific experiments has experienced substantial changes from the cookbook or recipe experiments to computer-based laboratories through the use of simulation software to perform virtual experiments or a data logger to perform hands-on and real science experiments. The cookbook practical work normally requires students to follow specific procedures and solve specific questions provided in the laboratory manual (Gallet, 1998). These activities lack authenticity and do not reflect students' input and ownership. However, it is an entirely different situation if students integrate their science learning via technology-enhanced learning (TEL) particularly computer-based laboratory (CBL), where they can display the data in graphical or tabular form and all routine jobs are computerized, thereby saving more time for other activities such as creating and answering their own "what if" questions (Ng & Yeung, 2000; Steinberg, 2003; Taylor, 1997; Tho & Hussain, 2011).

The rapid advancement of technology and the prevalent use of the Internet in education have enabled practical scientific work to be performed in remote-controlled laboratories (RCL; also known as web-based laboratory or remote laboratories [RLs]), which have recently adopted cloud computing. Torre et al. (2013) claimed that the RLs can be considered as a constructivist method that enables students to participate actively and explore certain scientific questions and ideas. In addition, RLs can enhance the social constructivism learning environment through the experiments conducted remotely and the shared experimental data among users from different locations (Abdulwahed & Nagy, 2011).

RCL afford an experiential, real-time, interactive, online learning environment in which students can control, observe, and respond to selected science experiments (Grober, Vetter, Eckert, & Jodl, 2007; Tho & Yeung, 2015). Using a flexible RCL learning environment enables science students to easily manipulate real-time experiments anywhere and anytime (Scanlon, Colwell, Cooper, & Di Paolo, 2004). Therefore, RLs can be exploited to overcome issues related to limited class time, weather, safety, and distance problems.

Numerous previous studies on RCL system development and literature have anticipated that remote-controlled technologies will play a crucial role in science and engineering learning (Barrios et al., 2013; Hercog, Gergič, Uran, & Jezernik, 2007; Ma & Nickerson, 2006; Scanlon et al., 2004). Moreover, recent reforms in science laboratory procedures have identified the importance of technology-enhanced science learning, which can be achieved in science education by applying RCL system (Kong, Yeung, & Wu, 2009; Lowe, Newcombe, & Stumpers, 2013). The following section provides the rationale for developing and evaluating a novel and innovative RCL system that can be applied to the TEL of science in schools.

## 1.2 Rationale of the Research

With the rapid development of information and communication technology (ICT), real-time science practical work in the form of RCL can be performed via the Internet. In the RCL system, "the basic idea is for a user to connect via the Internet with a computer from place A to a real experiment carried out in place B" (Grober et al., 2007, p. 11). RCL is not only useful for learning and teaching but also in conducting science experiments by researchers (e.g., the Beijing synchrotron is used by researchers at Sun Yat-sen University). Using this RCL system, students can view and control apparatus and equipment during experiments and download real-time data in the classroom, computer laboratory, or even at home. RCL can be considered as a kind of new development in TEL in which appropriate technology and effective pedagogies are innovatively applied in science education.

Therefore, the rationale for conducting this development and evaluation study was three-fold. First, as a science teacher educator with research interests that involves technology-enhanced science learning (Chan, Yeung, & Tho, 2014; Tho & Hussain, 2011; Tho, Chan, & Yeung, 2015; Tho & Yeung, 2013, 2014a; Tho, Yeung, & Chan, 2013; Zhang, Yeung, Xiao, Zhou, Wang, & Tho, 2014) I have realized that understanding the implications of state-of-the-art RCL technology for practical work and self-learning in science education is essential.

Second, designing and developing RCL system is considered as a new laboratory work for science education in Hong Kong. Additionally, Hong Kong Education Bureau (EdB) has begun to frame, support and promote e-learning in schools (EdB, 2009). Moreover, the Third Strategy on IT in Education stated that developing the "right technology at the right time for the right task" (EdB, 2007, p. 1) is also a crucial reference and guide for developing this project. More recently, the Fourth Strategy on IT in Education emphasized that e-learning could be applied "to unleash the learning power of all our students to learn and to excel through realising the potential of IT in enhancing interactive learning and teaching experiences" (EdB, 2014, p. 1). Therefore, determining whether applying this novel RCL system in laboratory work is more effective than using conventional laboratory methods or whether it is merely supplemental is crucial.

Finally, to evaluate how students learn from this newly developed RCL system, understanding how students and teachers think at various points when handling and learning this RCL system is essential.

## 1.3 Scope of Research Context

The first part of this study involved designing and developing an innovative RCL system for use in the science education context in Hong Kong by applying technology-enhanced inquiry methods. However, it is hard to evaluate this innovative RCL system merely according to the design or development itself. As a result, a critical evaluation in a real classroom setting was conducted in the second part of the study.

RCL is a subset of TEL, which involves employing the latest innovative technology that has potential for science education applications, particularly in Hong Kong. Therefore, the researcher began by reviewing and discussing the science education and science learning in the core subject Hong Kong science education at secondary level. Subsequently, the researcher systematically reviewed laboratory work in science education (particularly in RLs), possible learning gaps, the RCL system, and its application in science education.

The RCL system is typically divided into two major parts, namely, hardware and software. The hardware consists of a data acquisition (DAQ) system, digital input–output (DIO), a camera, and various types of sensors. The software executes data logging, controls and displays the real-time experiment on the computer screen through the Internet. The RCL system can be applied to study certain scientific principles underlying topics from various areas of discipline, including physics and biology. Guided inquiry experiments on the topics of electricity, light, living things – plants and sound were developed for the RCL system. The underlying scientific concepts and principles closely corresponded to the science education curriculum in Hong Kong as recommended by the EdB (2002).

## 1.4 Research Aim

The aim of this study was to evaluate critically an innovative RCL system specifically designed and developed to facilitate technology-enhanced guided inquiry and enhance certain scientific knowledge, practices, and attitudes related to science education.

## 1.5 Research Objectives

- To design and develop a novel RCL system that promotes technology-enhanced inquiry for enhancing student understanding of several scientific principles by enabling participation in remote-controlled and web-based activities in real-time experiments.
- To evaluate student perceptions of, suggestions regarding, and difficulties encountered when implementing the RCL system, which was evaluated by two laboratory classes of undergraduate students during the first iterative cycle of evaluation and refinement.
- To evaluate the learning effectiveness of the students and the difficulties encountered in implementing the RCL system, which was tested in two secondary schools during the second and third iterative cycle of evaluation and refinement.

## 1.6 Significance of the Study

Numerous findings on RCL system development have revealed that these remote-controlled technologies play a crucial role in the engineering learning process (Gillet, Ngoc, & Rekik, 2005; Hercog et al., 2007; Ko, Chen, Chen, Zhuang, & Tan, 2001). However, most published papers focus on technical issues of development and lack a critical evaluation of student learning effectiveness and attitude toward the RCL system. Thus, little empirical evidence has verified whether this technology can be used effectively to facilitate and assist student development in science learning. In this paper, the researcher provides reliable research findings on how the effectiveness of science learning was developed among students who used the novel RCL system. Additionally, the researcher revealed whether students can be actively and confidently engaged in science learning by using the RCL system to engage in related remote-controlled experiments.

As abovementioned, the RCL is important for experiential and real-time interactive online learning environments in which students can control, observe, respond and share selected experiments (Abdulwahed & Nagy, 2011; Grober et al., 2007; Lowe et al., 2013; Tho & Yeung, 2015). Therefore, the RCL learning environment enables science students to easily manipulate real-time experiments anywhere and anytime (Kong et al. 2009; Scanlon et al., 2004). As a result, RCL system can be applied to overcome problems related to limited class time, weather, health, safety, and accessibility.

Moreover, applying science process skills or more recently science practices are key elements in learning scientific principles. The investigation of scientific achievement and the perception as well as motivation of science students using the RCL system is considered as a substantial contribution to science education research.

Policy or decision makers in education may use the findings of this study as a reference for future science education and related curriculum planning (e.g., Hong Kong secondary school science curriculum) to recommend alternative methods for science experiments, life-wide learning, science experiential learning, and the effective use of technology in science classes.

Finally, this study on RCL research can probably provide meaningful information for teachers, lecturers, and laboratory instructors regarding their teaching methods, resources, and goals that can facilitate improving teaching strategies and enhancing student understanding and motivation in science learning.

## 1.7 Definition of Terms

The terms used throughout this paper are as follows:

**Remote-controlled laboratory (RCL):** RCL, also known as RLs or web-based laboratories, integrate hardware and software in the form of the camera, data acquisition system, sensors, user interfaces, and the Internet for use in science experiments. Therefore, the benefits of access to RCL are real-time web-based experiments, interactivity, anytime and anyplace. (Grober et al., 2007; Scanlon et al. 2004; Tho & Yeung, 2015). In this study, several feasible remote experiments were developed for school science education.

**Effectiveness:** The meaning of effectiveness can come in many forms or interpretations such as conducting systematic review and meta-analysis on the effectiveness of certain topics (Cook et al., 2013; Free et al., 2013; Kay, & Locker, 1998). Besides that, system effectiveness can be defined as "accuracy and completeness with which users achieve specified goals" (ISO 9241-11, 1998; Frøkjær, Hertzum, & Hornbæk, 2000, p. 345). In addition, learning effectiveness is a "function of effective pedagogical practices" (Joy & Garcia, 2000, p.38) and it indicates how effectively the learners study and learn according to instructional strategies and media used. Hence, the learning effectiveness can be done through survey design (Shea, Fredericksen, Pickett, Pelz, & Swan, 2001) or quasi-experimental design (Chou & Liu, 2005; Rakes, 1996; Zhang, Zhou, Briggs, & Nunamaker, 2006). Commonly, the learning effectiveness of new learning and teaching methods or resources is generally assessed through a series of evaluations, which include achievement tests and surveys (Chou & Liu, 2005; Rakes, 1996; Zhang, Zhou, Briggs, & Nunamaker, 2006). In this study, system effectiveness was tested by researcher during the development and students during the implementation. For learning effectiveness, it was measured according to student understanding, which was assessed using a multiple-choice conceptual understanding test. Then, student perceptions were determined and suggestions gathered through questionnaires and interviews.

**Design-based research (DBR):** DBR is a flexible methodology that enables understanding the adoption of innovations (Anderson, 2005; Feng & Hannafin, 2005). A characteristic of this method is “developing and designing an intervention of certain technology in a real learning environment” (Van den Akker, Gravemeijer, McKenney, & Nieveen, 2006, p. 5). In this study, DBR is adopted for developing the RCL system in three iterative cycle trials and refinements.

## 1.8 Organisation of the Study

This paper is organised into eight chapters. The first chapter describes the introduction. Chapter 2 details a systematic review and related literature review. Chapter 3 describes the research questions and research methodology, including the three iterative cycles of evaluations and refinements. The RCL design principles and findings in the form of RCL system development are presented in Chapter 4. Chapters 5–7 present the results from of the three iterative cycles and the related refinements. Finally, Chapter 8 concludes, describing the final set of RCL design principles, responses to the research questions, study limitations, and recommendations for future studies.

# CHAPTER 2

# LITERATURE REVIEW

Drawing on both the theoretical framework and empirical studies in the literature review related to science learning is essential for creating a solid basis to develop and explore remote-controlled laboratory (RCL) for science education. First, the researcher reviewed science education in general and the school curriculum in Hong Kong. Subsequently, a literature review was conducted and included literature pertaining to two main aspects of integration in science learning, namely, scientific inquiry through laboratory work and scientific inquiry through informal contexts; literature on technology-enhanced learning (TEL) was also reviewed. Next, a systematic review of laboratory work in science education with particularly the most recent remote laboratories (RLs) was performed by visualising its history with *HistCite* and *Citespace* software. Use of RCLs in science education was then illustrated to identify possible learning gaps.

In this chapter, several relevant papers are reviewed in detailed. First, studies on remote-controlled experiments used for science education in schools (i.e., primary and secondary schools) are reviewed; the papers included are “Evaluation of the Use of Remote Laboratories for Secondary School Science Education”, piloted by Lowe et al. (2013), “An Experience of Teaching for Learning by Observation Through the Remote-controlled Experiments on Electrical Circuits”, conducted by Kong et al. (2009), and “It’s Lab Time—Connecting Schools to Universities’ Remote Laboratories”, conducted by Tannhäuser and Dondi (2012). The second section discusses an article and book that are pertinent to inquiry experiment planning and development, namely, “Simplifying Inquiry Instructions”, written by Bell, Smetana, and Binns (2005), and *Teaching High School Science through Inquiry and Argumentation, Second Edition*, written by Llewellyn (2013). A review of the theoretical framework of the study design and development follows, as well as a description of determining the research framework for this study.

## 2.1 Science Education

The word *science* originated from the Latin word *scientia*, meaning knowledge. Science is defined as "both a body of knowledge that represents current understanding of natural systems and the process whereby that body of knowledge has been established and is being continually extended, refined, and revised" (Duschl, Schweingruber, & Shouse, 2007, p. 26). Therefore, two essential aspects of science are understanding and the scientific process. In current science education, understanding scientific knowledge and obtaining favourable examination results appear to be the primary goals of students; however, students must integrate both the understanding of and the practical application of scientific knowledge into their learning. For this meaningful integration, scientific inquiry can enable developing and understanding scientific knowledge (National Research Council, 1996). Additionally, the National Science Education Standards indicated that

> Understanding science requires that an individual integrate a complex structure of many types of knowledge, including the ideas of science, relationships between ideas, reasons for these relationships, ways to use the ideas to explain and predict other natural phenomena, and ways to apply them…Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work (National Research Council, 1996, p. 23).

Thus, scientific inquiry is a multifaceted approach that normally occurs in the classroom or laboratory. When the richness of science learning and teaching is enhanced with the help of technology, scientific inquiry can even be conducted in informal contexts. This integration of scientific inquiry in the laboratory and informal contexts is discussed in more detailed after science education in Hong Kong is reviewed in the following section.

## 2.2 Hong Kong Science Education

Science education in Hong Kong includes various subjects taught during primary and secondary school. Science subjects for primary schools are included in the general studies (GS) curriculum, which integrates two other key learning areas: technology education and personal, social, and humanities education. Moreover, six fundamental strands comprise the core of the GS curriculum: Health and Living; People and Environment; Science and Technology in Everyday Life; Community and Citizenship; National Identity and Chinese Culture; Global Understanding and the Information Era. Then, the Integrated Science is a compulsory course taken by all junior secondary level students from Secondary 1–3 (Form 1–3) that includes topics from various science disciplines. The science education curriculum is based on the six strands of Scientific Investigation; Life and Living; the Material World; Energy and Change; The Earth and Beyond; Science, Technology and Society. Before 2009, physics, chemistry, biology, and human biology were optional subjects taught at the senior secondary level (Secondary 4–5). Physics, chemistry and biology were divided into advanced supplementary level and advanced level subjects in the Form 6 curriculum (Curriculum Development Council [CDC], 2002, p. 4). In 2009, the senior secondary education system in Hong Kong was restructured into the new senior secondary (NSS) education system, which involved converting the 4-year secondary education system (2-year certificate level and 2-year advanced level) into a new 3-year senior secondary level (CDC, 2009; Lee, Lam, & Yeung, 2011; Yeung, Lee, & Lam, 2012). Elective science education subjects in the NSS is offered through five separate curriculum and assessment guides including biology, chemistry, physics, integrated science, and combined science.

Consequently, the science education curriculum prepares students for “participating actively in a dynamically changing society, and for contributing towards a scientific and technological world” (CDC, 2002, p. 17). Junior secondary science education has two vital learning targets: by the time the students graduate, they should “have developed an ability to define problems, design experiments to find solutions, carry out practical work, and interpret the results" and also be able to "apply their understanding of science to technological applications, social issues, and their daily experiences" (CDC, 2002, p. 22). In addition, secondary school science learning in Hong Kong should

> …enhance students' scientific thinking through progressive learning activities. These involve asking questions, hypothesizing, observing, measuring, designing and evaluating procedures, analyzing data, and examining evidence. Learning science will encourage our students to learn independently, and will enable them to deal with new situations, reason critically, think creatively, make decisions and solve problems. (p. 5)

According to the first strand of the science education curriculum guide (CDC, 2002), scientific investigation is vital to becoming an active science learner through "minds-on" and hands-on activities.

> Students should be engaged actively in designing and conducting experiments to explore science concepts and develop science investigation skills for their own construction of science knowledge. Students should also be exposed to frontiers of science and develop an interest in the advancements of science and technology. (p. 10)

Additionally, information and communication technology (ICT) tools can play an essential role in student learning with appropriate teacher guidance at the primary level (CDC, 2011). Therefore, using ICT tools for learning and teaching is becoming popular, and teachers are encouraged to apply various student-centred learning approaches in their lessons. In addition, the CDC (2002) emphasised using ICT tools in science learning:

> While the use of IT allows space for developing students' scientific thinking, creativity and problem-solving skill, teachers should exercise their professional judgement in the appropriate use of IT and ensure that the students are provided with sufficient opportunity for hands-on experiments to develop their science process skills. (p. 50)

In this study, the researcher studied and developed innovative remote experiments for the RCL system that can be applied in science learning. In fact, the RCL is suitable for application in the Hong Kong education system, particularly in science subjects, for several reasons, including an intense syllabus and large class size (Cheng, 2004), which reduces the amount of individual attention teachers can provide to students. Thus, e-learning is required to facilitate and supplement regular classroom learning and teaching, particularly in the self-learning aspect. Therefore, RCL can potentially enhance the educational value of existing ICT tools to promote science learning.

Because RCL system must be controlled by a computer through the Internet, the Internet is an essential feature. The availability of reasonably priced Internet access in Hong Kong is considerably wide because the Hong Kong Special Administrative Region (HKSAR) government aims to provide high quality telecommunication facilities with optimal capacity, quality, and cost (Information Services Department HKSAR, 2013). Consequently, learning and teaching with ICT tools and the Internet is receiving gradual attention (Lai & Ng, 2009; So & Cheng, 2009). The Hong Kong Education Bureau (EdB) has further dedicated itself to incorporating e-learning in schools and has developed a research and development plan for improving learning and teaching through e-learning (EdB, 2009, 2014). Moreover, the "i Learn at home" programme (eInclusion Foundation Limited and the Hong Kong Council of Social Service, 2011), initiated in the middle of 2011, is a 5-year government IT policy that assists qualified families in obtaining computer resources, particularly Internet access services. Therefore, the present study can further the development of science experiments conducted using the Internet as a learning environment.

## 2.3 Scientific Inquiry through Laboratory Work

Scientists must conduct experiments to verify theories, whereas students must perform experiments to understand theories. Therefore, "laboratories are essentially simulation environments where once create various experiments and learning experience" (Reddy & Goodman, 2002, p. 13). Moreover, the effectiveness of laboratory exercises in science education is recognized as crucial for understanding scientific principles (Abrahams & Reiss, 2012; Hofstein & Lunetta, 2004). Nagaraju (2008, p. 139) claims, "No course in Science can be considered as complete without including practical work in it". Therefore, practical work in a science laboratory is acknowledged as a fundamental component of science learning (Reddy & Goodman, 2002; Hofstein & Mamlok–Naaman, 2007; Nagaraju, 2008; Tho & Yeung, 2014). Additionally, practical work is an aspect of scientific inquiry, which is defined as follows:

> Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. Students will engage in selected aspects of inquiry as they learn the scientific way of knowing the natural world, but they also should develop the capacity to conduct complete inquiries. (National Research Council, 1996, p. 23)

Recently, science, technology, engineering, and mathematics (STEM) education has been emphasised and applied in the United States is to create "a globally competitive workforce" (Reeve, 2014, p. 8) within the four discipline areas. STEM education is directly related to a new set of school science standards, called the Next Generation Science Standards, which has been implemented in the United States. The framework of these standards is based on core concepts in the field of natural science from the book *A Framework for K–12 Science Education* (Schweingruber, Keller, & Quinn, 2012). Three crucial dimensions can be derived from the framework: practices, core disciplinary ideas, and crosscutting concepts. In particular, the science practices directly relates to practical work. According to the new science standards, the word "practices" is used instead of "inquiry or science processes" skills for a specific purpose. The National Research Council Framework (Schweingruber et al., 2012, p. 30) states: “We use the term “practices” instead of a term such as “skills” to emphasise that engaging in scientific investigation requires not only skill but also knowledge that is specific to each practice.”

In the practices of science and engineering, students should engage in eight major elements:

(a) Asking questions (for science) and defining problems (for engineering)
(b) Developing and using models
(c) Planning and carrying out investigations
(d) Analysing and interpreting data
(e) Using mathematics and computational thinking
(f) Constructing explanations (science) and designing solutions (engineering)
(g) Engaging in argument from evidence
(h) Obtaining, evaluating, and communicating information

Conventionally, science practical work commonly known as cookbook experiments require students to follow specific procedures and solve specific questions provided in laboratory manuals. A longer time is required to manually conduct such routine tasks that include recording data, plotting graphs, and analysing data. Furthermore, Gallet (1998) indicated that:

> Recipe experiments tend to sterilize imagination and initiative, leave no room for hypothesis, trials, errors, individual responsibility in a group, and above all, preclude the student’s involvement in a decision-making process—which is so important to our modern society. In other words, many parameters that are fundamental to the scientific method are left out by the macroscale cookbook formula approach. (p. 73)

However, this approach is radically changed when learners integrate inquiry into TEL by using data logger or computer-based laboratory (CBL) system. Thornton and Sokoloff (1990) introduced the initial CBL, a microcomputer-based laboratory (MBL), which afforded novel methods for teaching physics. In the MBL system, all routine jobs are computerised, thereby conserving time for other activities (Redish, Saul, & Steinberg, 1997; Tanahoung, Chitaree, Soankwan, Sharma, & Johnston, 2009; Thornton & Sokoloff, 1998). For example, in a study on applying the data logging system to indoor, outdoor, or underwater environments, Baker (2007, p. 21) concluded that the CBL is "ideal for applications with field studies, transportation monitoring, high voltage tests, troubleshooting, quality studies, general research and educational science."

A data logger (also called datalogger, data acquisition, or data recorder) is a digital device that records data with instruments or sensors and generally enables instantaneous display of data in graphical or tabular form. These sensors are either external or built into in the data logger, and all routine jobs are computerised, thereby conserving time for other activities (Barton, 2004; Ng & Yeung, 2000; Taylor, 1997; Tho & Hussain, 2011). Several main characteristics of the data-logging process were summarised by Ng and Yeung (2000) as follows:

> Data-logging is a trend in practical activities in science education. Its major advantages are the High sensitivity for measurement of very small changes and the ability to monitor changes over a very short or a very long period of time. It can record and store data of one or more parameters. The variations of several parameters can be shown on the same graph for comparison of trends and analysis for inter-relationship. As the recording and the presentation of data are automatic, time can be saved for repeating the experiment with different settings and parameters. (p. 3)

Furthermore, computer-based practical work can encourage and prompt students to create and answer their own "what if" questions, rather than blindly following the instructions given in the laboratory manual (Barton, 2004). This new learning approach is feasible because CBLs can efficiently reduce the time required to conduct experiments, yielding more time for interpreting or evaluating data. Thus, students can engage in more higher-order thinking activities, such as improving experimental design skills or modifying existing experiments through creativity and critical thinking skills. Furthermore, Steinberg (2003) claimed that the CBL approach provides science teachers with more opportunities for engaging students intellectually by using meaningful and exciting subject matter.

With the fast development of technology and the use of Internet, RCLs have recently been developed and used through computers or mobile devices with Internet access. Simply put, “the basic idea is for a user to connect via the Internet with a computer from place A to a real experiment carried out in place B” (Gröber et al., 2007, p. 127). Using this RCL system, students can display, control, and download real-time data in their homes, classrooms, science laboratories, or computer laboratories. In the present study, the researcher applied this technology to science education in secondary schools in Hong Kong. Thus, the development of the RCL activities and the system evaluation were focused on science practices.

## 2.4 Scientific Inquiry through Informal Contexts

What is science learning in informal learning environments? When students follow direct instructions from teachers in the classroom or what is directly done for them in the form of “feeding” while learning science, the students cannot benefit from the multifaceted nature of learning through scientific inquiry. To overcome this problem, science learning in informal environments is an appropriate solution. In *Learning Science in Informal Environments: People, Places, and Pursuits*, Bell, Lewenstein, Shouse, and Feder stated:

> Learning science in informal environments is a diverse enterprise and serves a broad range of intended outcomes. These include inspiring emotional reactions, reframing ideas, introducing new concepts, communicating the social and personal value of science, promoting deep experiences of natural phenomena, and showcasing cutting-edge scientific developments. (2009, p. 41)

Furthermore, six strands compose the fundamental framework of informal science learning, a framework that corresponds to the following certain strands described in *Taking Science to School* (Duschl, Schweingruber, & Shouse, 2007):

> Strand 1: Experience excitement, interest, and motivation to learn about phenomena in the natural and physical world.
> Strand 2: Come to generate, understand, remember, and use concepts, explanations, arguments, models, and facts related to science.
> Strand 3: Manipulate, test, explore, predict, question, observe, and make sense of the natural and physical world.
> Strand 4: Reflect on science as a way of knowing; on processes, concepts, and institutions of science; and on [the individual] process of learning about phenomena.
> Strand 5: Participate in scientific activities and learning practices with others, using scientific language and tools.
> Strand 6: Think about themselves [students] as science learners and develop an identity as someone who knows about, uses, and sometimes contributes to science. (Bell et al., 2009, p. 44)

The idea of integrating informal science learning with formal scientific inquiry learning entails developing a learning environment that allows the learner to "interact physically and intellectually with instructional materials through 'hands-on' experimentation and 'minds-on' reflection" (Hofstein & Rosenfeld, 1996, p. 87). Furthermore, Hofstein and Rosenfeld suggest, "Future research in science education should focus on how to effectively blend informal and formal learning experiences in order to significantly enhance the learning of science" (p. 107).

Recent studies focusing on informal programmes involving community-based learning in science are critical (Eshach, 2007; Weinberg, Basile, & Albright, 2011). Community-based learning highlights the need for a concerted and intentional effort to engage all students in learning (The Coalition for Community Schools, 2006). Interactivity is another main focus of informal learning. Van Schijndel, Franse, and Raijmakers (2010) indicated that learners' views of interactivity in a science museum environment increased. Consequently, they suggested that informal science learning can be meaningful in a learning environment outside of school.

Science learning in informal settings can be classified into three categories: everyday learning, designed environments, and programme (Bell et al., 2009; Fenichel & Schweingruber, 2010). Hence, informal learning can be based on various learning approaches that can be implemented in numerous learning environments, such as in museums (e.g., the My ArtSpace Museum created by Vavoula, Sharples, Rudman, Meek, and Lonsdale [2009]; and the Hong Kong Science Museum), science centres (e.g., Hong Kong Hoi Ha Marine Life Centre), science fairs (e.g., Hong Kong Primary Science Project Exhibition), wetland parks (e.g., Hong Kong Wetland Park) and at home though the Internet. In this study, the science experiments involving the RCL system can be conducted in formal (e.g., classroom, computer or science laboratory) or informal (e.g., home) learning environments (Cranmer, 2006; Selwyn, 2007; Valentine, Marsh, & Pattie, 2005) in which computers with Internet access are available.

## 2.5 Technology-enhanced Learning

As mentioned, TEL is a crucial element in science experiments; therefore, this section details a review of TEL-related literature. TEL not only enables advancement in technology-enhanced conditions for science learning, but is also one of the most essential aspects of developing and adopting new types of technology to improve science learning (Kyza, Erduran, & Tiberghien, 2009; Slykhuis & Krall, 2012). “TEL environments can support the gradual development of higher-order skills, such as critical thinking and problem-solving in inquiry-based learning, [and] the development of domain-based reasoning” (Kyza et al., 2009, p. 124).

A group of workers from the Joint Information Systems Committee has assumed the task of promoting effective practice with e-learning (Knight, 2004). They have defined e-learning as enhanced learning in which “learning [is] facilitated and supported through the use of information and communications technology” (Knight, 2004, p. 10). They have also claimed that e-learning may involve using a wide range of technological tools to support effective learning, such as computers, software, interactive whiteboards, digital cameras, mobile phones, email, discussion boards, chat rooms, video conferences, virtual learning environments, and learning activity management system.

Kyza et al. (2009) classified tools currently applied to support science learning, some of which are closely related to those used in science experiments and TEL, into five categories: scientific visualisation tools, databases, data collection and analysis tools, computer-based simulations, and modelling tools. Scientific visualisation tools, including high-end technology tools used by scientists, can be used to analyse complex data sets and resource-based learning through visual models (Chang, 2007). Databases use existing data to enables a comprehensive understanding of science practices. Data collection and analysis tools, such as those used in data loggers (also known as data acquisition system), can be used to obtain and save real-time data and then present the data in graphical form automatically or manually. Computer-based simulations, such as simulation-based virtual laboratories (Chen, 2010), easy java simulations (Hwang & Esquembre, 2003), and physics education technology simulations (Mckagana et al., 2008) facilitate simulating science experiments in which students can manipulate parameters. Furthermore, modelling tools enable learners to create and manipulate their own science models.

Numerous types of TEL tools for promoting science experiments have recently been proposed, and fortunately several research studies that related to laboratory work (refer to Appendix M2) have been conducted during the PhD study. According to the literature review and relevant studies, TEL applied to science experiments involves a range of technological tools and techniques. In this paper, several topics are selected and discussed: (a) data acquisition system, (b) simulation software, (c) mobile learning, (d) Wiimote projects, and (e) RCLs.

First, CBLs (Amrani & Paradis, 2010; Steinberg, 2003) or computer-mediated experiments (Yeung, 2008; Zhou & Yeung, 2010) using data acquisition system (or data loggers) were initially referred to as MBLs, as previously mentioned. In such system, laboratory sessions are more effective and less time-consuming. Technology-enhanced laboratory work can be performed in several techniques (Chen et al., 2012), including through instructor or demonstrator demos, student individual work, and student group work. Recently, open source software and freeware-based hardware experimental development has become an essential feature of laboratory work and demonstration kits used in science learning and teaching (Ajith Kumar, Satyanarayana, Singh, & Singh, 2009; Tho & Hussain, 2011; Wheeler, 2011; Wu, Liao, & Yeung, 2006; Wu, Yeung, & Zhou, 2011).

Second, learners can observe and conduct science experiments according to demonstrations using simulation software, another central element in science experiments (Chen, 2010; Hwang & Esquembre, 2003; Mckagana et al., 2008). Moreover, the simulation software can be applied to various learning methods, particularly in science education (Honey & Hilton, 2011).

Third, a recent popular research topic is educational study through mobile learning, which “can offer new opportunities for learning that extend within and beyond the traditional teacher-led classroom” (Sharples, Arnedillo–Sánchez, Milrad, & Vavoula, 2009, p. 233). In addition, Chan et al. (2006) suggested that seamless learning with mobile devices can enable gaining learning experiences through various learning environments. In fact, mobile devices, particularly smartphones, are not only used for communication, but also for personal digital assistant and other technological capabilities, such as built-in acceleration, magnetic and light sensors, microphones, cameras, and global positioning system. Hence, smartphone technology has the potential to be an effective tool for students who are conducting scientific investigation and learning scientific concepts (Tho & Yeung, 2013, 2014a; Zhang, et al., 2014).

Fourth, the study tends to employ a Wiimote controller as tool for conducting science experiments, particularly those related to physics (Wheeler, 2011). The Wiimote is widely used in playing video games. The beauty of this controller is that it can be connected to a personal computer (PC) through a Bluetooth device and can convert an acceleration signal into data and graphic forms. Because of the popularity of using

Wiimote controllers in science experiments, several studies have proposed integrating Wiimote controllers into the practical aspects of experiments (Kawam & Kouh, 2011; Ochoa, Rooney, & Somers, 2011; Tomarken et al., 2012; Tho et al., 2015).

After several TEL-related research studies were conducted at the Hong Kong Institute of Education, RCL-related research gained importance and can potentially be applied in future science education, particularly for secondary school. Therefore, RCL-related studies and RCL applications were investigated in this study; a detailed literature review, development, and evaluation are presented in the following sections. The publications of this RCL research study are listed in Appendix M1 and Section 8.2.

## 2.6 A Systematic Review of Remote Laboratories

Practical work in a science laboratory is acknowledged as a fundamental aspect of science learning (Hofstein & Mamlok–Naaman, 2007). The effectiveness of laboratory exercises is crucial to student understanding of scientific principles and developing insights into the scientific enterprise, practices, and abstract ideas (Abrahams & Reiss, 2012; Emden & Sumfleth, 2014; Hofstein & Lunetta, 2004). The new framework for science education in the United States emphasizes the importance of science and engineering practices that are an integral part of laboratory investigations and design activities (Schweingruber et al., 2012). In addition, science practical work through the use of technology has flourished in the past two decades (Wang et al., 2014). With the fast growth of laboratory studies, real-time science experiments using the Internet (i.e., web-based laboratories or RLs) have been developed recently by using cloud computing. Using these RLs, students can display, control, interact with, and download real-time data in the classroom, science or computer laboratory, or other places with Internet access. Therefore, RLs are a subset of laboratory work for employing the latest and most innovative technology.

This section explored the development of laboratory work and RLs by a series of review processes involving a systematic review of laboratory work and RLs in science education with innovative software (*HistCite* and *CiteSpace*) for visualizing their histories (Tho, Yeung, Wei, Chan, & So, 2014). It is believed that the results of this systematic review can provide insights into laboratory-based and computer-based practical work to inform classroom practices with the existing evidence base and identify areas for further research.

### 2.6.1 Systematic Review with the Support of HistCite and Citespace Software

A systematic review can be defined as an orderly way of reviewing and summarising a research study. Bennett, Lubben, Hogarth, and Campbell (2005) stated that:

> Systematic reviews of educational research aim to answer specific review questions from published research reports by identifying relevant studies, characterizing such studies to form a systematic map of research in the area, extracting relevant data to establish the value of the findings, and synthesizing and reporting the outcomes. (p. 387)

The Cochrane Collaboration (2014) stated that a "systematic review is a high-level overview of primary research on a particular research question that tries to identify, select, synthesise, and appraise all high quality research evidence relevant to that question in order to answer it" (Systematic reviews, para. 1). Yoshii, Plaut, McGraw, Anderson, and Wellik (2009) identified this approach "as a preeminent source of synthesized knowledge for evidence-based practitioners" (p. 21). Lin, Lin, and Tsai (2014) pointed out that the purpose of a systematic review in science education was to get a "clearer view of the recent status" (p. 1347). Furthermore, systematic analysis procedures are important in identifying associations between instructional design and theoretical characteristics of research study and best practices (Lin et al., 2012). However, there has been little attention paid to systematic reviews in science education (Bennett et al., 2005), which is likely due to the labour-intensive nature of such approaches and the demand placed on the researchers' judgments and understandings of the underlying values of the research quality and outcomes. Thus, this study aimed to use established procedures, identify any connected structure, and address research gaps or any incompleteness in this area suggestive of future studies.

Bennett, Lubben, and Hogarth's (2007) study of RLs was particularly useful for the current research because they focused on how to conduct and evaluate systematic review research through the use of the Evidence for Policy and Practice Information and Co-ordinating (EPPI) guide. However, no specific judgments on the quality of the articles selected for the current study were made because these RCL studies focused more on development than evaluation and the assumed quality of these published studies in peer-reviewed sources. The EPPI data extraction or coding tool (Social Science Research Unit, n.d.) is a systematic review method for assembling all relevant research evidence, increasing the quality of the literature review and minimizing the research bias. Basically, the in-depth review process using the EPPI guide consists of a number of processes, namely:

> Data extraction, where information from the studies is extracted in a systematic way. Information extracted from the studies includes study aims and rationale; study research questions; study design methods, including selection of groups, sampling, and consent of subjects; data collection methods; data analysis methods; reliability and validity of methods of data collection and analysis; results and conclusions; quality of reporting; [and] quality of the study in relation to methods and data. (Bennett et al., 2007, p. 351)

However, EPPI has not addressed the time, judgment, and understanding barriers to conducting systematic reviews using modern technologies.

*HistCite* (http://interest.science.thomsonreuters.com/forms/HistCite/) and *CiteSpace* (http://cluster.ischool.drexel.edu/~cchen/citespace/download.html) software recently received attention as they are able to link and visualise the citation history and citation structure of articles in a graphical form (Chen, 2006; Chen, Hu, Liu, & Tseng, 2012; Garfield, 2009; Liang, 2010; Lucio-Arias & Leydesdorff, 2008). The combined use and support of this software can increase the time efficiency and supplement the judgment and understanding demands involved in systematic review analysis. *HistCite* is free software that focuses specifically on generating "chronological maps of bibliographic collections resulting from subject, author, institutional or source journal searches of the *ISI Web of Science*® [WoS]. WoS export files are created in which all cited references for each source document are captured." (Garfield, 2009, p. 173). This provides an evidence trace from listed journals that can guide and reinforce the researchers' decisions and interpretations.

*CiteSpace* software performs many functions to simplify the understanding and explanation of the chronology structure and linkages of past research patterns based on WoS data by "identifying the fast-growth topical areas, finding citation hotspots in the land of publications, decomposing a network into clusters, automatic labelling clusters with terms from citing articles, geospatial patterns of collaboration, and unique areas of international collaboration" (Chen, 2004, para. 1). This free software with Java application:

> supports a unique type of co-citation network analysis—progressive network analysis—based on a time slicing strategy and then synthesizing [sic] a series of individual network snapshots defined on consecutive time slices [to identify] nodes that play critical roles in the evolution of a network [and] are candidates of intellectual turning points. (Chen, Ibekwe–San Juan, & Hou, 2010, p. 1393)

### 2.6.2 Design of the Systematic Review via Histcite and Citespace Software

The literature review suggested a systematic review of laboratory work, particularly RLs, in science education with the *HistCite* and *CiteSpace* software would be appropriate and worthwhile. It is believed that there may be significant advantages linked with RCL approaches in science education that might inform further research and development work on infusing technology in science classrooms. However, there are several essential questions to be explored:

- What is the growth of RLs in laboratory work?
- What is the design of RLs in laboratory work?
- Do learning and teaching via the use of remote technologies help students understand science better?
- Do learning and teaching via the use of remote technologies enhance students' attitudes toward this new mode of learning?
- Are there any gender differences in learning and teaching via the use of remote technologies?
- Does learning and teaching via the use of remote technologies develop students' practices and processes for this new mode of learning?

The following sections begin by considering the methods and design steps on how to review previous research in laboratory work and RLs. The evidence of the study is then reviewed and analysed. Finally, the findings and future work flowing from the study are reported.

### 2.6.3 Methodology of the Systematic Review via Histcite and Citespace Software

This study focused on previous research studies on laboratory work, particularly RLs, found in the WoS Education and Educational Research categories and was divided into three main parts. First, *HistCite* analysis was conducted to identify the universe of articles and their citation links to central studies. Second, the RLs studies were identified and isolated through the *HistCite* and *CiteSpace* analysis. Third, a number of articles were selected based on criteria and the EPPI guide for in-depth document analysis to identify trends, design principles, and areas for further research.

*Part 1:* HistCite *Analysis Procedures*

The WoS database was used for the main source of journal exploration. A search for laboratory and RCL research studies based on education and educational research studies was conducted. Once the journal lists were created, the *HistCite* software was applied to generate chronological historiographs (i.e., a time-based network diagram) based on the relationship of the cited works (i.e., the local citation score), which is the number of citations to a paper within the collection. Once the chronological historiographs of studies in the large pool were generated, they were screened and highlighted to identify the sub-pool of RCL studies. This was followed by the *HistCite* analysis of RCL studies through the topic of remote experiments or laboratories to identify the citation pattern and select the related studies for further in-depth document analysis.

*Part 2:* CiteSpace *Analysis Procedures*

The identified RCL database was submitted to *CiteSpace* analysis for reporting the cluster terms and searching for other important articles through the cited references or bibliographic collections. The *CiteSpace* software identified cluster terms and other important highly cited articles that were not listed in the WoS database through the cited references or bibliographic collections.

*Part 3: In-depth Analysis of Selected Articles*

This part of the study concentrated on 40 research articles for an in-depth analysis that was conducted using two elements of the EPPI guide, namely, reporting and quality of study. Each article was subjected to a screening process involving decisions of further selection and classification based on the established criteria flowing from the essential questions for this study. As a result, this process can be claimed as valid, consistent, and unbiased; it can be further replicated and updated. The overall goal of the systematic review for the RCL research and development was to ascertain what evidence exists that RCL teaching and learning approaches that highlight development and evaluation to improve the understanding of science and the attitudes toward this new learning mode for all level students. Studies included in the review met the following criteria:

- Their principal focus is on the effects of RCL approaches on design, understanding, attitudes, gender, and practices.
- They report evaluations of RCL materials.
- They have been published in English-language journals or reported in conference proceedings during the period 1992–2013.

Using this three-part procedure facilitated the analysis process, which could include identifying research gaps and combining ideas of different research topics. Furthermore, this procedure reduced research bias; for instance, the review procedure is not overly influenced by the results in the study abstracts. Where the nature of the review process involves a clear or detailed review of the methodology and results, researchers can use this review format to summarize different constructs of evaluation; this should be very useful in research discussions, conclusions, and suggestions.

*An Overview of the Literature Review Process*

In the methodology section, the originality framework for effectively conducting the literature review was described for analysis of the RCL research studies. In the following, the process of conducting the literature review based on three important phases was summarised.

(a) *HistCite* analysis

- WoS database search; Topics: Laboratory
- Generates the chronological historiographs: laboratory pattern & RCL area
- WoS database search; Topics: Remote laboratory / remote experiment
- Generates the chronological historiographs: RCL studies' relationship of the cited works
- Choose related RCL with Full articles: most cited works and cite other work

(b) *CiteSpace* analysis

- Searching for other important RCL articles through the cited references
- Reporting the cluster terms via the topic of cited references

- Choose most cited works on cited references but not in *HistCite*

(c) EPPI guide: reporting of study

- EPPI-Centre data extraction & coding tool for education studies
- Section M: Quality of the study - reporting

### 2.6.4 The Findings and Analysis of HistCite, Citespace and Systematic Review

***For Histcite* analysis** – The *HistCite* software was applied to analyse the structure of the studies and relationships among the 1,583 papers identified in the WoS (Figure 1). The 62 RCL research studies (Figure 2) were found based on the education and educational research studies using the WoS database on the larger pool of laboratory or practical work studies.

**Date: Feb 2014**
**Results: 1,583**
*(from All Databases)*
**You searched for:**
**TOPIC**: (laborator*)
Refined by: RESEARCH AREAS=( EDUCATION EDUCATIONAL RESEARCH )
Timespan=All years.
Search language=Auto

Figure 1 WoS Search Result for the Topic Laboratory

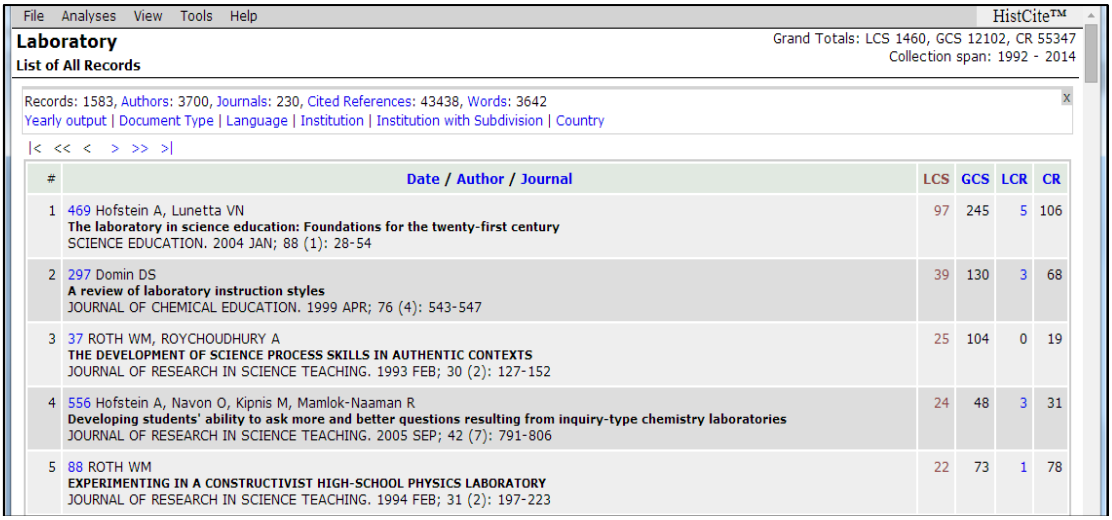
**Date: Feb 2014**
**Results: 62**
*(from All Databases)*
**You searched for:**
**TOPIC**: (remot* laborator*) ORTOPIC: (remot* experiment*)
Refined by: RESEARCH AREAS=( EDUCATION EDUCATIONAL RESEARCH )
Timespan=All years.
Search language=Auto

Figure 2 WoS Search Result for the Topic of Remote Laboratory

Because of the number of articles in the *HistCite* file, the full findings cannot be completely described here. Hence, the first page of the *HistCite* file of laboratory work is included (Figure 3) that provides general information about the results in the first line of the file. Due to the subscription history of the library, the coverage of

WoS, the collection spans from 1992 to 2014. The timeline for the growth of laboratory work in educational research is exhibited by a *HistCite* presentation of the ranked citation index of 1,583 research articles within 230 journals by 3,700 authors and with 43,438 cited references. The meanings of the acronyms used in Figure 3 and elsewhere in the text are:

- GCS: global citation score presents the total number of citations to a paper in WoS.
- LCR: local cited references presents the number of citations in a paper's reference list to other papers within the collection.
- LCS: local citation score presents the count of citations to a paper within the collection.
- CR: cited references presents the number of cited references in the paper's bibliography.


File Analyses View Tools Help HistCite™

**Laboratory**
**List of All Records**

Grand Totals: LCS 1460, GCS 12102, CR 55347
Collection span: 1992 - 2014

Records: 1583, Authors: 3700, Journals: 230, Cited References: 43438, Words: 3642
Yearly output | Document Type | Language | Institution | Institution with Subdivision | Country

|< << < > >> >|

| # | Date / Author / Journal | LCS | GCS | LCR | CR |
|---|---|---|---|---|---|
| 1 | 469 Hofstein A, Lunetta VN<br>**The laboratory in science education: Foundations for the twenty-first century**<br>SCIENCE EDUCATION. 2004 JAN; 88 (1): 28-54 | 97 | 245 | 5 | 106 |
| 2 | 297 Domin DS<br>**A review of laboratory instruction styles**<br>JOURNAL OF CHEMICAL EDUCATION. 1999 APR; 76 (4): 543-547 | 39 | 130 | 3 | 68 |
| 3 | 37 ROTH WM, ROYCHOUDHURY A<br>**THE DEVELOPMENT OF SCIENCE PROCESS SKILLS IN AUTHENTIC CONTEXTS**<br>JOURNAL OF RESEARCH IN SCIENCE TEACHING. 1993 FEB; 30 (2): 127-152 | 25 | 104 | 0 | 19 |
| 4 | 556 Hofstein A, Navon O, Kipnis M, Mamlok-Naaman R<br>**Developing students' ability to ask more and better questions resulting from inquiry-type chemistry laboratories**<br>JOURNAL OF RESEARCH IN SCIENCE TEACHING. 2005 SEP; 42 (7): 791-806 | 24 | 48 | 3 | 31 |
| 5 | 88 ROTH WM<br>**EXPERIMENTING IN A CONSTRUCTIVIST HIGH-SCHOOL PHYSICS LABORATORY**<br>JOURNAL OF RESEARCH IN SCIENCE TEACHING. 1994 FEB; 31 (2): 197-223 | 22 | 73 | 1 | 78 |

Figure 3 The *HistCite* File of Article Publications linked to the Field of Laboratories

The historiograph of laboratory studies is too large and complex to be shown here; but Figure 4 shows the historiograph generated based on the LCS, which has been cropped partially to display and trace the historical pattern of the RCL studies conducted by identifying the related papers using a circle to denote critical nodes of the evolutionary network of background citations. Based on these historiographs, the RCL was found to be a state-of-the-art subset of laboratory work. Hence, it is a new way of conducting laboratory work, particularly in science education; this practice has gained fairly wide research attention over the past two decades in the engineering area.

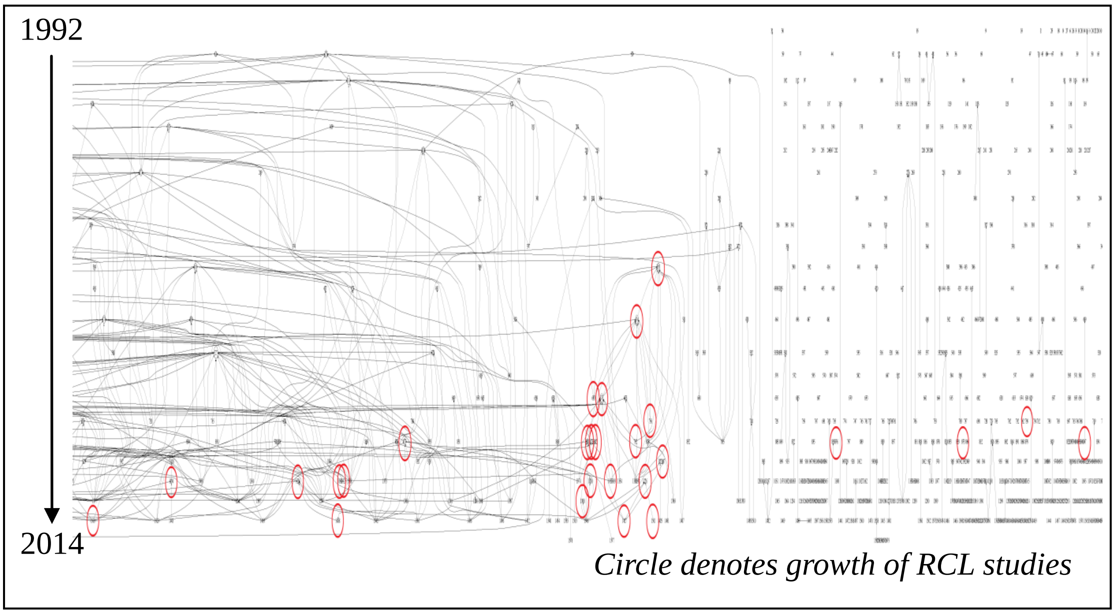



Figure 4 The Chronological Historiographs of Laboratory Work from 1992 to Early 2014

The RLs studies were explored with a separate *HistCite* analysis that revealed the timeline for the growth of RCL educational research based on the ranked citation index of 62 articles within 21 journals by 217 authors with 1,581 cited references. Figure 5 shows the *HistCite* graphmaker display of the historiograph of RLs that was generated based on the LCS and the relationship of cited works with circle diameters proportional to the LCS and arrows exhibiting the citation direction. Even though the number of RCL articles is much smaller than that of ordinary laboratory work, it is still large enough to trace the related RCL studies via the chronological historiograph.

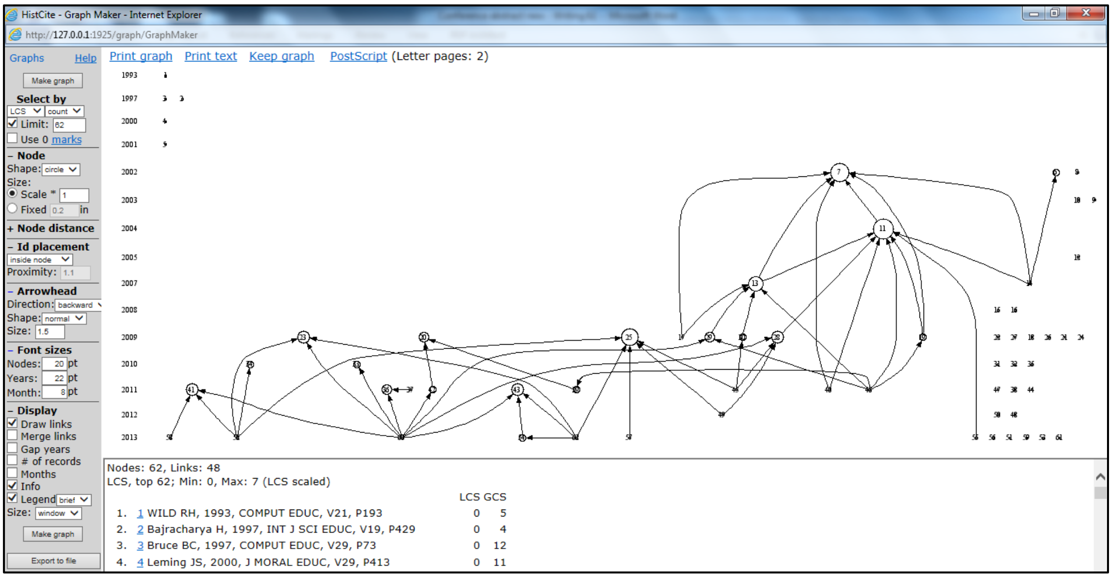


Figure 5 The *HistCite* Graphmaker Display of the Historiographs of RCL from 1993 to 2013

The citation direction arrows show that 32 articles were either cited by others or cited other works within the WoS collection and illustrate the relationship of citations between papers. Therefore, the number of influential articles has been substantially reduced from 62 to 32 articles. These articles are important for tracking the related sources and giving credit to other research with similar ideas. Two articles were excluded from further review because one was written in a language other than English (Prezelj & Cudina, 2009 – written in Slovenian) and another was related to virtual laboratories rather than RLs (Wannous & Nakano, 2010), resulting in a total of 30 articles for further in-depth review using the EPPI criteria.

***For Citespace* analysis** – The purpose of this study involving searching the important RCL articles that are highly cited within the community required this step in the analysis to consider the original 62 articles selected for *CiteSpace* analysis instead of the restricted 30 RCL articles. Thus, the data of the *CiteSpace* analysis originated from the 62 articles and from the 50 most-cited papers each year between 1993 and 2013. Figure 6 shows an overview of the co-citation networks generated by the *CiteSpace* software; Figure 7 presents a timeline visualization of the clusters with automatically created labels (only highly cited papers in major clusters are shown). Thus, the 507 references and 1981 co-citation links were allocated into 32 clusters with major clusters identified, but the limitation of the software allowed only 29 major clusters to be listed in Figure 7. The cluster labels shown were useful for understanding the research scope or direction of RLs because these terms were frequently used within the community. Furthermore, these terms were very useful for conducting research related to RCL development, results, discussion, conclusions, and suggestions.

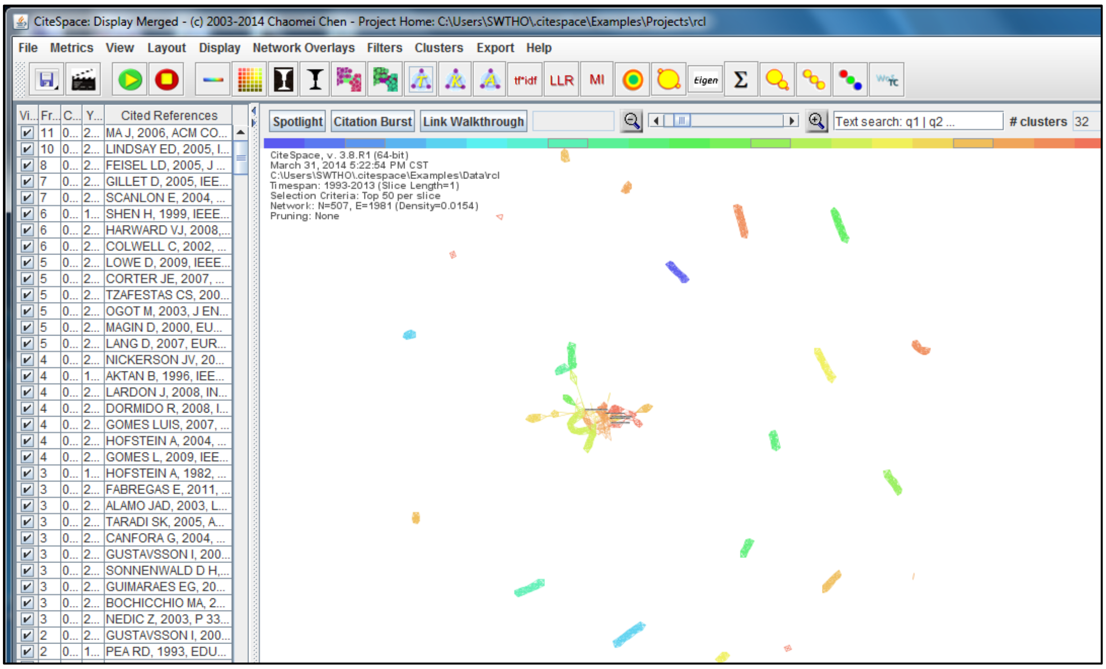


Figure 6 An Overview of the Co-citation Networks

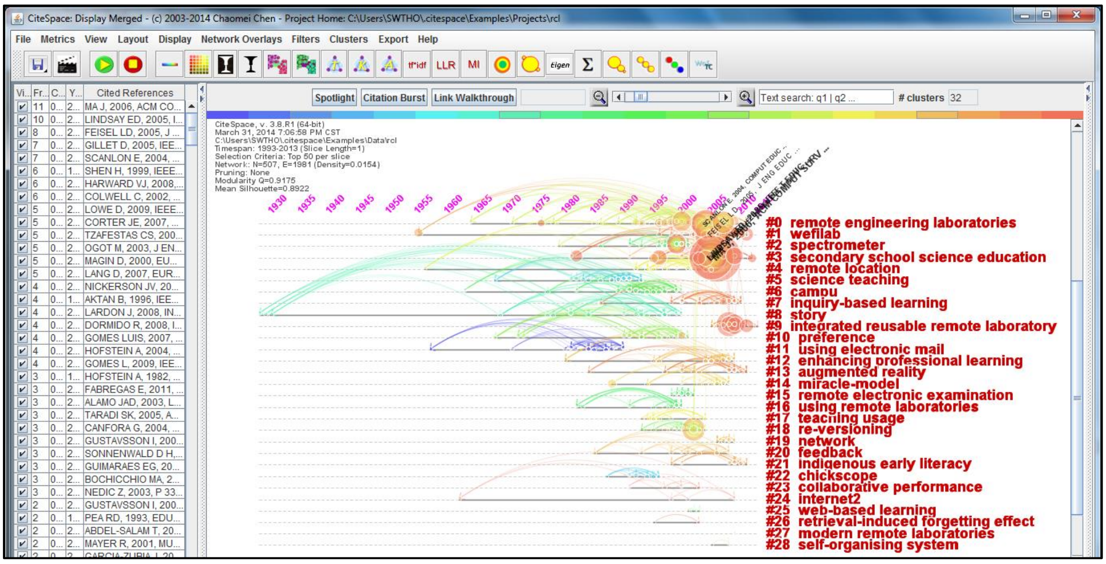


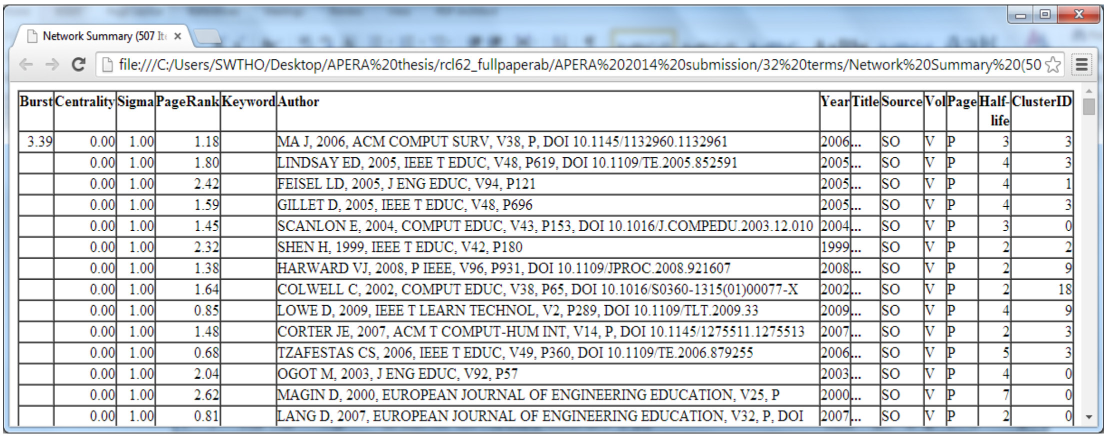
Figure 7 32 Cluster Terms Generated from 1993 to 2013 (*CiteSpace* parameters: time slice length=1; selection criteria - Top 50 per slice; Network - N= 507, E= 1981; modularity=0.9175; mean silhouette=0.8922; clusters=32)

A narrative was then generated to analyse the largest cluster. Table 1 shows the automatically selected cluster labels for the ten largest clusters along with their size, identity number, and silhouette value in brackets. The silhouette value is used for estimating the uncertainty involved in identifying the nature of a cluster with the value of 1, meaning a perfect separation from other clusters where no single article is clustered in two or more clusters. Chen et al. (2010) stated that “cluster labeling or other aggregation tasks will become more straightforward for clusters with the silhouette value in the range of 0.7~0.9 or higher.” (p. 1391). The top-ranked title terms by log-likelihood ratio (LLR) were chosen as cluster labels. The largest cluster *remote engineering laboratories* (#0, 0.838) had 60 papers. The second largest cluster (#1, 0.888), with 34 papers, was labelled as *wefilab* (web-based Wi-Fi laboratory). The third and fourth largest clusters were *spectrometer* and *novel ICT* (#2, 0.997; #3, 0.896) and had 32 papers each. Then, the fifth to tenth largest clusters were *remote location* (#4, 1), *science teaching* (#5, 1), *campus* (#6, 1), *inquiry-based learning* (#7, 1), *story* (#8, 1), and *integrated reusable remote laboratory* (#9, 0.963); all had fewer than 30 papers.

Table 1
Summary of the Ten Largest Clusters

| # | Size | Silhouette | Label (LLR) |
|---|---|---|---|
| 0 | 60 | 0.838 | remote engineering laboratories |
| 1 | 34 | 0.888 | Wefilab |
| 2 | 32 | 0.997 | Spectrometer |
| 3 | 32 | 0.896 | novel ICT |
| 4 | 26 | 1 | remote location |
| 5 | 26 | 1 | science teaching |
| 6 | 25 | 1 | campus |
| 7 | 24 | 1 | inquiry-based learning |
| 8 | 23 | 1 | story |
| 9 | 21 | 0.963 | integrated reusable remote laboratory |

The network summary table (Figure 8) was generated for choosing another ten most-cited papers that were not listed in the WoS database. These articles were added to the 30 articles identified earlier for in-depth review using the EPPI criteria.




| Burst | Centrality | Sigma | PageRank | Keyword | Author | Year | Title | Source | Vol | Page | Half-life | ClusterID |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3.39 | 0.00 | 1.00 | 1.18 | | MA J, 2006, ACM COMPUT SURV, V38, P, DOI 10.1145/1132960.1132961 | 2006 | ... | SO | V | P | 3 | 3 |
| | 0.00 | 1.00 | 1.80 | | LINDSAY ED, 2005, IEEE T EDUC, V48, P619, DOI 10.1109/TE.2005.852591 | 2005 | ... | SO | V | P | 4 | 3 |
| | 0.00 | 1.00 | 2.42 | | FEISEL LD, 2005, J ENG EDUC, V94, P121 | 2005 | ... | SO | V | P | 4 | 1 |
| | 0.00 | 1.00 | 1.59 | | GILLET D, 2005, IEEE T EDUC, V48, P696 | 2005 | ... | SO | V | P | 4 | 3 |
| | 0.00 | 1.00 | 1.45 | | SCANLON E, 2004, COMPUT EDUC, V43, P153, DOI 10.1016/J.COMPEDU.2003.12.010 | 2004 | ... | SO | V | P | 3 | 0 |
| | 0.00 | 1.00 | 2.32 | | SHEN H, 1999, IEEE T EDUC, V42, P180 | 1999 | ... | SO | V | P | 2 | 2 |
| | 0.00 | 1.00 | 1.38 | | HARWARD VJ, 2008, P IEEE, V96, P931, DOI 10.1109/JPROC.2008.921607 | 2008 | ... | SO | V | P | 2 | 9 |
| | 0.00 | 1.00 | 1.64 | | COLWELL C, 2002, COMPUT EDUC, V38, P65, DOI 10.1016/S0360-1315(01)00077-X | 2002 | ... | SO | V | P | 2 | 18 |
| | 0.00 | 1.00 | 0.85 | | LOWE D, 2009, IEEE T LEARN TECHNOL, V2, P289, DOI 10.1109/TLT.2009.33 | 2009 | ... | SO | V | P | 4 | 9 |
| | 0.00 | 1.00 | 1.48 | | CORTER JE, 2007, ACM T COMPUT-HUM INT, V14, P, DOI 10.1145/1275511.1275513 | 2007 | ... | SO | V | P | 2 | 3 |
| | 0.00 | 1.00 | 0.68 | | TZAFESTAS CS, 2006, IEEE T EDUC, V49, P360, DOI 10.1109/TE.2006.879255 | 2006 | ... | SO | V | P | 5 | 3 |
| | 0.00 | 1.00 | 2.04 | | OGOT M, 2003, J ENG EDUC, V92, P57 | 2003 | ... | SO | V | P | 4 | 0 |
| | 0.00 | 1.00 | 2.62 | | MAGIN D, 2000, EUROPEAN JOURNAL OF ENGINEERING EDUCATION, V25, P | 2000 | ... | SO | V | P | 7 | 0 |
| | 0.00 | 1.00 | 0.81 | | LANG D, 2007, EUROPEAN JOURNAL OF ENGINEERING EDUCATION, V32, P, DOI | 2007 | ... | SO | V | P | 2 | 0 |

Figure 8 *Citespace* Network Summary Table

***Systematic review*** – The 40 research articles identified by the *HistCite* and *CiteSpace* software procedures were systematically reviewed using the EPPI criteria for reporting and quality of study. However, on deeper investigation, only 26 articles met both of these criteria; the other 14 studies just reported on the development of the RCL system (5), discussed the RCL literature review (3), or focused more on describing the architecture of RLs with incomplete data collection and analysis (6). The detailed data extractions of those selected articles (Table 2) show the evaluation of the 26 selected studies. Based on the findings, 19 studies reported on the design of the RLs, 23 on understanding, and 12 on attitude. It was noted that 12 studies reported on a combination of these three aspects; two aspects were of relatively low concern from the previous researchers. Five studies reported on related skills and only one study reported on gender aspect. Thus, an overview and the evidence of these articles are discussed in the following section.

Table 2

*Reporting Details on Evaluation of the 26 Studies*

| Author(s) | Sample (*n*) | Partici-pants | Discipline | Methods | Outcomes D | U | A | G | P |
|---|---|---|---|---|---|---|---|---|---|
| Abdulwahed & Nagy (2009) | 70 (E:n/a; C:n/a) | U | Physics | E, Quan | √ | √ | | | |
| Abdulwahed & Nagy (2011) | 65 (E:n/a; C:n/a) | U, G | Physics | E, Quan | | √ | √ | | |
| Barrios et al. (2013) | 43 | U | Physics | NE, Quan | √ | | | | |
| Cooper & Ferreira (2009) | 153 | U | Physics | NE, M | | √ | √ | | √ |
| Corter et al. (2007) | 306 | U | Physics | NE, M | √ | √ | √ | | √ |
| Corter et al. (2011) | 457 (E:169; $C_H$: 121, $C_S$: 167) | U | Physics | E, Quan | √ | √ | √ | | |
| Cui et al. (2012) | 315 | U | Physics | NE, Quan | √ | √ | √ | | |
| Fabregas et al. (2011) | 60 | U | Physics | NE, Quan | | √ | √ | | |
| Fiore & Ratti (2007) | 27 | U | Biology | NE, M | √ | √ | | | |
| Gillet et al. (2005) | 96 | U | Physics | NE, M | √ | √ | | | |
| Gustavsson et al. (2009) | 78 | U | Physics | NE, Quan | √ | | | | |
| Kong et al. (2009) | 23 | P | Physics | NE, Quan | | √ | √ | | |
| Lang et al. (2007) | 52 (E:31; C:21) | U | Physics | E, Quan | √ | √ | | - | √ |
| Lindsay & Good (2005) | 146 (E:n/a; C:n/a) | U | Physics | E, Quan | | √ | | | |
| Lowe et al. (2013) | 112 | S | Physics | NE, Quan | √ | √ | √ | - | √ |
| Nickerson et al. (2007) | 29 | U | Physics | NE, Quan | √ | √ | √ | | |
| Ogot et al. (2003) | n/a (E:n/a; C:n/a) | U | Physics | E, Quan | √ | √ | √ | | |
| Sauter et al. (2013) | 123 (E:n/a; C:n/a) | U | Physics | E, M | √ | √ | √ | | |
| Scanlon et al. (2004) | 12 | U | Physics | NE, Qua | √ | √ | √ | | |
| Shyr (2011) | 110 (E:55; C:55) | U | Physics | NE, M | √ | √ | √ | | |
| Stefanovic (2013) | 1595 (E:n/a; C:n/a) | U | Physics | E, Quan | √ | √ | √ | √ | √ |
| Tawfik et al. (2013) | 64 | U | Physics | NE, Quan | √ | √ | √ | | |
| Tiwari & Singh (2011) | 54 | U | Physics | NE, Quan | √ | √ | √ | | |
| Torre et al. (2013) | 115 (E:62; C:53) | U | Physics | E, Quan | | √ | | | |
| Tzafestas et al. (2006) | 60 (E:n/a; C:n/a) | U | Physics | E, M | | √ | | | |
| Vargas et al. (2011) | 120 | U | Physics | NE, Quan | √ | | | | |
| **Total** | | | | | 19 | 23 | 16 | 1 | 5 |

*Notes.* Sample: E = experimental group, C = control group, $C_H$ = hands-on control group, $C_S$ = simulation control group; Participants: G = postgraduate, U = undergraduate, S = secondary, P = primary; Methods: E = experimental, NE = non-experimental, M = mixed, Qua = qualitative, Quan = quantitative; Outcomes: D = design, U = understanding, A = attitude, G = gender, P = practices.

### 2.6.5 Discussion of the Systematic Review

To guide the reader, the finding or assertion in **boldface** type were reported. Discussion of the assertions is provided in normal font.

*An overview of related studies on RCL*

**Four geographic regions contributed most of the studies, and most of these studies were funded small-scale research.** The countries of origin of the data for the articles are grouped into four subsets (the number in brackets refers to the number of articles): Europe (13), the United States (6), Australia (4), and Asia (3). Almost 70% of the research and development received funding, which is an important element to develop and sustain RLs. Generally, RCL research was applied to small-scale samples, with nearly 85% of the studies having fewer than 200 participants. Therefore, more advanced data analysis could not be performed due to sample sizes; most studies did not report effect sizes, which meant that a meta-analysis could not be done. This problem may be due to the limitation of the RCL system explored that cannot be used, controlled, and monitored by many participants at the same time.

**Evaluation of education level and content focus showed that most of the studies were conducted at the university level and involved physics.** Almost all studies involved university students as participants; 23 studies were undertaken by undergraduate students and one by undergraduate and postgraduate students. Only one study each was found at the primary (Kong et al., 2009) and secondary levels (Lowe et al., 2013). Regarding remote experiments, all were related to physics topics except for one relating to biology (Fiore & Ratti, 2007) that involved observing mouse behavior.

**The methodology used in these studies varied.** Ten studies used an experimental design, and 16 studies used nonexperimental designs. However, seven of the ten experimental studies did not clearly state the number of participants in the experimental and control groups. Seven of the studies used mixed methods, 18 used quantitative methods, and only one used qualitative methods for collecting and analyzing their data. Almost 80% of the research studies did not mention a pilot study, one study explicitly identified a pilot test (Lang et al., 2007), and five claimed that the study itself was a pilot study (Barrios et al., 2013; Gillet et al., 2005; Lowe et al., 2013; Nickerson, Corter, Esche, & Chassapis, 2007; Tzafestas, Palaiologou, & Alifragis, 2006). Unexpectedly, none of the studies reported the effect size and none discussed the ethical consent for conducting the research.

*The evidence of design of the RCL system*

**Generally, the data for the design of the RLs were collected via questionnaire items and open-ended questions as well as interviews.** Evidence for the design of the RCL system comes from the findings of 19 articles (Table 2) that discussed the RCL design itself (i.e., format, content, quality, and manual guide), sense of reality, acceptance, usability, usefulness, and technical problems encountered. Based on these data, there appeared to be educational merits for the RCL system with the design, sense of reality, acceptance, usability, and usefulness aspects. However, some general limitations were found such as guidance; since RLs were a new laboratory approach, some participants had difficulty performing tasks. Another limitation related to access; there were system crashes due too many users wanting to use the same remote experiment as well as Internet connection problems.

*The evidence of understanding through the use of the RCL system*

**Normally, the data on understanding of certain concepts were collected via conceptual tests, laboratory tests, and laboratory reports.** The evidence of understanding through the use of the RCL system comes from the findings of 23 articles (Table 1), in which 17 articles reported data on understanding using conceptual tests, four articles (Fabregas, Farias, Dormido-Canto, Dormido, & Esquembre, 2011; Fiore & Ratti, 2007; Nickerson et al., 2007; Torre et al., 2013) reported the data using student examination grades, and five studies reported laboratory reports as proof of understanding. Several studies used more than one method to collect data on understanding, with laboratory reports produced considered as essential data for evaluating the newly developed RLs. Interestingly, there were four articles (Corter et al., 2007; Lang et al., 2007; Nickerson et al., 2007; Tzafestas et al., 2006) that reported equally good performance of the remote experiments and hands-on or simulation experiments. Thus, RLs appear to be an alternative laboratory learning experience or complementary to hands-on practical work.

*The evidence of attitude through the use of the RCL system*

**Most of the studies used questionnaire items and open-ended questions for their data collection about attitudes.** The evidence about attitudes as an outcome through the use of the RCL system comes from the findings of 16 articles (Table 1). Most of these studies discussed enjoyment, satisfaction, motivation, collaboration, and confidence. The data analysis of several studies used descriptive statistics (e.g., mean, standard deviation, percentage) for summarizing their data on attitude and narrative comments from open-ended questions. However, they did not fully compare the participants' outcomes. Thus, more inferential statistical analysis should be performed for testing the statistical hypotheses.

*The evidence of gender and practices through the use of the RCL system*

**Few studies involved consideration of gender and practices.** Unpredictably, only one study stated that no significant gender difference was found (Stefanovic, 2013); and two studies (Lang et al., 2007; Lowe et al., 2013) reported that statistical analysis could not be performed due to the limited number of female participants. Another important aspect that received little attention was students' practices; only five studies reported on practices (Table 1). The data on practices for RLs were collected via RCL tasks/assignments (Cooper & Ferreira, 2009; Stefanovic, 2013), standardized test items (Corter et al., 2007), questionnaire items (Lang et al., 2007), and open-ended questions (Lowe et al., 2013). Several different RCL practices were considered: ICT

(Cooper & Ferreira, 2009; Lowe et al., 2013), experimentation (Lowe et al., 2013; Stefanovic, 2013), visualization (Corter et al., 2007), and English language (Lang et al., 2007).

### 2.6.6 Conclusion and Future Work of Systematic Review in Remote Laboratories

This study set out to identify the importance and innovation of advanced procedures for document analysis and systematic reviews. Three important phases to analyse the structure of laboratory or practical work studies were concluded that focused on RCL studies and how to review the selected articles. Figure 9 summarizes the procedures.

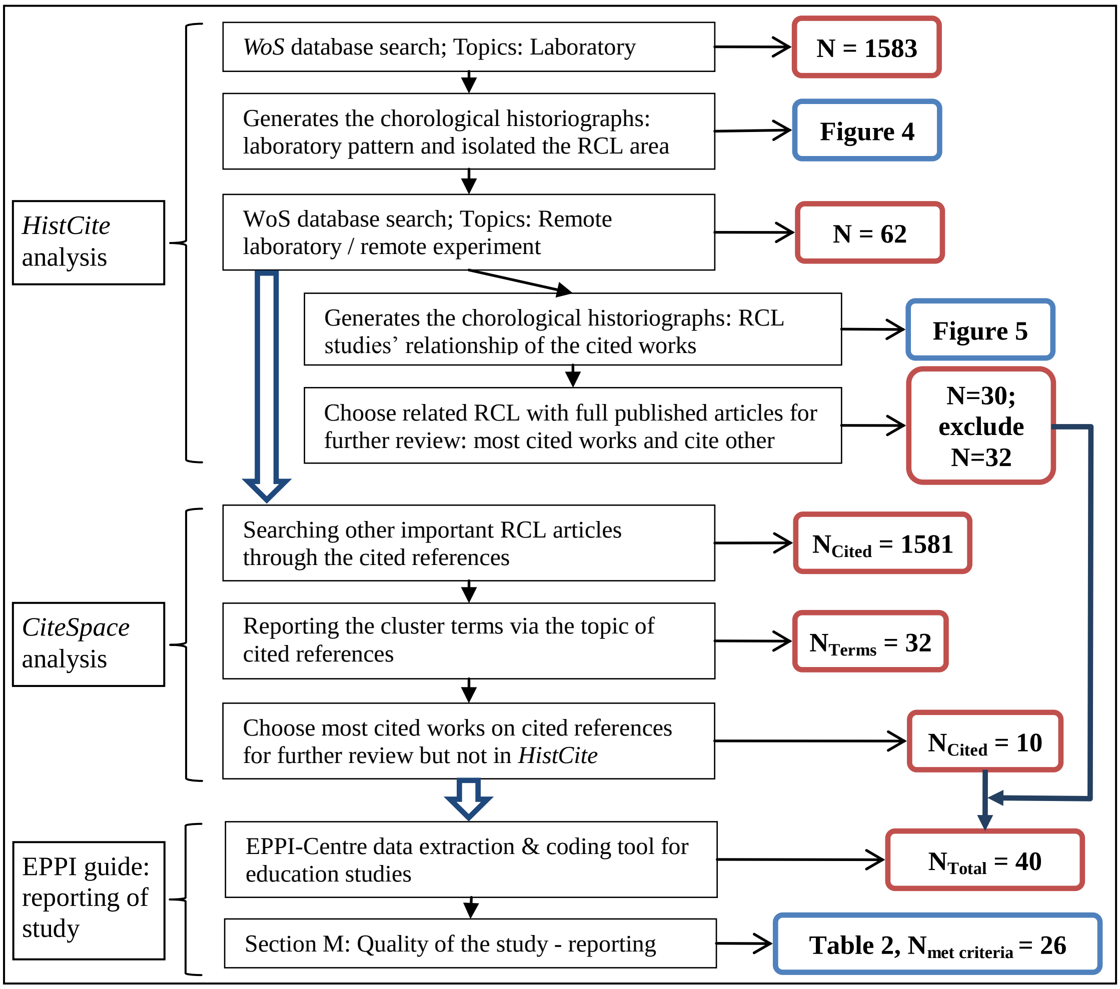


Figure 9 The Summary of Findings in the Literature Review

The relationship of the cited works was observed in the historiographs of laboratory work and RCL research studies through *HistCite* analysis. Then, more information about RCL was obtained with *CiteSpace* analysis, which identified a manageable number of studies for further consideration. The in-depth analysis identified and deleted some studies that passed the software screens but did not fully meet the EPPI criteria. The in-depth consideration of the remaining studies showed that (a) RCL in the engineering area are quite well-established, (b) this technology has begun to attract attention from secondary and primary school science education, and (c) very little development of RCL system matching the secondary science education curriculum has been done. Moreover, the other issues that need to be considered when conducting development and evaluation of RCL in science education are pilot tests, research ethics approval and informed consent, and gender issues. As a whole, this study has contributed to the literature on laboratory work in science education and, more particularly, sheds light on the growth of RCL. It may also have implications for the teaching of diverse science discipline areas. Alternatively, the social network analysis method can also be further applied for identifying research collaboration networks among researchers who have published articles related to laboratory work (Yeung, Liu, & Ng, 2005).

Future studies of practical work in science, where RCL are a subset employing the latest and most innovative technology, need more work and to be applied to K–12 and new science education reforms. Further development of RCL at the K–12 school level will need to consider the underlying scientific concepts and practices and cross-cutting principles to closely match contemporary science education reforms and curricula and to maximize the important features of RCL (i.e., long-time observation, dangerous experiments, real-time interactivity, anytime and anywhere access, and engagement). Additionally, the development of feasible remote experiments across the science disciplines (e.g., biology and chemistry) should be considered in future work.

## 2.7 Remote-controlled Laboratory Applications

Despite the educational merits of applying practical work in science education, the conventional manner of providing practical activities may be severely limited. Limitations include long setup times, resource depletion, laboratory space requirements, and inadequate experimentation skills. In addition, students may lack sufficient knowledge, skills, and safety training to conduct practical work effectively and safely. However, such limitations or problems can be resolved by using RCL system in experiments. For example, expensive equipment can be shared among institutions and the risks or dangers encountered by students in experimental work can be largely eliminated (Cooper, 2005; Grober, Vetter, Eckert, & Jodl, 2008). Additionally, the benefits of access to remote experimental equipment according to Cooper and Ferreira (2009) enable the following:

(a) enabling distance learning,
(b) the sharing of high costs and complex experimental equipment, and
(c) the efficient managing of an increasing number of students in a limited laboratory space.

However, conducting experiments through RCL system is an imperfect solution because the RCL activities may be affected by certain constraints or problems, such as Internet concerns (e.g., problems with Internet connection and hacking problem etc.) and the limited number of learners that can control or observe the experiment at the same time. In addition, RCL is normally connected with "specific apparatus which is not available in normal laboratories. As a result, the investigation is limited to a few experiments tied to the apparatus. It is not designed to support a high degree of openness" (Chen et al., 2012, p.8). Some of these problems can be partially resolved by appropriately refining the design and development of the RCL system.

Various previous studies on RCL system development have indicated that these remote-controlled technologies may play a crucial role in the science and technology learning process (Barrios et al., 2013; Scanlon et al., 2004). However, most published papers focus on technical concerns in the engineering development aspect and overlook rigorously evaluating student learning effectiveness and attitude toward the new mode of learning (Gillet et al., 2005; Hercog et al., 2007; Ko et al., 2001).

According to search results from the WoS database, this remote learning approach remains uncommon in school science learning environments; little empirical evidence is available to verify that this technology can be used effectively as a tool for enabling students to further their science learning (Kong et al., 2009; Lowe et al., 2013). A review of other scholarly databases suggested that the RCL method had been extended and applied in secondary science education since 2008 (Schauer, Lustig, Dvorak, & Ozvoldova, 2008), and numerous studies involve a secondary school as the research sample (Claesson & Håkansson, 2012; Fernandes, 2012; Schauer et al., 2008). Thus, studies on RCL use in secondary education have attracted attention from the international science educators' community. Therefore, the researcher extended, applied, and investigated a novel RCL system applied to guided-inquiry experimentation in Hong Kong secondary school science education.

The following section describes an analysis of practical problems encountered by researchers and possible learning gaps that may result in low motivation and achievement levels and limited skills in science. In addition, a rationale for why the design and evaluation of the RCL system can facilitate overcoming the related learning and teaching challenges in Hong Kong science education by using the Internet is provided.

## 2.8 Possible Learning Gaps and the Need for the RCL System

According to recent research in science education, numerous issues and difficulties hinder the effective learning and teaching of science in schools, particularly during laboratory work (Cheung, 2008; Souter & MacVicar, 2012). First, practical work in science classes has tended to be replaced by experiment simulations or teacher demonstrations, a trend that worries science educators (Magin & Kanapathipillai, 2000; Tho & Yeung, 2015; Yeung et al., 2012). In addition, experiencing real phenomena while learning and teaching is essential for effective learning (Ming & Lo, 2012). Therefore, substituting real experiments with simulations may cause science teachers to misinterpret the meaning and role of experimentation. Students should be encouraged to discover results or create real science experiments. Nevertheless, using simulations is appropriate for certain applications, such as investigating microscopic phenomena (Leleve, Benmohamed, Prevot, & Meyer, 2003; Shirinifard et al., 2009), including tumour growths, and dangerous phenomena, such as car accidents (Champion, Mandiau, Kolski, Heidet, & Kemeny, 1999).

Second, insufficient time for learning and teaching in science education is a great challenge (Cheng, 2004; Cheung, 2008) and may be attributable to a demanding syllabus. In addition, large class sizes (Watson, Handala, Maher, & McGinty, 2013) may reduce teaching time because teachers require more time for explanations and class control. Consequently, the time allocation for science experiments may be affected; in particular, "experiments that take longer than a standard science lesson may frequently be ignored" (Souter & MacVicar, 2012, p. 11). In other words, science experiments in school are normally predictable and short.

Third, regarding learning diversity, slow learners or underperforming students often must spend more time on hands-on and minds-on learning activities, such as science experiments for school-based assessment or drills in problem-solving exercises for public examinations (Yeung et al., 2012). The EdB (2009) reported that e-learning resource development should be based on the ability of the students. Then, students with low ability can engage in learning activities during their leisure time, usually outside of the school environment.

Finally, most experiments cannot be performed outside of school during free time because ordinary science practical work involves using the science laboratory in school. Therefore, RCL system can resolve this problem by enabling students to learn during their free time at home or anywhere with a computer and Internet access; students need only to install a Laboratory Virtual Instrument Engineering Workbench (LabVIEW) Run-Time Engine and a browser (e.g., Internet Explorer or Google

Chrome) to monitor and control the real-time experiment from their computer. Thus, students can conduct real-time science experiments by using the RCL system, which can complement, enrich, and extend conventional activities in school. Therefore, they find a new learning experience in conducting science experiments by using the RCL system. In the present study, the researcher sought an alternative manner (i.e., using RCL activities) through which to conduct real-time experiments.

## 2.9 Key Related Studies

### 2.9.1 Studies on RCL Applied in School Learning Environments

A key related study, "An Experience of Teaching for Learning by Observation: Remote-Controlled Experiments on Electrical Circuits", was conducted by a group of researchers from the Hong Kong Institute of Education (HKIEd; Kong et al., 2009). The authors applied and investigated the state-of-the-art tool known as remote-controlled experiments by using open source software, the LabVNC-based system, in learning and teaching the topic of electricity in a Hong Kong primary school classroom. This trial of teaching through learning by observation continued approximately one hour, and a mixed research method was applied for evaluation. Until now, this was the only remote laboratory study conducted in a Hong Kong school.

Kong et al. (2009) began by guiding Primary Four students through a lesson incorporating a remote-controlled experiment setup in which the system required various tools and related teaching materials, namely, a computer with Internet connection, a projector, an interactive whiteboard, the LabVNC-based system, and related worksheets. First, the students responded to a pre-test instrument that included a prediction, conceptual knowledge test, and survey questions. This was followed by the lesson, taught with the LabVNC-based system. Finally, a post-test instrument was employed, together with 4-point Likert scale questionnaires and two open-ended questions pertaining to the students' views of learning achievement and difficulties encountered when using the LabVNC-based system. The entire process was observed and followed up with semi-structured interviews with the teacher and selected students.

The study by Kong et al. (2009) was beneficial because the authors investigated the effectiveness of remote-controlled experiments. Their study can potentially further the development of RCLs in science education and benefit future generations in conducting scientific investigation. Therefore, Kong et al. were pioneers in the research and development of incorporating this remote-controlled technology in Hong Kong school science education.

Kong et al. (2009) noted that the results of the pre-test and post-test evaluations were statistically significant, and their remote-controlled experiment system received positive feedback from the teacher and students. Moreover, by using surveys and interviews, the authors investigated other aspects of motivation and problems encountered by the learners. They provided several crucial recommendations for further application of remote-controlled experiments in a school learning environment, suggesting the use of a collaborative approach and the development of RCL system that supports multiple user logins. Thus, their study was particularly influential on this current study because it provided numerous suggestions regarding the development and evaluation of the RCL system.

The second key study, "Evaluation of the Use of Remote Laboratories for Secondary School Science Education", was conducted by a group of researchers from Australia (Lowe et al., 2013). They evaluated the use of existing RLs at the University of Technology, Sydney, by students and teachers in several Australian secondary schools. This trial explored the use of RLs by secondary students and teachers to evaluate their opinions of using the system compared with ordinary hands-on practical work. A survey was used for the evaluation.

Lowe et al. (2013) addressed several critical suggestions for further applying RLs in secondary school learning environments by using the science laboratory environment inventory (Fraser & McRobbie, 1995), to understand the RLs. The authors claimed that the physical environment and open-endedness were not appropriate when using the existing RLs. However, the study by Lowe et al. differed from the current study because the researcher also develops RCL system.

The revised science laboratory environment inventory (Fraser & McRobbie, 1995) is an instrument designed to assess student perceptions toward science laboratory situations. Lowe et al. (2012) planned to partially adapt this inventory for further large-scale evaluation. Thus, the study was particularly valuable because it offered an initial view of applying the RCL system in secondary education and provided suggestions regarding evaluating RCL system.

The third key study, “It’s Lab Time—Connecting Schools to Universities’ Remote Laboratories”, was conducted by Tannhäuser and Dondi (2012). This study was part of the European Commission funded project called UniSchooLabS, and was conducted for expanding science experiment “by promoting collaboration between universities and schools in the provision of remote access to science laboratories for primary and secondary schools through the development of an online toolkit and the deployment of the inquiry-based teaching methodology” (p. 1). However, this study focused on constructing a collaboration model for RLs between schools and universities.

In their conference paper, Tannhäuser and Dondi (2012) discussed the integration between inquiry-based learning and RLs, claiming that inquiry-based learning is a modern learning approach for science education. They conducted a remote experiment in school through a university–school partnership project, adding that related experiments would be developed for use in primary and secondary schools.

Another aspect of their study that was useful in the current study was the discussion of existing obstacles to accessing remote experiment equipment for primary or secondary schools. The obstacles identified and briefly describe by Tannhäuser and Dondi (2012) are as follows:

- Awareness of the existence and accessibility of RL resources is lacking amongst science teachers.

- Obtaining appropriate RL activities from universities for application in primary or secondary schools is difficult, and the activity materials are not available in many languages.
- No social or professional networks were formed for pioneer teachers who utilised RLs.
- Collaboration between schools and universities was lacking.

After searching the Internet for information related of Tannhäuser and Dondi (2012), the researcher found an evaluation report from 2011 that discussed obtaining learner opinions and refining the effectiveness and usefulness of RL packages. The report presented key outcomes from the RL pilot process, focusing on evaluating RLs; data collection and analysis were performed to obtain information from the schools. The report was critical for integrating and applying remote or virtual laboratories at universities into the science learning and teaching in schools. This detailed evaluation report was returned to the development unit to enable improving the quality of the RL. Thus, an evaluation report is essential for further refinement of RLs.

Tannhäuser and Dondi (2012) used online questionnaires with additional open-ended questions to determine the teachers' views towards RL technology; in addition, group interviews were used to evaluate student learning outcomes. The authors found that the RL was favourably received as an innovative manner in which to conduct inquiry-based experiments by most of the teachers and laboratory instructors. However, a major technical problem with the RL was encountered during login. Tannhäuser and Dondi recommended that the login problem should be resolved in a newer version of the RL. Moreover, their findings were primarily based on teacher perceptions; only one focus interview instrument was used to evaluate student learning outcomes. The science topics related to primary level education were also not clearly stated in the evaluation report.

Hence, the conference paper and evaluation report were essential because they yielded a reference for a group interview instrument and described problems encountered and valuable suggestion for future development of integrating inquiry-based science learning with RLs. The results indicated that creating a strong connection between schools and universities is essential for promoting RCL system use.

In summary, the studies by Kong et al. (2009), Lowe et al. (2012), and Tannhäuser and Dondi (2011, 2012) were particularly beneficial to the study because they focused on conducting and evaluating experiments performed using RCLs. Moreover, valuable suggestions and strategies for integrating inquiry-based science learning with RCLs and methods for effectively collecting qualitative and quantitative data were discussed. Additionally, the researcher derived several essential elements of evaluation that should be considered during the development stage after reviewing the related research (i.e., a science laboratory environment inventory, student focus group interviews, and learner attitudes and understanding). Thus, the researcher conducted a scientific investigation involving the use of RCL system; a learning environment outside school that integrates the RCL system has potential for application in Hong Kong secondary school science education.

### 2.9.2 Research on Inquiry-Based Science Learning

A crucial reference article and book pertaining to RCL activity development were "Simplifying Inquiry Instructions", by Bell et al. (2005), and *Teaching High School Science through Inquiry and Argumentation, Second Edition*, by Llewellyn (2013). In their article Bell et al. identified the level of the inquiry activity, claiming that the degree of complexity in an inquiry activity varies and depends on the level of openness and the cognitive demands required. Figure 10 shows details of the level of inquiry adapted from Bell et al. (p. 32). Finally, guided inquiry is appropriate for use as the model with which to develop RCL activities after the first cycle of trial and refinement.

| How much information is given to the student? | | | |
|---|---|---|---|
| **Inquiry** | **Question?** | **Methods?** | **Solution?** |
| 1 | √ | √ | √ |
| 2 | √ | √ | |
| 3 | √ | | |
| 4 | | | |

Figure 10 Modified Version Four-level of Inquiry (Bell et al., 2005, p. 32)

In *Teaching High School Science through Inquiry and Argumentation, Second Edition*, Llewellyn (2013) explored and described applying the latest learning approach for science education, inquiry-based science learning. Currently, inquiry-based science learning had been widely discussed and applied in Hong Kong (Chan, 2010; Cheung, 2008; Chu, 2009; So, 2013; So & Kong, 2007; Song, Wong, & Looi, 2012; Sun & Looi, 2013) and internationally (Bybee, 2006; Dunne, Mahdi, & O'Reilly, 2013; Magonigle, 2011; Solano, 2009; Tannhäuser & Dondi, 2012).

Llewellyn (2013) began by surveying the value of inquiry-based learning and the meaning of this approach according to teacher and student perspectives. The author revealed insight about applying inquiry-based science learning in secondary education by providing a clear description of the method's characteristics and applying this approach in science classes. The manner of conducting inquiry-based learning through the 5E learning cycle (Engagement, Exploration, Explanation, Elaboration, and Evaluation) described in the book is valuable and descriptions of teacher experiences, challenges, and assessments are provided. In addition, several valuable inquiry-based experiments, particularly for beginners, are provided as examples for teacher reference.

The researcher derived the research questions in this study from a review of studies on remote-controlled experiments and inquiry-based science learning. First, how can a novel RCL system involving inquiry-based learning be developed to enhance science education? Second, how does the design of such a system applied in an inquiry-based learning environment influence student learning effectiveness? The researcher drew from the ideas and knowledge of Kong et al. (2009), Lowe et al. (2012), Tannhäuser and Dondi (2011, 2012), Bell et al. (2005), and Llewellyn (2013), because their integration of remote-controlled experiments and inquiry-based science learning fostered engagement and motivation in secondary school students. RCL afford an alternative manner in which students can engage in scientific investigation and also contribute to the study of the state-of-art technology in science education.

### 2.9.3 Review of Theoretical Frameworks for Designing and Developing Technology-enhanced Learning

In general, the design, development, and evaluation of TEL tools and activities must be guided by applying a technology-related framework. Therefore, this section discusses well-known design and development studies. Finally, this section presents the decision of a research framework for the present study. Simon (2002) suggested that the basic principles of educational technology and learning design should first focus on the learner, and then on a task analysis in which the “learning takes place in the head of the student, and depends entirely on the activities of the student” (p. 62). This opinion was supported by Mor and Winters (2007), who asserted that the learner or user in a TEL environment is the main focus of design approaches, because the learner is the target user of the developed TEL tools employed for achieving the learning goals. The following three principles were identified and briefly defined by Simon:

- First, the learning environment must focus on the learner or user. “Learning depends wholly on what the student does; [and] only indirectly on what the teacher or the university does” (p. 63).
- Second, the environment must include an appropriate learning assignment. “Analysis of the student behaviours begins with analysis of the learning task” (p. 63).
- Finally, the technological tools must enable the learner to learn meaningfully. “We must not use technology just because it is available. We must use it when, and only when, we can see how it will enable us to do the educational job better” (p. 63).

Instructional system design framework is currently common accepted for developing and studying novel learning programme related to the TEL environment (Zimnas, Kleftouris, & Valkanos, 2009). Zimnas, Kleftouris, and Valkanos defined instructional system design as “a step-by-step system [for evaluating] students’ needs, the design and development of learning materials, and the evaluation of the effectiveness of the learning intervention” (p. 367). The general principle of such design is analysis, development, design, implementation, and evaluation. Conventionally, the instructional process was concentrate on the instructor and teaching. However, the latest design of the Dick, Carey, and Carey model (2005) for designing the instructional process is “a more contemporary view of instruction [that is] a systematic process in which every component (i.e., teacher, learners, materials, and learning environment) is crucial to successful learning” (p. 2). Although this is an effective theoretical framework for use in a TEL environment, one of the key elements of this framework is based on the instructional process, a teaching element that may not be appropriate for the current study.

Linn (2003) developed a framework called the scaffold knowledge integration framework. Future developers and researchers can use this framework as a guide for research and development involving technology to promote science learning. This framework has four main principles, namely, making thinking visible, making science accessible, enabling students to learn from each other, and promoting autonomous learning. The fourth principle, promoting autonomous learning, was refined and renamed as promoting lifelong learning (Linn, Clark, & Slotta, 2003). Although this framework pertains to encouraging lifelong learning, no element in this framework was refined or redesigned, an aspect that is critical for developing a TEL approach.

The community practice framework is increasingly valuable for integrating technology, science, community, and education (Duran, Runvand, & Fossum, 2009; Moore, 2008; Tsai, Laffey, & Hanuscin, 2010). In other words, community practice is a framework model for “connecting people in the spirit of learning, knowledge sharing, and collaboration as well as individual, group, and organisational development” (Cambridge, Kaplan, & Suter, 2005, p. 1). Originally, “the goal of community design is to bring out the community’s own internal direction, character, and energy" (Wenger, McDermott, & Snyder, 2002, p. 51). Hence, the concepts of community practice focus on the community experience and interaction in a real-life setting. Wenger (1996) stated that "knowledge, belonging, and doing are not separable: What we know, who we are and what we do seamlessly come together in one experience of participation" (p. 22). In general, this framework has four main steps for attaining to the purpose of study, namely, developing relationships, learning and developing practices, executing tasks and projects, and creating new knowledge (Cambridge, Kaplan, & Suter, 2005). Therefore, this framework is appropriate for certain aspects of using RCL in science education; for example, students can conduct remote-controlled experiments at home, which can be categorised as a community. However, students may also conduct experiments from various locations, such as in the school computer laboratory or even at a cafe. However, this framework does not focus on the refining and redesigning element. Thus, the community of practice may not be suitable for the current study.

Another framework for designing and developing the TEL tools and activities, called design-based research (DBR), seems more appropriate. Anderson and Shattuck (2012) reviewed DBR critically, scrutinising the use of DBR over the past decade. They observed that the DBR framework is increasingly used for related technology-enhanced research papers. The idea central to this framework is integrating technology with real-world settings in education (Amiel & Reeves, 2008; Hoadley, 2004; Kong et al., 2009; Reeves, 2006; Rowe, 2012). The DBR framework includes a continuous cycle that comprises four major steps, namely, design, enactment, analysis, and redesign (Collins, 1992; Design-Based Research Collective, 2003). In other words, by using this framework, the researcher can evaluate and improve the novel RCL system.

Moreover, five essential DBR characteristics were summarised by Van den Akker and his colleagues (2006, p. 5):

- Interventionism pertains to developing and designing an intervention involving technology in real learning environments.

- Iteration indicates conducting a study by applying a cyclic method that involves design, evaluation, and refinement.
- Process orientation relates to understanding and improving interventions.
- Utility orientation is about the practicality for users in real contexts.
- Theory orientation is based on the theoretical application and field testing of the design and how it contributes to theory building.

The detailed analysis and redesign phase of DBR is crucial for the current study. One of the basic characteristic of the DBR framework is the integrative component that requires a mixed-method approach for improving the objectivity, validity, and applicability of the research and development (Anderson & Shattuck, 2012; Feng & Hannafin, 2005). The mixed method can be used to evaluate the learning process of the students. Because RCL system can only support use by a few students in this current study, the DBR approach closely suited the current study objective to adopt and develop a series of RCL activities that promote meaningful science learning inside and outside the classroom. The DBR approach was considered suitable because of the crucial iteration process as well as the emphasis on the correlation between design, research, and practice. The present study involved various methods of data collection. The evaluation component was based on the mixed-method design that employs both quantitative and qualitative research methodologies.

Mixed methods research is frequently referred to the "process and outcomes of using both qualitative and quantitative methods and types of data" (Creswell & Tashakkori, 2007, p. 303). The quantitative method is able "produce results to assess the frequency and magnitude of trends" (Creswell, 2004, p. 559). The qualitative data is gathered using interview that present "many different perspectives on the study topic and provide a complex picture of the situation" (Creswell, 2004, p. 559). Thus, these collecting of qualitative data offered deeper insight against just working with quantitative data (Cameron, 2011; Creswell & Plano Clark, 2011). In addition, Creswell and Plano Clark (2011, p. 67) stated that the data integration can be performed through (a) merging the two data sets, (b) connecting from the analysis of one set of data to the collection of a second set of data, (c) embedding of one form of data within a larger design or procedure, and (d) working with a framework (theoretical or program) to fix together the data sets.

According to the aforementioned literature, DBR is not new. In addition, Amiel and Reeves (2008) clearly critiqued this approach, indicating related limitations. However, they found that the new application of DBR relates to studying the “complexity of technology as a process and shaping the question of value of research by establishing relationships between practitioners and researchers” (p. 35). They inquire, “How does a new research framework such as design-based research address the conception of technology as a process and the issue of value in educational technology research?” (p. 35). Therefore, Amiel and Reeves further described that determining technology that can enhance the complex process of integrating tools into educational environments is crucial.

After reviewing several existing design frameworks, the researcher selected the DBR framework illustrated by Reeves (2006), shown in Figure 11, for this study. The critical aspect of DBR is to “build a stronger connection between educational research and real world problem[s]” (Amiel & Reeves, 2008, p. 34). In addition, the researcher found a conference paper closely related to the DBR framework, entitled “Design-Based Research and Doctoral Students: Guidelines for Preparing a Dissertation Proposal”, written by Herrington, McKenney, Reeves, and Oliver (2007). In this paper, the authors guide other researchers or postgraduate students in applying the DBR method to their research. This paper was valuable because it detailed guidelines for designing the RCL system, which is the main focus of the study. Thus, the development of the RCL system and activities in the present study was based on RCL design principles. Chapter 3 details the DBR method, and Chapter 4 described the RCL design principles and system development.

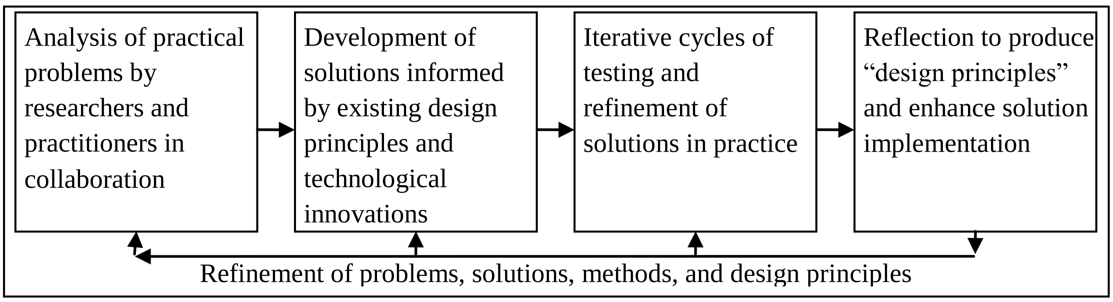



Figure 11 DBR Process illustrated by Reeves (2006, p. 59)

## 2.10 Theories underlying the RCL Design and Development

The learning theory of constructivism concerns how learners actively construct their own knowledge according to interpretation in response to interaction with certain learning environments or methods (Aubusson & Watson, 2002; Bell, 1993; Jonassen, 1999; Jonassen & Rohrer–Murphy, 1999). In science learning, the vital role of the constructivism is to let "students' direct experiences with the physical world and its recognition of the active construction of meaning that takes place whenever students interact with their environment" especially in web-based learning (Jang, 2009, p. 248). For science laboratory work, students are required to actively participate and explore science knowledge through laboratory activities (Roth, 1994). Torre et al. (2013) stated that RCL via web-based learning are considered a constructivist method. In addition, RCL can provide a social constructivism learning environment for conducting remote experiments and sharing experiment data among users in different locations (Abdulwahed & Nagy, 2011). Woo and Reeves (2007) illustrated that students can obtain assistance from "adults or peers who are more advanced in their meaning-making, [and] begin to grasp concepts and ideas that they cannot understand on their own" (p. 18) through social constructivism. Moreover, the Internet is frequently used as a web-based learning environment for promoting social constructivism (Abdulwahed & Nagy, 2011; Chuang, Hwang, & Tsai, 2008; Woo & Reeves, 2007).

Therefore, the RCL learning environment has its foundation on constructivism in which users can acquire and construct knowledge by themselves in remote techniques though real-time experiments that are useful and significant for them (Abdulwahed & Nagy, 2011; Torre et al., 2013). In other words, constructivist approach in science learning proposes that knowledge is constructed while students performing the remote experiments. This RCL approach can offer a new alternative for practical learning that extends within and beyond the traditional practical work, particularly long-term observation in science experiments (Souter & MacVicar, 2012; Tho & Yeung, 2015), experiment that located at distance places and those science students with physical disabilities (Cooper & Ferreira, 2009; Scanlon et al., 2004). However, it is anticipated that web-based learning should be extended to include RCL in science education (Jang, 2009; Scanlon et al., 2004) because laboratory practice is acknowledged as a fundamental component of science education (Abrahams & Reiss, 2012; Hofstein & Lunetta, 2004; Reddy & Goodman, 2002). Additionally, the conventional web-based science learning or e-learning are unable to perform real-time science experiment. In the current study, the RCL used in science education was originally created as a guided constructivist learning environment that enabled students to actively engage in and investigate remote science experiments in the web-based learning environment. By using the RCL approach, students have the opportunity to experience constructivist science learning embedded in their science practices.

## 2.11 Conclusion

According to the suggestion and conclusions derived from the literature review, most studies have focused on the strengths of developing RCL system at the university level; few studies have examined the effectiveness of developing RCL system in secondary schools. Because supporting data for RCL system applied in secondary science education is limited, DBR was adopted in the current study to develop, evaluate, and improve the RCL system for secondary school education application. The development and refinement of and findings from RCL system in this study can contribute to the body of RCL research.

# CHAPTER 3

# RESEARCH METHODOLOGY

The major focus of this study was to design, develop, implement, evaluate, and refine the RCL system for use in science education, particularly in secondary schools, and address the research questions listed in the first section of this chapter. This chapter describes the research questions, research framework that incorporated the DBR method, and details the sampling, implementation, and data collection steps, as well as the data analysis of three iterative cycles.

## 3.1 Research Questions

The following research questions were formed according to the literature review and baseline study:

1. What forms of novel RCL system incorporating guided inquiry can be developed to enhance science education?
   - 1.1 What feasible guided-inquiry experiments can be incorporated into the RCL system?
   - 1.2 How can the RCL system be implemented in a school environment for use by students inside and outside of the classroom?
   - 1.3 What are the major problems encountered in the system development process and in the implementation stage? How can such problems be resolved?
2. How can the RCL system be designed to influence student learning effectiveness in a guided-inquiry learning environment?
   - 2.1 What science learning outcomes did using the developed RCL system produce (in terms of student conceptual understanding and perception)?
   - 2.2 What are the strengths and weaknesses of the RCL system in the real school environment?

2.3 What are the major problems encountered in implementing the RCL system in real classroom? How can such problems be resolved?

2.4 How can teacher and student opinions be used to improve the RCL system in the school environment?

3. What are the educational implications of the research findings for future RCL implementation?

## 3.2 Research Framework

In developing and designing the RCL system and its activities, the DBR framework was adopted. Based on the literature review, the DBR framework is increasingly used for technology-enhanced studies (Anderson & Shattuck, 2012). The core idea of this framework is designing and developing teaching methods or resources by integrating technology into a real-world setting in education (Amiel & Reeves, 2008; Kong et al., 2009; Nelson, Ketelhut, Clarke, Bowman, & Dede, 2005; Reeves, 2006). Therefore, the DBR method is not used to determine universal explanations or solutions; instead, it enables obtaining a deep understanding of innovations and the problems that may affect developing teaching methods or resources in real settings (Anderson, 2005). In other words, this framework can be used to evaluate and improve a newly developed system. In similar terms, Feng and Hannafin (2005, p. 6) defined DBR as "a systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings".

Since the DBR method is flexible and affords in-depth understanding of the adoption of innovation (Feng & Hannafin, 2005; Nelson et al., 2005; Van den Akker et al., 2001), the DBR method applied to educational technology research as proposed by Reeves (2006) was adapted for developing and designing the RCL system for secondary science education. Various minor modifications were made to adapt the method to the particular research setting. The DBR method involved four essential stages; however, the iteration cycles in the third stage were modified (Figure 12).

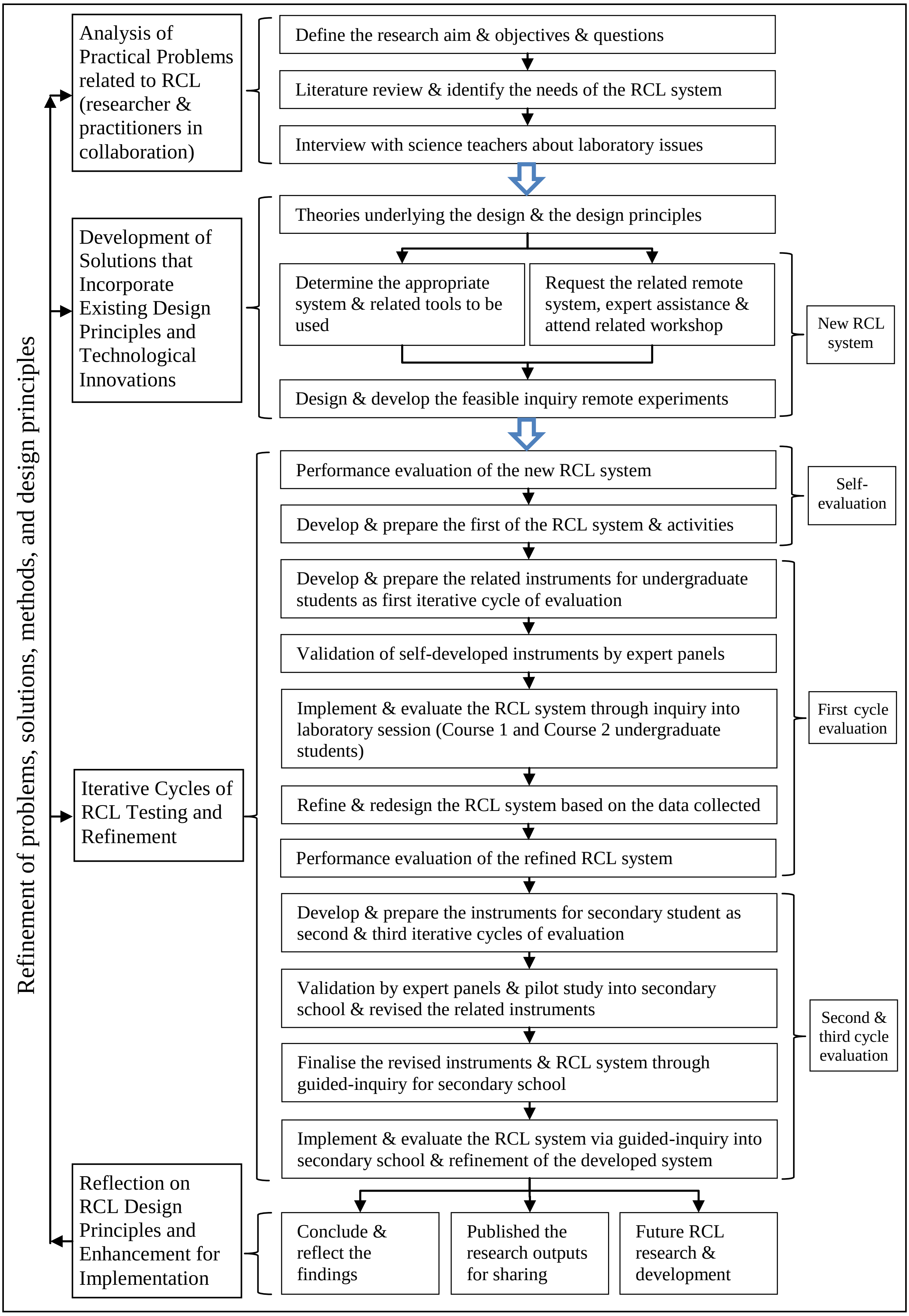



Figure 12 Research Process

## 3.3 Analysis of Practical Problems Related to RCL

In the first stage of this study, a literature review and analysis of practical problems or needs related to laboratory work in Hong Kong (as abovementioned), several problems were identified and are summarised as follows: (a) The meaning and role of experimentation is unclear, and real experiments tend to be replaced by simulations or teacher demonstrations; (b) Insufficient time is spent on learning and teaching in science education; (c) Students with different ability levels require varying amounts of time on hands-on and minds-on learning activities; (d) No such real hands-on experiments involving practical work are available for students to conduct during free time; (e) Exploring an alternative or new learning method for conducting practical scientific work is necessary.

With past experience as a science teacher and now as science teacher educator with research interest in technology-enhanced science laboratory learning (Chan et al., 2014; Tho et al., 2015; Tho & Hussain, 2011; Tho & Yeung, 2013, 2014a; Tho et al., 2013; Zhang et al., 2014) is essential for understanding the implications RCL technology has for practical work in science education.

Two interview sessions with experienced science teachers were conducted (Appendix K) and are described in the following section. Related practitioners (i.e., undergraduate students) commented positively or negatively on conventional science laboratory work (see Section 5.1). The data collected from the practitioners were analysed to determine positive and negative themes. Subsequently, the same practitioners in collaboration were required to provide critical comments and suggestions after the iteration process. Involving users in the development and design process by obtaining their views, comments, and suggestions concerning the difficulties encountered is a critical aspect of DBR.

### *Analysis of Practical Problems: Interviews with Two Experienced Science Teachers*

In addition to determining related practical problems through a literature review, the researcher conducted interviews with two experienced science teachers. The interviewees have been pseudo named as T1 and T2 for ethical reasons. These interviews were essential for exploring the problems encountered during scientific practical work. Involving experienced practitioners is a crucial aspect of DBR, because the practitioners can share the views they "hold for the everyday activities and issues that relate to the problem area" (Herrington & Reeves, 2011, p. 597). According to an analysis of the interview data pertaining to the teachers' experiences with science experiments, both teachers mentioned similar practical work approaches used in their school and claimed that practical work is essential for science learning.

T1: *It is important because experiment is necessary for learning science, because the goal of science is to teach [students] how to verify, how to seek to be true, and why it is happening. So, they have to verify it by doing experiment.*

T2: *It is important because [students] can witness the results in person. They use knowledge from textbooks and it would be quite impressive; they are interested in the experiments.*

According to the interview data, several topics were identified and three related themes were generated: (a) conventional science experiments and related disadvantages, (b) simulation experiments, and (c) difficulties encountered when conducting science experiments. These themes were crucial for developing the RCL learning environment. The first theme addressed the conventional method of conducting science experiments. The teachers indicated that conventional science experiments are normally used and some related disadvantages.

T1: *They [Students] primarily conduct mainly the conventional science experiments… The shortcomings of the conventional experiments are we have to set everything for students, and they actually know the results of most of the experiments.*

T2: *They [Students] would usually follow the procedures to do experiments, conventional one…For the shortcomings we really have to see if the students are going to complete [the experiments]them seriously.*

Regarding the second theme, numerous practices of the teachers that were consistent with practices determined in the literature review were derived from the interview data. T1 and T2 also used simulated experiments in class.

T1: *Simulation experiment, if the experiment is quite dangerous then the teacher would demonstrate it to [students] them… The shortcomings of the simulation experiment are the students could not do it by themselves. As the teacher demonstrates the experiment to the students, they could only see things in one way.*

T2: *…because the effect of the CD-ROM (simulation experiment) is good enough, and getting clear results is difficult in some experiments.*

According to the first two themes, the conventional experiments are normally short and may be uninteresting to perform. Moreover, teachers may use alternative experiments (i.e., simulation experiments), which are used because of danger concerns or unclear experimental results. Therefore, in the current study, alternative methods for conducting real-time experiments through the Internet were developed.

The third theme focused on the difficulties encountered when conducting science experiments. The teachers provided differing perspectives on difficulties they encountered; these explanations are essential for further development. T1 mentioned the meaning or role of the experiment, in which the teacher is responsible for informing students about the purpose of the experiment. T1 explained: "They think it is fun to do experiments, but they ignore the meaning of the experiment all the time". T1 added that another problem pertains to students needing to share the limited laboratory apparatus; because of "the structural problem of Hong Kong, there is too many students". Some students may take advantage by not conduct the experiments, which causes problems for them in future science-related education or careers. Therefore, the learning outcomes of using the RCL system must be mentioned clearly and the time allocated for each group to perform remote-controlled experiments must be sufficient.

T2 addressed another two crucial perspectives related to laboratory instruction and English. Regarding laboratory instruction, T2 explained: "I think they are weak at following the rules for the problems they get". Additionally, English language instruction is used in practical work. For example, T2 said they “use English to do the report. As they are quite weak at looking them in a point-by-point way, also the words, they might not be able to follow the steps.” These findings indicate that Chinese words should be included to clarify difficult English words in the developed worksheet, survey, and conceptual understanding test. The instruments must be able to evaluate perception and science concepts, but not the language perspective (English). In fact, this is the issues or problems of language-mediated instruction, particularly in Hong Kong science classes, have been discussed by previous researchers (Li, 1998; Yip, Tsang, & Cheung, 2003).

Thus, three main themes related to laboratory work were identified from the initial interview data, which seemed to warrant further RCL development. These interview data were also consistent with those derived from the literature review.

## 3.4 Development of Solutions that Incorporate Existing Design Principles and Technological Innovations

A Google Scholar search yielded no literature addressing the design principle and criteria of RCL in secondary science education. However, several design principles related to RCL in engineering were borrowed and revised in the current study (Cagiltay, Aydin, Aydin, Kara, & Alexandru, 2011; Gadzhanov & Nafalski, 2010). Such design principles are presented in Section 4.1.

The researcher tested several existing online experiments and attended classes and workshops related to remote-controlled technology to identify the appropriate system for use in the present study. The tested system included innovative use of Internet Protocol (IP) cameras, the Internet School Experimental System (Schauer, Lustig, Dvořák, & Ožvoldová, 2008), and open source RCLs using LabVNC or National Instruments (NI) system. Related experiment tools and potential science topics were also investigated.

Consequently, the appropriate remote technology system was finally selected. The selection process involved several critical steps, such as (a) purchasing the NI products, Laboratory Virtual Instrument Engineering Workbench (LabVIEW) software, and IP camera, (b) attending related NI workshops in early 2013, and (c) seeking expert assistance.

Several feasible experiments that could be incorporated into the RCL system were identified from a critical review of the local school science curricula. In addition, developing the new RCL system included sensor calibration, software development, and the design of a complete remote-controlled experimental setup for an array of scientific experiments.

First, a version of the novel RCL system was developed according to the information gathered from the classes, workshops, literature review, and science education syllabus. The criteria for the developed system stipulated that the system must be innovative, enable long-term observation in daily activities, and be repeatable. Four feasible remote experiments that could be incorporated into the first version of the RCL system were designed and developed for use in secondary science education. Inquiry worksheets (refer to Appendix A) regarding scientific concepts related to the selected science topics in the Hong Kong science education curriculum guide were developed. The format of the inquiry plan was adapted and modified from *Inquire Within: Implementing Inquiry-Based Science Standards in Grades 3–8* by Llewellyn (2007). Subsequently, an initial RCL user guide was developed according to the remote experiments, inquiry worksheets, and the IP camera guide (Refer to Appendix B). Thus, this novel RCL system can be beneficial for science students; the educational goal can be achieved through experiments involving varied science disciplines, including physics and biology. In the following, the newly RCL system were keep upgrading and developing based on the first version of RCL system through evaluation and refinement.

## 3.5 Iterative Cycles of RCL Testing and Refinement

The third stage of the study consisted of implementing the RCL system as mentioned in the second stage of the study. A total of three iterative cycles of testing and refinements of the newly developed RCL system were performed.

### 3.5.1 System Performance Evaluation of Newly Developed RCL System

After the RCL system was successfully developed, the system performance was evaluated to ensure that the RCL system prototype was stable for implementing.

### 3.5.2 First Iterative Cycle

The first implementation and evaluation was based on the mixed-method design, which involves both quantitative and qualitative research methodologies. The RCL system was first quantitatively evaluated by two groups of undergraduate students. Subsequently, the system was refined according to suggestions received and difficulties encountered. The data and findings were triangulated and analysed descriptively and inferentially by using the mixed-method technique (Cameron, 2011; Creswell & Plano Clark, 2011; Creswell & Tashakkori, 2007; Olsen, 2004). In this study, the data triangulation in this study aims to maximizing the strengths of the quantitative and qualitative data with minimizing their weaknesses. In other words, the data triangulation does not accept all survey or achievement test results alone; instead it tries to get support from the interview and open-ended question. Thus, the data triangulation enabled the data analysis to be more comprehensive and reliable in determining the participation of undergraduate students in science-related teacher education courses that applied the developed RCL system.

Synthesising the findings from data collected by using various methods (merging and connecting data adapted from Creswell and Plano Clark [2011]) facilitated developing solid and valid conclusions concerning the research questions and topics.

#### 3.5.2.1 Sampling of First Iterative Cycle

This first evaluation study was conducted in a tertiary teacher education institution. For testing and evaluation, 69 undergraduate students in two different science-related teacher education courses voluntarily participated in this mixed-method study. The technology-enhanced lessons pertaining to the topics of sound, plants, and electrical circuits were firstly taught in a laboratory session by using the RCL system.

Therefore, this study focused the analysis on the undergraduate student views and suggestions for refining the RCL system before its subsequent formal implementation and evaluation in secondary schools. The first evaluation was essential for ensuring the reliability of the system; the student views and suggestions were highly relevant, because the participants studied various science education, web technology, and teacher training courses. Moreover, the study afforded them the opportunity to practice teaching laboratory work, and the RCL system could be applied in their future laboratory work at school.

#### 3.5.2.2 Research Instruments of First Iterative Cycle

Three types of instruments were developed for the first iteration: a pre-survey, a post-survey, and interview questions. According to previous research experience of conducting similar technology-enhanced learning projects (Tho et al., 2015) and the standard methods in educational research (Cohen, Manion, & Morrison, 2007; Creswell, 2008; Patton, 2002), the researcher used a self-developed pre-survey questionnaire and post-survey featuring a 4-point Likert scale and open-ended questions, as well as interviews, to determine participants' views on the advantages and disadvantages of conducting remote experiments, based on their learning experiences, in addition to their perceptions, attitudes, concerns, issues, and feedback on science learning and teaching with the RCL system. However, no cognitive test was used in this first iterative cycle because the students' cognitive understanding of the science concepts was not the main concern of this study.

The pre-survey questionnaire was divided into three sections (Refer to Appendix C): personal and other information (i.e., smartphone, tablet, and Internet data plan their presently hold), perception (i.e., present level of science knowledge, teaching science topic, ICT tools used to teach science, ability in conducting scientific experiments, and experience in inquiry-based learning or RCL activities), and previous experience in conducting conventional scientific experiments. Before beginning the RCL project, participants were asked to list the advantages and disadvantages of conducting conventional scientific experiments or science practical work in school or other science courses according to personal experience.

The post-survey questionnaire was divided into three main sections (Refer to Appendix D): RCL experience, survey items, and open-ended questions. (a) Participants listed the advantages and disadvantages of conducting remote experiments according to personal experience. (b) Survey items included eight categories of educational merits obtained by using the RCL system for science learning and teaching (rated on 4-point Likert scale 1=*strongly disagree*, 2=*disagree*, 3=*agree* and 4=*strongly agree*), namely, providing insight into science and ICT, operating the RCL system, enriching learning, developing application, stimulating motivation, improving teaching skills, promoting group work, and enhancing self-efficacy in learning and teaching. Three questions pertained to the first seven categories and six questions pertained to the last category (Table 3). (c) Four open-ended questions collected more in-depth feedback on learning experiences.

Table 3
Distribution of Post-survey Items on Eight Categories

| **Category** | **Item Number in Survey** | **Total Items** |
| --- | --- | --- |
| Insight of Science & ICT | 1, 2, 3 | 3 |
| Operating the RCL system | 4, 5, 6 | 3 |
| Enriching learning | 7, 8, 9 | 3 |
| Developing application | 10, 11, 12 | 3 |
| Stimulating motivation | 13, 14, 15 | 3 |
| Improving teaching skills | 16, 17, 18 | 3 |
| Promoting group work | 19, 20, 21 | 3 |
| Enhancing self-efficacy in learning & teaching | 22-27 | 6 |
| | **Total Items** | 27 |

Finally, the interview was conducted for triangulation with the questionnaire findings to ensure a more reliable evaluation of the RCL activities (Appendix E). During the interview, students elaborated on their perceptions expressed in and explanations of their responses to the interview questions, several survey items and open-ended questions on the questionnaire survey.

#### 3.5.2.3 Pilot Study of First Iterative Cycle

To ensure content validity, the questionnaire underwent review and commentary by a panel of research experts regarding the content and language used. Subsequently, to ensure that the participants in the sample could understand and complete the questions, two undergraduate students in the sample were asked to complete and evaluate the survey by commenting in writing on the instruments. Because they provided comments, both of them were excluded from the study (Creswell, 2008, p. 402). According to the data and comments obtained during the pilot study, the instrument underwent minor revision.

#### 3.5.2.4 Data Collection Procedure of First Iterative Cycle

As previously mentioned, a combination of research methods was adopted to determine the participants' perceptions, concerns, issues, and feedback from learning and teaching science through the RCL study. The data were collected through five major means (Connecting and Merging data, [Creswell & Plano Clark, 2011]): research participation consent, a pre-survey, RCL system guidelines and together with newly developed technology-enhanced inquiry worksheets, a post-survey, and interviews of three participants (Figure 13).

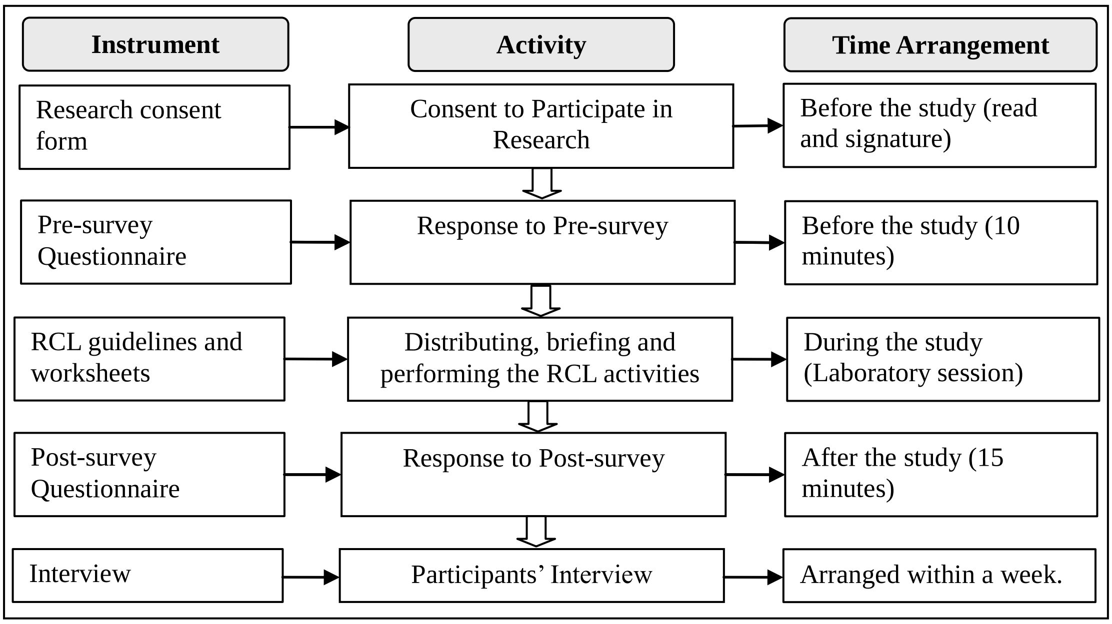



Figure 13 Summary of the Data Collection Procedures for Undergraduate Students

*Research consent form*: To comply with the educational research code, participants were required to complete and sign a form consenting to voluntary participation in the research before the initial briefing session began. They were informed of the study purpose and their right to withdraw any time without any penalty, and were told that all information they provided remained confidential and identifiable by codes known only to the researcher.

*Pre-survey questionnaire:* The pre-survey questionnaire was distributed before the laboratory sessions. Participants filled in their student number and had ten minutes to complete the questionnaire without discussion. They were instructed to answer the survey items according to their honest opinions. Participants were informed that participation was voluntary and would not affect their laboratory assignment or examination results.

*RCL worksheets and guidelines:* The RCL system guidelines and developed technology-enhanced inquiry worksheets were distributed to the students during the laboratory sessions. The researcher briefed the students on the worksheets and operation of the RCL system, which could be accessed by students to manipulate or control real-time experiments through the Internet. Students then accessed the RCL system and performed the remote experiments according to the worksheets.

*Post-survey questionnaire:* Finally, once the remote experiments were completed by the students, the related post-survey was administered. Participants had 15 minutes to complete the questionnaire without discussion. Again, they filled in their student number and answered the survey items honestly. Participants were again informed that test participation was voluntary and would not affect their laboratory assignment or examination results.

*Interview:* The subsequent interviews with selected participants were conducted within a week. The interviews with participants continued approximately half an hour.

Through this first iteration of DBR, both the RCL system and design principles were refined. Subsequently, the performance of the refined RCL system was evaluated to test the system stability and response time experienced by users.

#### 3.5.2.5 Analysis and Evaluative Methods of First Iterative Cycle

The Statistical Package for the Social Sciences (SPSS) was used for quantitative questionnaire data analysis. First, the reliability coefficient was determined using Cronbach's alpha. This method was suitable for estimating the internal consistency reliability by determining how all items on the test were interrelated and related to the entire test (Gay, Mills, & Airasian, 2009). The descriptive statistics collected from participants were then summarised to ascertain the demographic characteristics of participant responses and perceptions towards using the RCL system to conduct remote experiments. The descriptive statistics were expressed as a central tendency (mean) and standard deviation. Furthermore, the independent samples *t* test and analysis of variance (ANOVA) were used to analysis the survey data. The independent samples *t* test was applied to examine the differences between two groups (i.e., course and gender). Subsequently, ANOVA was performed for more than two groups to compare the scores of the students' science knowledge level (i.e., low, medium, and high). The significant difference was accepted or rejected in any category at the .05 significance level.

For qualitative data analysis, the open-ended data from the pre-survey and post-survey were input for coding into the NVivo software, and themes based on students' previous and current learning and experience of laboratory work (i.e., conventional science experiments and RCL) were derived, as well as the difficulties encountered and suggestions. Subsequently, semi-structured and tape-record interviews with three participants were arranged after the RCL activities. The coding and derived themes were based on the remote experiments, difficulties encountered, and suggestions. This method yielded extensive, meaningful, or in-depth data that can be triangulated from the survey (Cameron, 2011; Creswell & Plano Clark, 2011; Olsen, 2004).

#### 3.5.2.6 System Performance Evaluation of Refined RCL System

According to the first cycle of iteration, both the RCL system and design principles were refined. Then, the system performance was evaluated again to ensure that the refined RCL system was stable for implementation in the second iteration.

### 3.5.3 Second Iterative Cycle

The second iteration was also based on a mixed-methods design, which included quantitative and qualitative research methodologies. The refined RCL system that involved a guided-inquiry learning approach was evaluated quantitatively by a class of junior secondary school students from School A. Refined guided-inquiry worksheets and a teacher's guide (Refer to Appendix F) for scientific concepts related to the selected science topics based on the Hong Kong science education curriculum guide were developed. According to the findings from the first iteration, the RCL guided-inquiry approach seems more suitable for application in secondary education. Therefore, the general format of the guided-inquiry worksheets was adapted and modified according to “Simplifying Inquiry Instructions”, by Bell et al. (2005), “Facilitating Secondary Teachers to Implement Inquiry-Based Laboratory Work”, by Cheung (2008), and “Teacher’s Guide of Inquiry-Based Laboratory Work”, by Cheung (2006). Moreover, the RCL user’s guide was refined according to the refined remote experiments, inquiry worksheets, and IP camera guide (Refer to Appendix G). Once the data were collected from the second iteration, the refinement was performed again on the basis of the participants’ understanding, suggestions, and difficulties encountered. The data and findings were triangulated and analysed descriptively and inferentially by using the mixed-methods technique (Cameron, 2011; Creswell & Plano Clark, 2011; Creswell & Tashakkori, 2007; Olsen, 2004). Data triangulation enabled the data analysis to be comprehensive and reliable for determining the participation of secondary students using the developed RCL system.

Synthesising the findings from the various data collections via merging and connecting data adapted from Creswell and Plano Clark (2011) in the second iteration facilitated developing strong and valid conclusions concerning the research questions and difficulties encountered.

#### 3.5.3.1 Sampling of Second Iterative Cycle

The second iteration was firstly conducted in a secondary school; the sampling method employed was convenience sampling because a class in local secondary school was invited to participate in this study. For the testing and evaluation of the refined RCL system, a teacher and 36 junior secondary school students from an integrated science class participated in this mixed-method research. The students who participated were selected because the aim of this study was to apply technology-enhanced guided inquiry involving the refined RCL system to the topics of plants and electricity in a real classroom setting. This study also focused the analysis of the refined system on the secondary student understanding, views, and suggestions.

3.5.3.2 Research Instruments for Secondary School

Four types of instruments were developed for the second iteration: a multiple choice question (MCQ) conceptual test, pre-survey and post-survey questionnaires, and interview questions. The instruments used with the students were adapted and modified from standardised, available, validated instruments that had been published in reputable books and journals. Only one instrument was used with the teacher: the interview questions.

The MCQ instrument used to evaluate students' physics (electricity) and biology (plants) knowledge were adapted and modified from standardised and accepted instruments (Appendix H). The physics (electricity) questions were adapted and modified from the Determining and Interpreting Resistive Electric Circuit Concepts Test (DIRECT) developed by Engelhardt and Beichner (2004), the basic electrical concepts test developed by Shipstone et al. (1988), the electricity module developed by the Commonwealth of Australia (2003), and a related physics test developed by Lehrman (1998). A total of 12 questions related to physics (electricity) concepts (i.e., electrical circuit connections, battery banks, and solar energy) were selected from the referenced tests; Table 4 lists relevant adapted questions. According to the findings from the pilot test, to facilitate student understanding of the questions, the test was written in English and the traditional Chinese characters for certain difficult words were presented in brackets.

Questions relating to biology (plants) were adapted and modified from the two-tier multiple choice test of photosynthesis and respiration in plants developed by Haslam and Treagust (1987), the plant growth and development diagnostic test developed by Lin (2004), and related plants concepts tests (Raven, Johnson, Losos, & Singer, 2005; Chan, Luk, & Kong, 2005). A total of 12 questions related to biology concepts (i.e., plants and light stimuli, plants and gravity stimuli, and plant respiration) were selected from among these tests; Table 4 shows the adapted questions. To enable students to understand the questions, the test was also written in English, and the traditional Chinese characters of certain difficult words were presented in brackets.

Table 4
Distribution of Items for Conceptual Understanding Test

| Aspect | MCQ | Total Items |
|---|---|---|
| R2 – Plant due to light stimuli | 1 – 4 | 4 |
| R1 – Plant due to gravity stimuli | 5 – 8 | 4 |
| R3 – Plant respiration | 9 – 12 | 4 |
| L1 – Electrical circuit connection | 13 – 16 | 4 |
| L2 – Battery bank | 17 – 20 | 4 |
| RCL – Solar energy experiment | 21 – 24 | 4 |
| | **Total Items** | 24 |

The pre-survey questionnaire was divided into three sections (Refer to Appendix I): (a) personal information and their current view of personal science knowledge level and ability in conducting scientific experiments; (b) survey items, including four categories of perception and attitude towards personal interest, science experiments, ICT learning, and personal science practices (graded on a 4-point Likert scale ranging from 1 [*strongly disagree*] to 4 [*strongly agree*]). Table 5 shows details of the survey items in each category.

Table 5
Distribution of Pre-survey Items on Four Categories

| Category | Item Number in Survey | Total Items |
|---|---|---|
| Personal Interest | 1, 2, 3 | 3 |
| Science experiments | 4, 5, 6 | 3 |
| ICT learning | 7, 8, 9 | 3 |
| Science practices | 10-24 | 15 |
| | **Total Items** | 24 |

The post-survey questionnaire was divided into three main sections (Refer to Appendix J): personal information and experience of conducting RCL-relate experiments, survey items, and open-ended questions. (a) Participants provided information pertaining to conducting remote experiments. (b) Survey items were divided into two main sections: The first section included seven categories of educational values obtained by using the RCL system for science learning and teaching (graded on a 4-point Likert scale ranging from 1 [*strongly disagree*] to 4 [*strongly agree*]), namely, personal interest, remote science experiments, operation of the RCL system, motivation stimulation, teamwork promotion, importance of RCL system, and enhancement of science practices. The second section of the survey items compared the RCL experience with school science practical work in general (graded on a 5-point Likert scale ranging from 1= School practical work is much better, 2= School practical work is somewhat better, 3= Equally good, 4= RCL is somewhat better and 5= RCL is much better). Table 6 details the two sections of survey items. (c) Three open-ended questions were used to collect in-depth feedback on learning experiences.

Table 6
Distribution of Post-survey Items on Two Sections

| **Category** | **Item Number in Survey** | **Total Items** |
|---|---|---|
| ***First Section*** | | |
| Personal interest | 1, 2, 3 | 3 |
| Remote science experiments | 4, 5, 6 | 3 |
| Operating the RCL system | 7, 8, 9 | 3 |
| Stimulating motivation | 10, 11, 12, 13 | 4 |
| Promoting teamwork | 14, 15, 16 | 3 |
| Importance of RCL system | 17-21 | 5 |
| Enhancing science practices | 22-33 | 12 |
| ***Second Section*** | | |
| Comparison between RCL experience and science practical work | 34-39 | 6 |
| | **Total Items** | 39 |

Interviews were also conducted for triangulation with the questionnaire findings to ensure a reliable evaluation of the effectiveness of the refined RCL system (Appendix K). The student interviews were based on the questionnaire and interview questions. During the interviews, students elaborated on their views and perceptions of conventional experiments and remote experiments or explained their responses to the questionnaire items and open-ended questions. Because teacher opinions were also highly valued in this study, the teacher was interviewed to reveal the normal practice of practical work in the laboratory, self-efficacy (both confident and competent, [Bandura, 1977; Schunk, 1991]), potential difficulties encountered by the students, and the views and opinions towards the entire programme, including experiential learning and scientific investigation, overall RCL system, and ICT scope. Once the interview questions were generated, the modified instruments were read, checked, reviewed, and commented upon by a panel of research experts regarding content and language used.

3.5.3.3 Pilot Study for Secondary School

To ensure content validity and reliability, the questionnaire and MCQ test underwent review and commentary by a panel of research experts who examined the content and language used; next, a pilot test was conducted with a group of 30 junior secondary school students who had not been previously involved in the study. This assurance of quantity was acceptable and recommended by Johanson and Brooks (2010, p. 399), who suggested that "30 representative participants from the population of interest is a reasonable minimum recommendation for a pilot study where the purpose is preliminary survey or scale development". Thus, the instruments, namely, the pre-survey, post-survey, and MCQ test, were piloted before implementation in the RCL study (Table 7).

Table 7
The Detailed of Pilot Arrangement

| **Session** | **Duration Time** | **Description** |
| --- | --- | --- |
| First session | 15 minutes | Plan to finish the pre-survey in 10 minutes with COMMENT in 5 minutes. |
| Second session | 15 minutes | A brief of RCL and conducting several remote experiments in 15 minutes. |
| Third session | 50 minutes | Plan to finish the post-survey in 15 minutes with COMMENT in 5 minutes and MCQ test in 25 minutes with COMMENT in 5 minutes. |

At the beginning of the 2014 academic year, a class of junior secondary 3 (Form three, Grade 9) students participated in a pilot test for the current study. They responded to the pre-survey items in ten minutes, which was adequate time to complete the items and also the comments in the survey. Generally, the items were understandable; however, several words required clarification during the pilot test. Thus, traditional Chinese translations were included in subsequent RCL implementation. Reliability analysis using Cronbach's alpha was performed with SPSS. Table 8 shows the category names, number of items, and item reliability. The Cronbach's alpha values of personal interest, science experiment, and ICT learning were 0.80, 0.70, and 0.62, respectively, and the overall value was 0.92. Although a Cronbach's alpha value exceeding 0.7 is generally accepted (George & Mallery, 2010, p. 231; Nunnally & Bernstein, 1994), for scale development purposes, a Cronbach's alpha value exceeding 0.6 is also acceptable (Codita, 2011, p. 103). Therefore, the pre-survey was valid and had acceptable reliability.

Table 8
The Pre-survey Categories Names, Number of Items and its Cronbach Alpha Value

| Categories Names | Number of Items | Cronbach Alpha |
|---|---|---|
| Personal Interest | 3 | 0.80 |
| Science experiments | 3 | 0.70 |
| ICT learning | 3 | 0.62 |
| Science practices | 15 | 0.92 |
| **Total** | 24 | 0.92 |

In the post-survey, participants responded to survey items in 15 minutes, which was adequate time to complete the items and also the comments in the survey. Similarly, the items were understandable; however, some of the words required clarification during the pilot test. Because of the limited time, some students indicated that they hoped to try the RCL at home. Again, traditional Chinese words for certain difficult or confusing English words were included in subsequent RCL implementation.

The post-survey data collected from the pilot test were subjected to reliability analysis with SPSS to assess the internal consistency. The answer to the negatively worded item (Item 10) was adjusted by using the SPSS transfer function. The Cronbach's alpha reliability coefficient for the post-survey varied from 0.49 to 0.83, as shown in Table 9.

Table 9
The Post-survey Categories Names, Number of Items and its Cronbach Alpha Value

| Categories Names | Number of Items | Cronbach Alpha |
|---|---|---|
| Personal interest | 3 | 0.68 |
| Remote science experiments | 3 | 0.61 |
| Operating the RCL system | 4 | 0.49 |
| Stimulating motivation | 4 | 0.66 |
| Promoting teamwork | 3 | 0.60 |
| Importance of RCL system | 5 | 0.69 |
| Enhancing science practices | 12 | 0.83 |
| Comparison between RCL experience and science practical work | 6 | 0.79 |
| **Total** | 40 | 0.92 |

The Cronbach's alpha of operating the RCL system fell into the poor range (George & Mallery, 2010, p. 231; Nunnally & Bernstein, 1994), possibly because of the ambiguous item: Item 10 ("It is more difficult to conduct experiments by using the RCL system than it is through conventional practical work") involved comparing the difficulty while performing the experiment between the RCL system and conventional practical work, instead of assessing direct operation of the RCL system. Thus, the meaning of Item 10 was not matched and was confused with its category. Consequently, item 10 was deleted. After the removal of Item 10, the Cronbach's alpha was retested and determined to be 0.80, which was within the reliability range (Table 10). According to the results, the post-survey was valid and reliable.

Table 10
The Refined Post-survey Categories Names, Number of Items and its Cronbach Alpha Value

| **Categories Names** | **Number of Items** | **Cronbach Alpha** |
|---|---|---|
| Personal interest | 3 | 0.68 |
| Remote science experiment | 3 | 0.61 |
| Operating the RCL system | 3 | 0.80 |
| Stimulating motivation | 4 | 0.66 |
| Promoting teamwork | 3 | 0.60 |
| importance of RCL system | 5 | 0.69 |
| Enhancing science practices | 12 | 0.83 |
| Comparison between RCL experience and science practical work | 6 | 0.79 |
| **Total** | 39 | 0.93 |

For the MCQ test, because the time allotted by the science teacher for the test was only one hour (the actual time was one hour and ten minutes, but the students required time to go to the science laboratory before the test and then return to their classroom after the test), instead of the entire class answering all of the questions, half of the class answered the first 12 questions, which were related to plants, and the other half of the class answered questions 13–24, which were related to electricity. Hence, approximately 20 minutes was adequate for completing the allotted MCQ items and also the comments in the test. The MCQ items were understandable; however, some of the words required clarification during the pilot test. Therefore, several words were modified and traditional Chinese characters for certain difficult or confusing English words were included in subsequent RCL implementation. According to the returned tests, some of the students responded to all of the MCQ items; therefore, 25 minutes is estimated to be adequate for RCL implementation. Thus, the aforementioned instruments were reviewed and revised according to the data obtained during the pilot study.

#### 3.5.3.4 Data Collection Procedure for Secondary School

The mixed-method design was adopted to determine the students' conceptual understanding, perceptions, concerns, and feedback regarding using the RCL system for science learning and teaching. The data were collected using eight major means (Connecting and Merging data, [Creswell & Plano Clark, 2011]): research participation consent, a pre-survey, a pre-test, video recording (briefing session and RCL learning), RCL system guidelines and refined guided-inquiry worksheets, a post-survey, a post-test, and interviews with three participants (Figure 14).

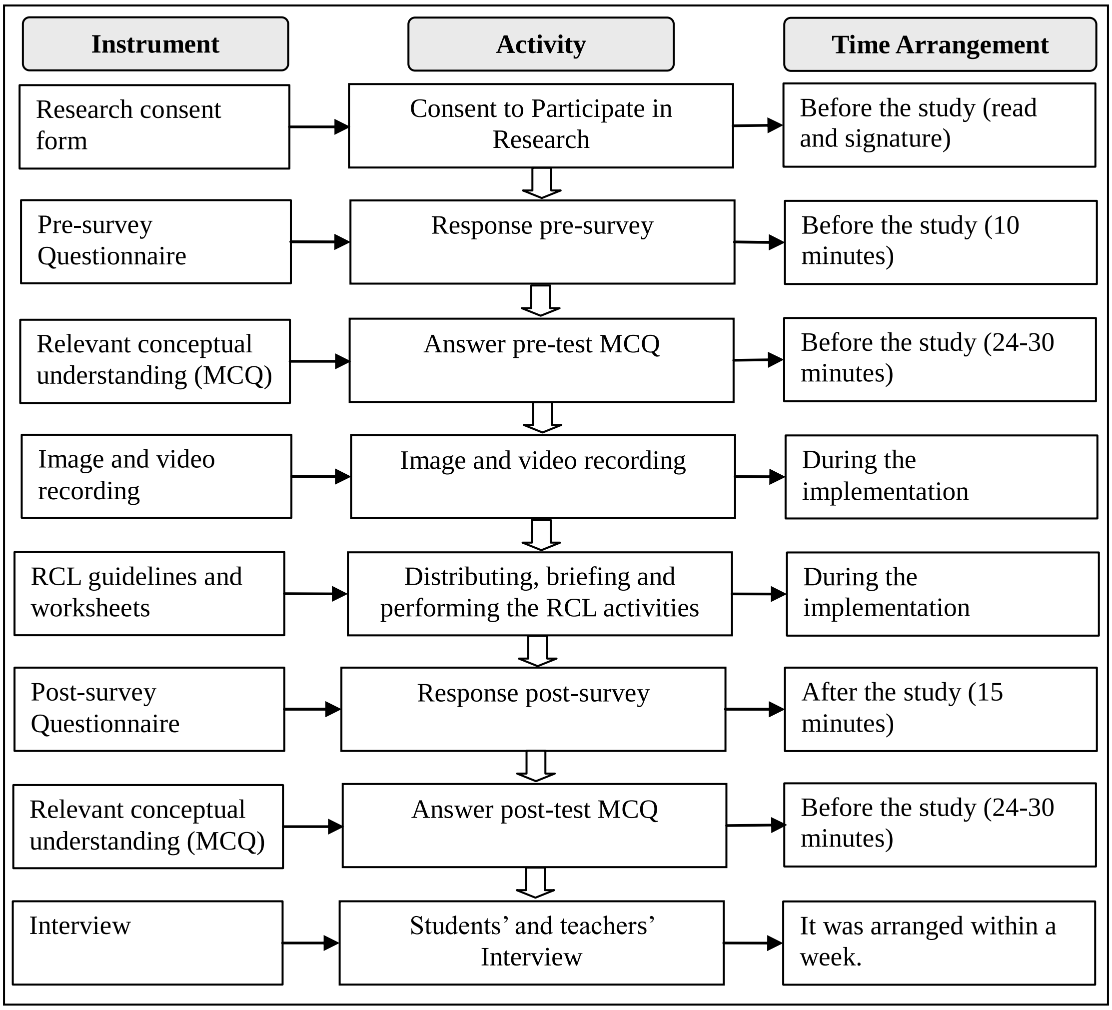


Figure 14 Summary of the Data Collection Procedures for Secondary Students

*Research consent form:* To comply with the educational research code, participants completed and signed a voluntary participation consent form before the briefing session began. They were informed of the study purpose and their right to withdraw from the study at any time without any penalty. In addition, they were told that all information provided would remain confidential and identifiable by codes known only to the researcher.

*Pre-survey questionnaire:* The pre-survey questionnaire was distributed before the RCL implementation began. Participants filled in their student number and had ten minutes to complete the questionnaire without discussion. They responded to the survey items based on what they actually, honestly, and personally think. Participants were told that participation in the survey was voluntary and would not affect their examination results.

*Relevant conceptual understanding (Pre-test MCQs):* To acquire a baseline of the students' relevant science knowledge, a pre-test consisting of 24 MCQs was administered before the briefing session began. The students had 24–30 minutes to individually complete the MCQ test. They responded to the items honestly, according to their knowledge and opinions. Participants were told that participation in the test was voluntary and would not affect their examination results.

*Image and video recording:* Video recordings of the RCL lesson, including the briefing and student presentation sessions of their personal experience and findings, were required for research observation of the learning response, actions, and presentations of the students. Each group of students performed the remote experiments in their free time (i.e., at school or home). The auto capture function of the system was used to detect the students' work, including the time they accessed the RCL system, the remote experiments they controlled, and the results they received. This combination of image and video yielded extensive, meaningful, or in-depth data that was triangulated with the survey results (Creswell & Plano Clark, 2011).

*RCL material, guidelines, and worksheets:* RCL system guidelines and guided-inquiry worksheets were distributed during the study. Subsequently, the researcher provided an induction set and a briefing of the related worksheets and how to use the RCL system; the briefing included instructions on accessing the refined RCL system to manipulate or control real-time experiments through the Internet. Students then accessed the RCL system and performed the remote experiments according to the worksheets. At the end of the study, students need to response the post-survey and conceptual test to determine student's self-perceptions and their understanding of related scientific concepts regarding to the RCL system of incorporating inquiry within their own classroom environments.

*Post-survey questionnaire:* Finally, after the students completed the remote experiments, the post-survey and open-ended questions were administered. Participants had 15 minutes to complete the questionnaire without discussion. Again, they filled in their student number and responded to the survey items based on what they actually, honestly, and personally think. Participants were told that participation in the test was voluntary and would not affect their laboratory assignment or examination results.

*Relevant conceptual understanding (Post-test MCQs):* To determine the effectiveness of applying the RCL system and guided-inquiry learning approach, a pre-test consisting of 24 MCQs was administered before the briefing session began. The students had 24–30 minutes to complete the MCQ test individually and no discussions were allowed. They were instructed to respond to the items honestly, according to their knowledge. Participants were informed that participation in the test was voluntary and would not affect their examination results.

*Interviews:* The subsequent semi-structured and tape-record interviews with the teacher and selected students were conducted within one week after the RCL session. Three students and a teacher from second and third iterations participated. The selection of students for the interviews was based on the students' science achievement level (high, medium, and low); one student from each level was included. Considering the different ability levels of the students enabled comprehensive exploration of student views and opinions regarding their learning perception, experience using the RCL learning, motivation level, and difficulties encountered during the experiment. The interviews with participants continued approximately half an hour.

Through this second iteration of DBR, both the RCL system and design principles were refined and revised. Subsequently, the performance of the refined RCL system was evaluated again to assess the system stability and response time experienced by users. These same data collection procedures were employed during the third iteration; however, the participants only answered electricity-related questions.

#### 3.5.3.5 Analysis and Evaluative Methods of Second Iterative Cycle

The data collected from the pre-test, post-test, pre-survey, post-survey, and interviews were entered into computer files for subsequent qualitative and quantitative analysis.

SPSS was used for quantitative analysis of the conceptual understanding test and questionnaire data. First, a paired samples *t* test of the pre-test and post-test scores was performed to examine the significant differences (.05 significance level) among student achievement. Regarding the pre-survey and post-survey, the descriptive statistics for participants were summarised to assess the demographic characteristics reflected in responses and participant perceptions towards the RCL system when conducting remote experiments. The descriptive statistics involved a central tendency (mean) and standard deviation. Furthermore, the paired samples *t* test (pre-survey and post-survey), independent samples *t* test (post-survey only) and ANOVA (post-survey only) were used to analyse the survey data. The paired samples *t* test was performed on certain parts or categories of the pre-survey and post-survey scores to ascertain significant differences in student science practices and attitudes. The independent samples *t* test was applied to examine significant differences between gender groups in using the refined RCL system. Subsequently, ANOVA was performed to investigate more than two groups (i.e., academic and practice levels) in using the refined RCL system. The significant differences were accepted or rejected in any category at the .05 significance level.

Data from the open-ended questions on the post-survey were coded using the qualitative data analysis software, NVivo software. Various themes based on student learning and experiences, difficulties encountered, and suggestions for the RCL system were assessed.

Data obtained during the semi-structured and tape-record interviews with the teacher and selected students were conducted within a week after the implementation of RCL study. Student views and opinions were explored by coding and deriving themes based on their learning perception, experience during RCL learning, motivation level, difficulties encountered, and suggestions. Regarding the teacher's interview data, the coding and derivation of themes was based on the school practical work involving ICT learning, the teacher's self-efficacy, potential difficulties encountered by the students, and the teacher's suggestions, views, and opinion towards the school science practical, overall RCL system, and ICT scope as well as suggestions. This analysis yielded extensive, meaningful, or in-depth data that were triangulated with the students' conceptual understanding and survey responses (Creswell & Plano Clark, 2011; Olsen, 2004).

### 3.5.4 Third Iterative Cycle

The third iteration was conducted to reduce the problems encountered during the second iteration; the number of remote experiments was substantially reduced because of the reasons mentioned in the discussion of the second iteration, section 6.3. The same instruments were kept (same as second iteration) because they were used for students of the same education level. Therefore, no pilot tests were required for the third iteration. However, the findings from the second and third iteration were compared. The compared findings were derived from the students' conceptual understanding and surveys.

The third iteration was also based on the mixed-method design, and involved both quantitative and qualitative research methodologies. The refined RCL system involving a guided-inquiry learning approach was evaluated quantitatively by another group of junior secondary school students. Subsequently, the system was refined according to the participants' conceptual understanding, suggestions, and difficulties encountered. The data and findings were triangulated and analysed descriptively and inferentially by using the mixed-method technique (Cameron, 2011; Creswell & Plano Clark, 2011; Creswell & Tashakkori, 2007; Olsen, 2004). Data triangulation enabled comprehensive and reliable data that could be used to determine the participation of secondary school students when using the developed RCL system.

Synthesising the findings from the various data collections in the third iteration facilitated developing strong and valid conclusions concerning the research questions and difficulties encountered.

#### 3.5.4.1 Sampling of Third Iterative Cycle

The third iteration was conducted in another secondary school; the sampling method employed was convenience sampling because one of the class in another school was invited to participate in this study. For the testing and evaluation of the refined RCL system, a teacher and 40 junior secondary school students from School B in an integrated science class participated in this mixed-method research. The students who participated were selected because the aim of this study was to apply technology-enhanced guided inquiry involving the refined RCL system to the topic of electricity in a real classroom setting based on their understanding, views and suggestions.

#### 3.5.4.2 Data Collection Procedure of Third Iterative Cycle

Because the instruments used in the second iteration were retained, no major changes were required. In other word, the data collection procedure was the same as that used in the second iteration of cycle. The mixed-method design was adopted to determine the conceptual understanding, perception, concerns, issues, and feedback of the students and teacher regarding science learning and teaching with the RCL system. The data were collected using eight major means: research participation consent, a pre-survey, a pre-test, video recordings (briefing session and experiential field learning), RCL system guidelines and technology-enhanced inquiry-based worksheets, a post-survey, a post-test, and interviews with three participants (see Figure 14).

#### 3.5.4.3 Analysis and Evaluative Methods of Third Iterative Cycle

The analysis method was similar to that in the second iteration. Data collected from the pre-test, post-test, pre-survey, post-survey, interviews, and observation in the third iteration were entered into computer files for subsequent qualitative and quantitative analysis. However, an additional data analysis (analysis of covariance [ANCOVA]) was conducted for comparing the conceptual understanding achievement of students between the second and third iterations.

SPSS was used for quantitative analysis of the conceptual understanding test and questionnaire data. First, a paired samples *t* test of the pre-test and post-test scores was performed to examine the significant differences (.05 significance level) among student achievement. Regarding the pre-survey and post-survey, the descriptive statistics for participants were summarised to assess the demographic characteristics reflected in responses and participant perceptions towards the RCL system when conducting remote experiments. The descriptive statistics were expressed as a central tendency (mean) and standard deviation. Furthermore, the paired samples *t* test (pre-survey and post-survey), independent samples *t* test (post-survey only) and ANOVA (post-survey only) were used to analyse the survey data. The paired samples *t* test was performed on certain parts or categories of the pre-survey and post-survey scores to ascertain significant differences in student attitudes towards science. The independent samples *t* test was applied to examine significant differences between gender groups in using the refined RCL system. Subsequently, ANOVA was performed to investigate more than two groups (i.e., academic and practice levels) in using the refined RCL system. The significant differences were accepted or rejected in any category at the .05 significance level.

As mentioned, an additional comparison with the data from the second iteration was performed. ANCOVA was conducted to analyse the data from the conceptual understanding test between School A in the second iteration and School B in the third iteration and to establish whether initial ability differences exist between School A and School B students. This method can minimise the experimental error according to statistics rather than according to an experimental procedure (Gall, Borg, & Gall, 2007). Significant differences were accepted or rejected in any category at the .05 significance level.

Data obtained from the open-ended questions of the post-survey were qualitatively analysed using NVivo software. Various themes were derived according to the student learning and experience, difficulties encountered, and suggestions related to the RCL research.

Data obtained during the semi-structured and tape-record interviews with the teacher and selected students were analysed. Student views and opinions were explored by coding and deriving themes based on their learning perception, experience during RCL learning, motivation level, difficulties encountered, and suggestions. Regarding the teacher's interview data, the coding and derivation of themes was based on the practical work involving ICT learning, the teacher's self-efficacy, potential difficulties encountered by the students, and the teacher's suggestions, views, and opinion towards the school science practical work, overall RCL system, and ICT scope. This analysis yielded extensive, meaningful, or in-depth data that was triangulated with the students' conceptual understanding and survey responses.

#### 3.5.4.4 Final System Performance Evaluation

Through the second and third cycle of iterations, both the RCL system and design principles were refined. The system performance was evaluated again to ensure that the refined RCL system was stable before sharing and publication.

## 3.6 Reflection on RCL Design Principles and Enhancement for Implementation

Although three iterative cycles of testing and refinement had been performed, it is still worthy for the researcher to reflect on the RCL development, evaluation, and learning process with the intention of further refining the RCL system and producing design principles that can enlighten the future development by other researchers to enhance the suggested approach of implementation. Through this DBR process, the refined RCL system is considered as a main output that can be shared and published.

## 3.7 Conclusion

This chapter discusses the methodology employed in developing the RCL system according to a DBR framework and in evaluating and refining the developed system. In this study, the methodology comprised the four major steps of (1) analysing practical problems related to RCL, (2) developing solutions according to existing design principles and technological innovations, (3) performing iterative cycles of testing and refinement to determine practical solutions, and (4) reflecting upon the RCL design principles and enhancement for implementation. Once the novel RCL system and activities were developed, the entire system was tested and improved through three iterative cycles of evaluation.

# CHAPTER 4

# OUTCOMES OF THE DESIGN OF RCL ACTIVITIES FOR ITERATIVE CYCLES OF TESTING

This chapter discusses the remote-controlled laboratory (RCL) design principles and the first prototype of the RCL activities. The RCL system development, including hardware configurations and software development, is then detailed. Finally, four novel remote experiments and a system performance evaluation are presented.

## 4.1 RCL Design Principles

In the second phase, the RCL system was developed as a solution to the problems encountered during practical work mentioned in the literature and during interviews. To develop a solution, the researcher reviewed related studies for existing design principles that may be used to resolve similar problems. A Google Scholar search of the literature and theories underlying the design yielded no literature addressing the design principle and criteria for applying the RCL system in secondary science education. Nevertheless, several RCL design principles in engineering were revised and borrowed in the current study. However, completely adapting identical RCL design principles from engineering directly into science education is difficult. Out of the several existing RCL and e-learning design principles, four essential principles were adopted with justification for the design of the RCL system as follows (Table 11).

Table 11
Sort Out the Pattern of the RCL Design Principles

| RCL design principles | The justification of the principle (with references in bracket) |
|---|---|
| Integrating the RCL into secondary science education may best be facilitated by learning designs which: | |
| 1. Integration with the science education curriculum | The pedagogy and learning activities must match with and align to the related curriculum (Anderson & McCormick, 2005). Recently, integration of remote laboratory into the secondary school curriculum began to get attention particular in physics subject (Dziabenko, Orduña & García-Zubia, 2013) |
| 2. Interactive learning | Interaction is an important for creating meaningful learning environment (Woo & Reeves, 2007; Van Schijndel et al. 2010). Then, the role of conducting real experiment is important where the experiment through simulation may be disconnected the "live" element (Hanson et al., 2009). Therefore, the RCL allows the opportunity to significantly interact with the remote experiments including the equipment and the science object. (Fiore & Ratti, 2007; Lowe, 2009) |
| 3. Learner engagement | In RCL learning environment, the learner may better construct the science knowledge and remember it for longer time of period due to the chance of using the remote laboratory technology (Corter et al., 2007). |
| 4. Wide-range of learner ability | The learner ability should be taken into consideration including the different learning style (Hanson et al., 2009), different learner achievement (Anderson & McCormick, 2005; Yeung, Lee & Lam, 2012), physical disabilities (Cooper & Ferreira, 2009; Scanlon et al., 2004). |

According to the design principles and justification, the implementation of the design principles through the use of RCL in science education had been created. Table 12 shows how the RCL system can be used as a solution to problems encountered during practical work. The RCL system is ready for implementation in science education; the first prototype of RCL activities were designed and developed, as described in the following section.

Table 12
Implementation of the RCL Design Principles

| **RCL design principles** | **Principles were implemented in the RCL learning environment by:** |
|---|---|
| Integrating the RCL into secondary science education may best be facilitated by learning designs which: | |
| 1. Integration with the science education curriculum | |
| • The designs of the RCL activities are based on science education curriculum. | The learner activities through the newly developed RCL system must integrate and align to the science education curriculum. |
| 2. Interactive learning | |
| • Encourage interaction with the remote laboratory system. | The RCL activities must be real-time and interactive. Thus, student can perform and repeat the real-time remote experiments via the Internet at anytime and anyplace. |
| 3. Learner engagement | |
| • Student involvement | The RCL activities must engage the learner in technology-enhanced inquiry with motivation. Student can conduct remote experiments, analyse and interpret experimental results and present their findings. |
| 4. Wide-range of learner ability | |
| • Student with different learning ability | The RCL activities must be suitable across a wide range of learner ability and available at any time as well as anywhere. |

## 4.2 First Prototype of RCL Activities

Capabilities of remote technology and pedagogy should be considered while designing effective RCL activities. In this section, the development of RCL activities for use in secondary science education is detailed. The first prototype of hardware configuration is first described, followed by an account of developing the first prototype software in the second section. The last section discusses developing four feasible remote experiments that can be used in the RCL system. Then, the initial prototype of the RCL system was refined after several iterations, described in the following chapters.

## 4.3 RCL System Development

As mentioned, the remote-controlled experiment system primarily depends on the LabVIEW software and associates with National Instruments (NI) hardware modules for controlling the instrument through the server computer and providing the system through the Internet for student to remotely access. Hence, the RCL system consists of two major parts: hardware and software.

### 4.3.1 Hardware Configurations

Figure 15 illustrates the remote technology hardware component and design. The hardware configurations are not the only configurations suitable for use in the RCL system; other combinations with different products can also be applied in remote laboratories (RLs; e.g., Internet School Experimental System). These existing remote-controlled experiments can be used for various experimental activities (Schauer, Lustig, Dvorak, & Ozvoldova, 2008), which, however, focus on and are applied in secondary physics education. In the current study on RCL, the developed system is based on the Web Publishing Tool function of the LabVIEW software, and associated with hardware modules for controlling and monitoring the experiments through the server computer. The hardware comprises a computer with a static (fixed) Internet protocol (IP) address, an eight-slot NI Compact DAQ 9188 Ethernet chassis model with a slot module, namely, an NI 9401 module with eight-channel digital input or output (DIO), and an IP camera. Several essential characteristics of the hardware functions and applications in science education are explained as follows:

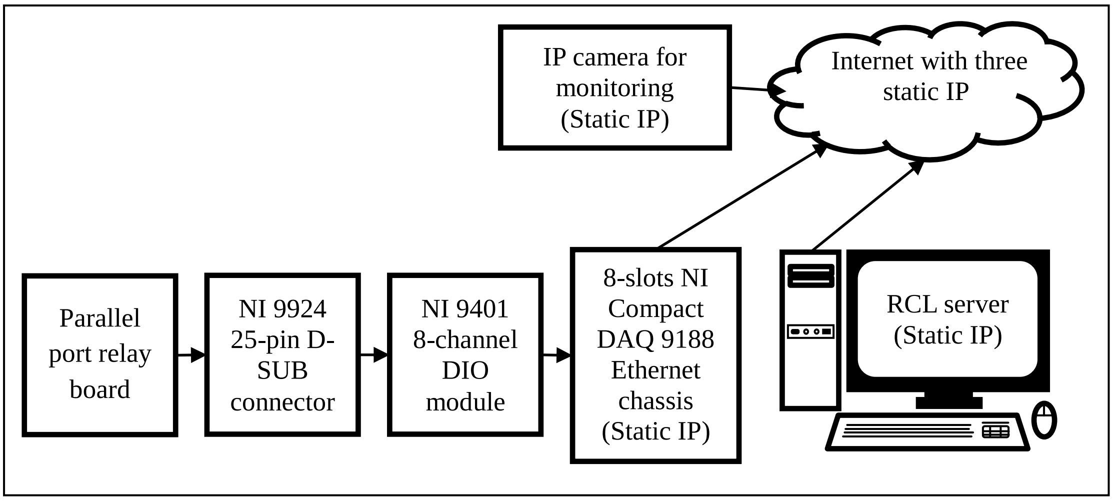



Figure 15 The RCL Hardware Configurations

*Internet:* In the RCL system, the Internet plays a crucial role because the computer, IP camera, and Compact DAQ 9188 Ethernet chassis must be configured with static IP address for easily managing. The IP address comprises four sets of numbers separated by periods that enable other devices or computers to identify each other; for example, the IP address of the IP camera is 175.159.131.221. A static IP address used in the RCL system is preferable because the computer and IP camera must use a port forwarding function, also called port mapping. Port forwarding directs traffic from the public or outside the institute (where the system located) to the RCL server inside the institute's local IP network. Internet services are recognised by a pre-set port number. For example, the IP camera operates with port number 81, indicating that the IP camera act as a webserver available to the public on the Internet; the port forwarding section in the router is configured to direct traffic to the IP address, http://rcl1.ied.edu.hk:81, in the private local area network. The ports are opened or closed in the firewall for protection reasons or because of a filter function, which controls the incoming and outgoing network traffic. Therefore, the port forwarding may not work properly if the device uses a dynamic IP address, particularly when the computer is restarted, in which case the device requires additional complex setup. Thus, three static IP addressed (Table 13) were obtained from the Information Technology Services unit at HKIEd for the RCL system.

Table 13
Static IP Address Arrangement

| Device and Location | Static IP address | Port forwarding | Domain Name |
|---|---|---|---|
| Computer, HKIEd | 175.159.131.220 | 8000, 21 | rcl.ied.edu.hk |
| IP camera, HKIEd | 175.159.131.221 | 81 | rcl1.ied.edu.hk |
| NI Ethernet chassis, HKIEd | 175.159.131.222 | - | rcl2.ied.edu.hk |

*Computer:* Before the RCL system is used, software must be installed on the computer. First, the IP camera software must be installed for monitoring, and then the file transfer protocol (FTP) server software must be installed to enable the file transferring function, which is used to transfer files from the server computer to another computer over the Internet. The FTP server software used in this study is freeware FTP software, FileZilla, available at https://filezilla-project.org/. To use the NI DAQ product, the computer must be equipped with the NI LabVIEW software and the NI hardware driver software. Once all the software is installed, the computer should be able to run the IP camera, FTP server, and LabVIEW software, and link to the NI hardware through the Internet.

*Data Acquisition Ethernet Chassis:* In the RCL system, the primary NI hardware is the DAQ Ethernet chassis, called Compact DAQ 9188 Ethernet, which is particularly designed to enable plug in of a maximum of eight slots of input/output (I/O) modules by the NI Company. In other words, because the Ethernet chassis house of the modules, it cannot function without plugging into the I/O modules. With appropriate I/O modules, the chassis can measure and control a broad range of analog and digital I/O signals and variety of sensors over an Institute of Electrical and Electronics Engineers 802.3ab gigabit Ethernet interface. Therefore, a static IP address was assigned to the DAQ Ethernet chassis: called 175.159.131.222. Currently, a crucial I/O module is plugged into the chassis, namely, an NI 9401 module with eight-channel digital DIO for device controlling. The detailed of the module is described as follows.

*NI 9401 DIO module:* The NI 9401 DIO module is an eight-channel with 100-ns bidirectional digital input for plug-in into NI Compact DAQ 9188 chassis. According to the NI product description, the module can configure the direction of the digital lines on the NI 9401 for I/O by nibble (four bits). Thus, the NI 9401 can be programmed in three configurations: eight digital inputs, eight digital outputs, or four digital inputs and four digital outputs. Additionally, the NI 9934 connector module (or another 25-pin D-Sub connector [known as electrical connector with its D-shaped metal shield]) is required for use with the NI 9401 module. The connector module contains a screw-terminal connector with strain relief as well as a D-Sub solders cup back shell for creating custom cable assemblies. To use the relay switch to control other devices with the NI module, the output terminals of the DIO module is connected to a CK1601 PC parallel port relay board. The CK1601 can be connected to the parallel port of a computer to control the electrical devices. The main function of DIO in this study was to enable the control function, performing a number of outputs and controlling remote-controlled devices (including light bulbs, a motor, and a stepper motor) and enabling or disabling other electrical devices. Because of a limited number of controls, the same DIO was shared for the electrical circuit connection and the plant growth stimulated by light experiments.

*IP camera (Tho & Yeung, 2015):* Recent education reforms have identified the importance of technology-enhanced learning, which can be achieved in science education through computer-mediated or datalogger-based experiments (Deaney, Hennessy, & Ruthven, 2006; Spector, Merrill, van Merrienboer, & Driscoll, 2008). There are several research studies on using various digital camera and video camera technologies for educational research and development (Lottero-Perdue, Nealy, Roland, & Ryan, 2011; Needham, 2013; Northcote, 2011; Souter & MacVicar, 2012; Sun & Cheng, 2009). It is anticipated that the Internet Protocol (IP) camera will become an important tool for observing, controlling and recording practical work in school science education, as it is now much more affordable, at around $50-100 (or £30-60). As Needham (2013) remarked, the "camera provides many opportunities for students to report their work."

The IP camera has been widely used for monitoring and surveillance purposes, and for tracking objects, for many years (Dinh, Yu and Medioni, 2009). There are few studies concerning its applications in school science experiments. The IP camera can be controlled by a computer or mobile device, such as a smart phone or a tablet. Then, students can control the IP camera and observe real-time experiments remotely at any time via the Internet. Students may therefore perform real-time, practical science experiments, which require more time than standard school laboratory sessions. The IP camera can be a solution to the problem highlighted by Souter and MacVicar (2012); "experiments that take longer than a standard science lesson may frequently be ignored."

*The Basics of IP camera:* An IP camera is a monitoring electronic tool, which can transmit image or video data anywhere, via the Internet. It is also known as a network camera, and is usually bundled with the manufacturer's own monitoring software and easy setup function/manual, so there are no standard setup procedures. Since the camera requires a specific IP address, the right Transmission Control Protocol or IP suite and the routing permissions for external access of the camera from outside the school network, it will be highly necessary to involve the school IT technician to get the system working properly. Nevertheless, these basic concept and functions are very similar across different brands or models, whether they are designed for monitoring their children, offices, factories, or shops.

In this study, innovative applications of the IP camera for remotely monitoring and/or controlling scientific phenomena or experiments are introduced. The IP camera can take time-lapse photographs, which can then be edited into films of science experiments. Some of the IP camera's functions, similar to those of digital, web or smartphone cameras, will be familiar to teachers, while other less familiar ones may also be useful in science learning and teaching.

*Types of science experiments with an IP camera:* For remote laboratory purposes, the IP camera can be set (a) to focus on a specific apparatus or scale in an experimental setup, (b) to observe the scientific phenomena and/or (c) to control the experiment for specific investigation activities. The resulting images and videos can be displayed on a remote computer or mobile device, which can enable students to clearly observe the actual progress of the experiment, and the changes of the process variables in real time. Experiments with a long completion time can be recorded in full, or at regular intervals, and students can then play back and edit the images or videos, rearrange them using video editing software, and create their own science films.

*Educational use of the IP camera:* Setting up an IP camera for science education is straightforward, and only the camera and an Internet connection are required. There is however several important features specific to the application of the camera in science education:

1. There is a function to pre-set the time recording and to upload the images to a specific server. This is useful for shooting time-lapse photography, which requires a prolonged period of observation (from several hours up to several weeks). Once the experiment is completed, students may download the images on to their computers/mobile devices.
2. An IP camera is usually equipped with an infrared illuminator for night-time or low-light recording. This feature can be combined with the time-lapse photography to detect the behaviour of living organisms, particularly useful for observing and understanding nocturnal behaviour of plants and animals.
3. The detection of a moving object can be automatically captured on video by the IP camera, resulting in an alert email being sent to the designated user and the images/videos uploaded to a specific server. This function is important in enabling students to detect and record the occurrence of sudden scientific phenomena, such as the visits of insects to a flower, or the time (stamped as an attribute of the image file) that different ripe fruits drop from a tree.
4. The camera can store data remotely, and does not require a local server. The images of the experiment can then be delivered to and stored in students' personal computers, without them visiting the laboratory.
5. The IP camera can be rotated freely, using its built-in pan-tilt-zoom function (Dinh *et al.*, 2009), and numerous IP cameras of the same type can be switched on simultaneously. Through a web browser, students are able to watch and manipulate the movements of the camera, allowing them to focus on a specific location and to conduct simple remote-controlled experiments and particular investigations.

*IP camera in RCL system:* In the remote-monitoring environment in this study, the IP camera was controlled to focus on a specific measurement device and remote experiment. The images and videos were displayed on the PC, enabling the students to observe the actual arrangement of the experiment and the change in the variables in real-time. The experiments (i.e., plant growth stimulated by light and gravity stimuli experiments) that required a long time to complete were fully or partially recorded. Subsequently, the students played back and edited the photo or video by using movie maker software to create science movies. The static IP address assigned to the IP camera was 175.159.131.221, with the port forwarding number 81.

### 4.3.2 Software Development

The software was used for data logging and for controlling and displaying the real-time experiment on the computer screen through the Internet. Software development was performed using the LabVIEW software, which is based on a graphical programming language. Several key elements for RCL software development were examined, including RCL software, a web publishing tool, a web browser in LabVIEW, login, tab control, and time management setup. These software functions are described as follows.

*RCL software:* The software for the RCL was successfully designed and developed. The particular graphical user interface in the software was user friendly because it enabled real-time interaction with the computer through the Internet. In the design and development phase, a flowchart of the software operation was an essential element. To begin, the user selects a “start” box and requests for control, and clicking on “run” button to begin the RCL system. In fact, the right click and request for control can only perform in the grey area of the RCL website, which is an internal area. The inputs are the four remote experiments, processed and operated using the NI LabVIEW system (NI compact DAQ and LabVIEW software) and the IP camera. Real-time visual data are obtained in the form of videos and images (output). Subsequently, the files are saved in the PC or ftp account. After the control process or experiment is completed, the user clicks "stop", and release the control for other client or user. Figure 16 depicts the flowchart of the software operation.

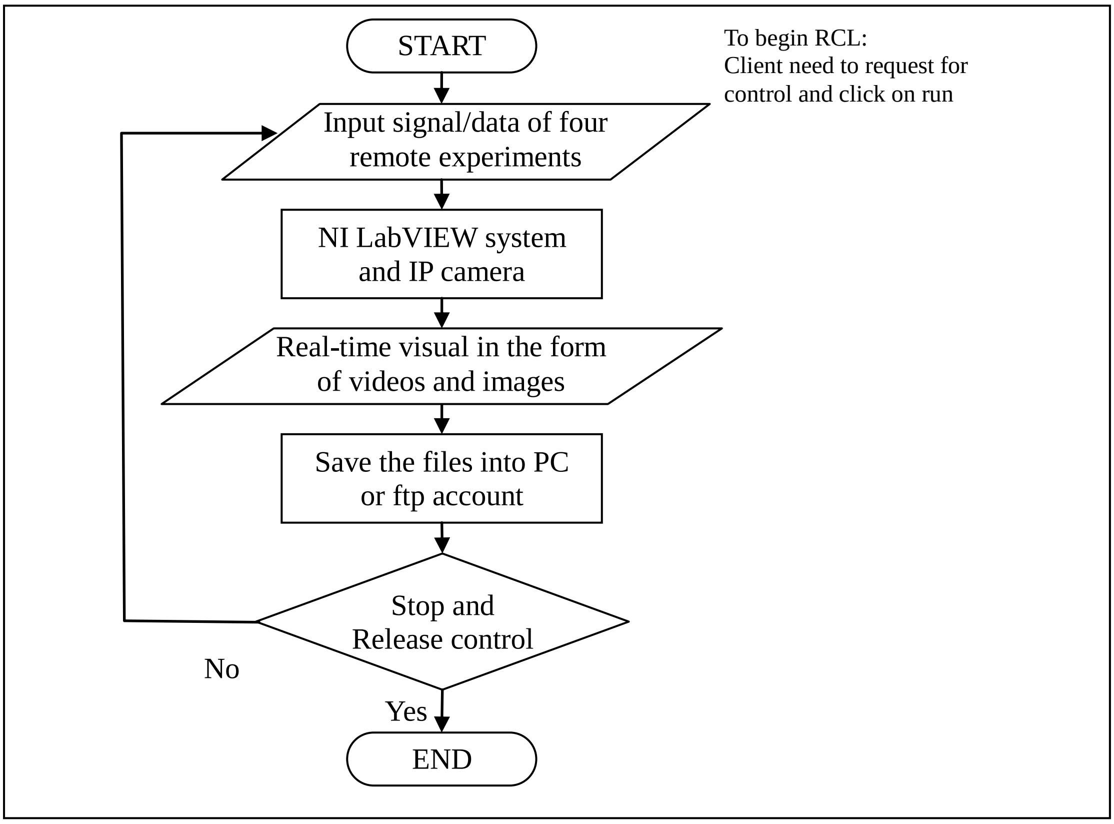
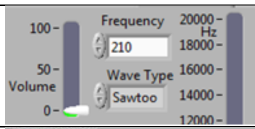
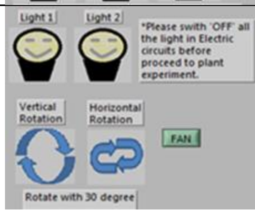
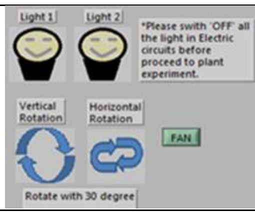



Figure 16 Flowchart of the Software Operation

Thus, several buttons for this remote experimental software were developed. The control buttons include image buttons, slider buttons, and text control buttons. All buttons and captions were developed using images and simple English words. Therefore, these buttons can be understood easily by users. Generally, the green colour indicates start and the grey or original image colour denote stop. Table 14 shows all buttons used in the remote experiments. The plant experiments (light and gravity stimuli) were operated using the same tab control.

Table 14
The Control Buttons for Remote Experiments

| RCL Experiment | Changing Parameter | Control Button |
|---|---|---|
| Sound as vibration (jumping beans) | Wave type, sound frequency and volume. |  |
| Electrical circuit connection (series & parallel) | Number of bulbs in series and parallel. |  |
| Plant experiment – light stimuli | Presence of light and plants' vertical axis of rotation. |  |
| Plant experiment – gravity stimuli | Plants' horizontal axis of rotation |  |

The related button, tab control, and DIO functions, as well as instructive messages, were input into the software program. Figures 17 and 18 illustrate the program execution by the software.

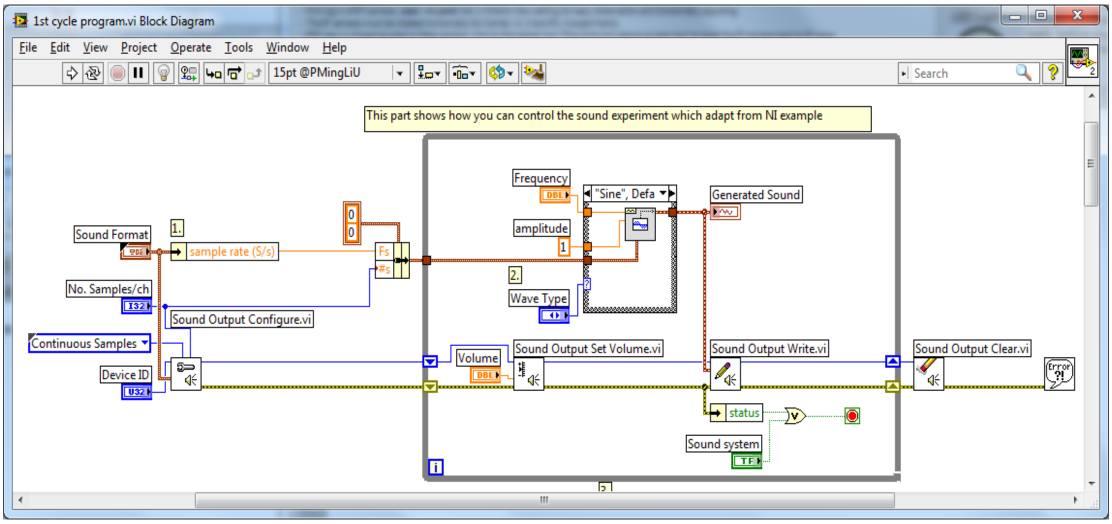



Figure 17 LabVIEW Software used to execute the RCL Program particularly Sound Experiment

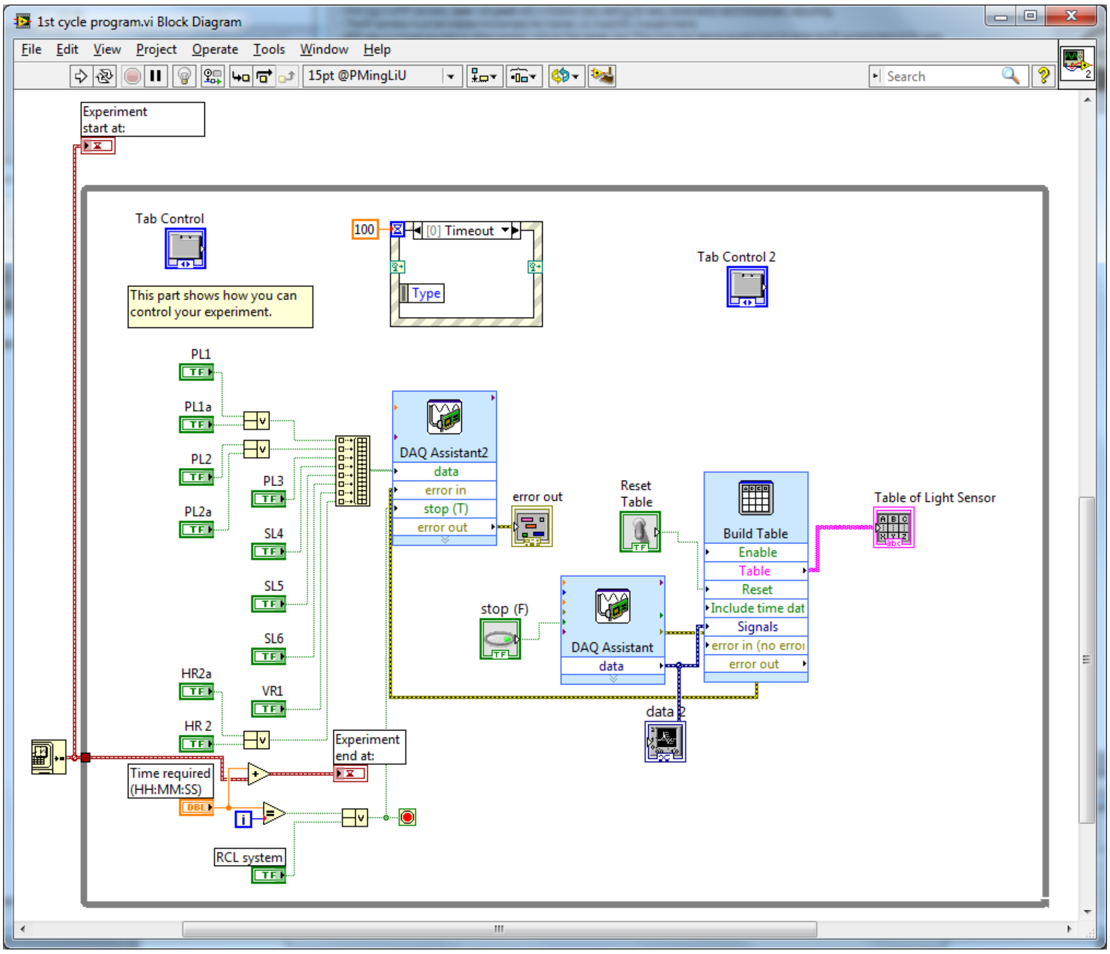



Figure 18 LabVIEW Software used to execute the RCL Program particularly Electrical Circuit and Plant Experiments

*Web browser function:* In the LabVIEW software, the web browser function was input into the RCL software with the purpose to include the IP camera interface for real-time observation. Figure 19 shows the program code used to input the IP camera function into the RCL program. An external input function of the LabVIEW software was substituted in an external web browser into the software interface. Therefore, the request for control could not be presented in this area.

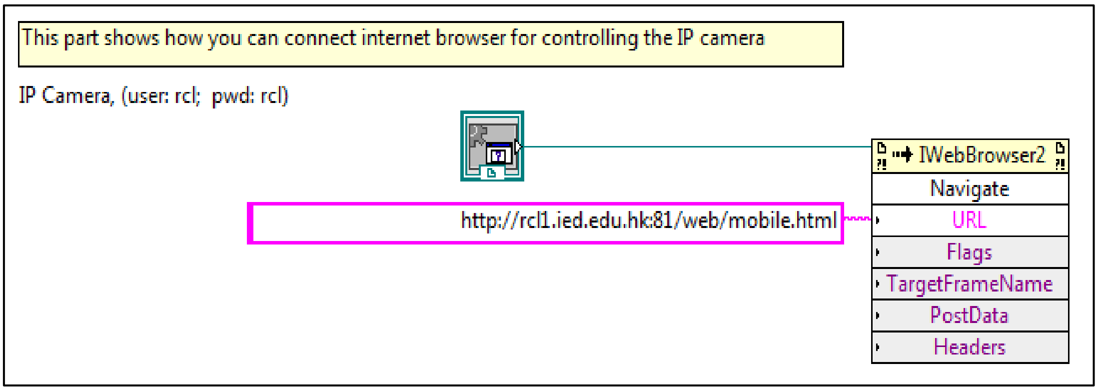


Figure 19 LabVIEW Software used to execute the External Web Browser Function of IP Camera

*Web publishing tool:* The web publishing tool generates an HTML file for remote application to the developed LabVIEW RCL virtual instruments program. The web publishing tools included with LabVIEW are used both for interfacing and remotely controlling the experiments through the Internet. Users or clients who do not have LabVIEW software installed must install LabVIEW Run-Time Engine 2011 for viewing and controlling the remote front panel. LabVIEW Run-Time Engine 2011 is free web browser plug-in software that can be easily downloaded from http://www.ni.com/download/labview-run-time-engine-2011/2531/en/.

*Login:* Users must enter a username and password for system identification. Additional information is then provided to notify the user about system use. The clients or users are divided in two groups: controller and observers. That request for control is the only client that can control the remote experiment. The observers can only observe experiments; they have no control rights in the RCL system. Because the IP camera is another external input in the LABVIEW software, other users can control the position of the camera. However, other users who are not the controllers should avoid disturbing the position of the camera.

## 4.4 Remote Experiments

In this section, RCL activities to deliver an inquiry setting are briefly introduced to illustrate the RCL design principles. The RCL system can be applied to enable students to learn certain scientific concepts related to various areas of science, including physics and biology. In particular, the topics of sound, electricity, and plants were investigated through inquiry-based experiments using the RCL system. The topics in Table 15 were selected according to several topics in the Hong Kong Science Education Key Learning Area Curriculum Guide (CDC, 2002) and Syllabuses for Secondary Schools (CDC, 1998).

Table 15
Integration of the RCL with the Hong Kong Science Education Curriculum

| **Scientific Concepts** | **Topics and subtopics of Science Education Curriculum** |
|---|---|
| Sound | Energy<br>- Different forms of energy: heat, light, sound, kinetic, potential,<br>Sensing the Environment<br>- How we hear: the production and transmission of sound; functions of main parts of the ear Living Things |
| Electrical circuit connection | Making Use of Electricity<br>- Idea of a closed circuit<br>- Circuit symbols: simple circuit diagrams<br>- Series and parallel circuits |
| Growth response of a plant to external (light and gravity) stimuli | Looking at Living Things<br>- Living things: characteristics of living things<br>- Living Things |

Through the technology-enhanced inquiry experiments, students can study the scientific principle underlying the ordinary growth response of a plant to external stimuli, such as light and gravity, to investigate a variety of interacting factors that affect the movement of plants, and to determine whether a pattern can explain the reaction of the plant to the stimulus. In addition, students can learn about the scientific principle underlying parallel and series circuit connections and sound as vibrations. Appendices A and B illustrate the inquiry-based worksheets and the RCL guide. The underlying mentioned scientific concepts and principles closely corresponded to those in the science education curriculum in Hong Kong, as recommended by the EdB of the HKSAR. The RCL experiments enable the students to think, apply, and extend their knowledge about related science principle. Using the combination of RCL hardware and software, students can perform various RCL activities consisting of short experiments (electrical circuit connection and sound) and long experiments (growth response of plants to light and gravity stimuli).

Thus, four feasible remote experiments (Table 16) that can be incorporated into the RCL system were successfully developed with reference to the local school science curricula. Figure 20 outlines the design of the RCL system that can be used to perform remote-controlled experiments with the aid of an IP camera and NI system. The NI system includes the LabVIEW software, which is a graphical programming language that uses icons, rather than lines of text, to generate programs. The LabVIEW software equipped with the data acquisition hardware and remote control application through the web publishing tool. Therefore, the remote-controlled experiments were developed primarily using the LabVIEW (2011 SP1) software and the NI hardware modules to control the instrument through a server computer, enabling remote access by student through the Internet.

Table 16
The Design and Content of Remote-controlled Experiments

| **RCL Experiment** | **Learning Objective** | **Changing Parameter** |
|---|---|---|
| Sound as vibration | Understand the nature of sound as vibration. | Wave type, sound frequency and volume. |
| Electrical circuit connection | Understand the series and parallel circuit connections. | Number of bulbs in series and parallel. |
| Plant experiment – Growth response of a plant to light stimuli | Long-time observation of plant with light source. | Presence of light and plants' vertical axis of rotation. |
| Plant experiment – Growth response of a plant to gravity stimuli | Long-time observation of plant due to effects of gravity. | Plants' horizontal axis of rotation. |

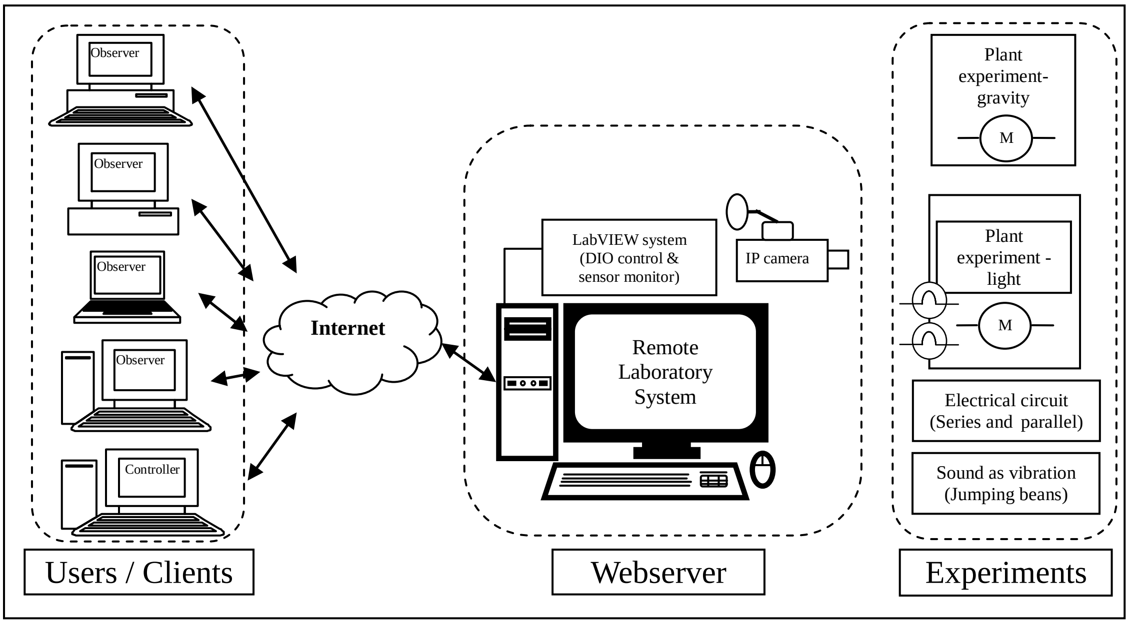



Figure 20 The Structure of RCL System used to Perform Science Experiments

Figure 20 shows each remote experiment has its own position around the IP camera that can be achievable; the remote experiments are located from right (sound experiment) to left (plant experiment: gravity).

### 4.4.1 Sound as Vibration

The learning objective of the sound experiment is to understand the nature of sound as vibration. Figure 21 shows the webpage of the sound experiment for students; the webpage illustrates how the remote technology is employed. The students plan and perform an investigation, altering the wave type and frequency to assess and observe when the beans jump the highest because of the vibrations.

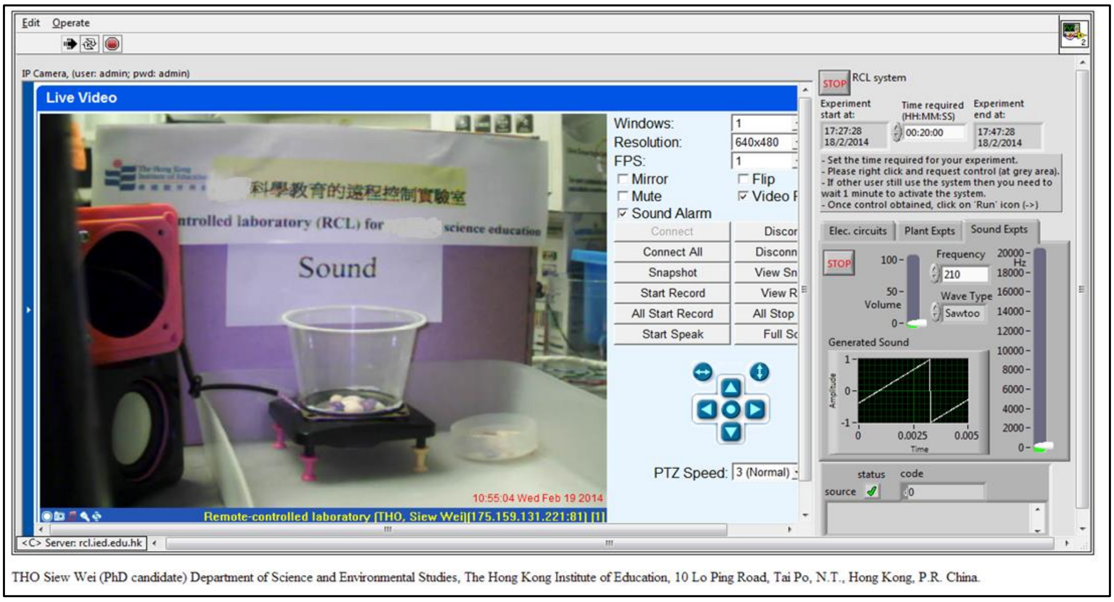



Figure 21 Webpage Display of RCL System: Sound Experiment

In this experiment, the students can control the wave type, sound frequency, and volume, observing the waveform and movement of beans according to their adjustments. The beans jump to different heights when the wave type, frequency, and volume are adjusted. Thus, the students can learn that sounds are produced by vibrations.

### 4.4.2 Electrical Circuit Connection

The learning objective of the electrical circuit connection experiment is to understand series and parallel circuit connections by identifying the difference between a series circuit and a parallel circuit. Figure 22 shows the webpage for the electrical circuit connection (series and parallel circuits) experiment; the webpage illustrates how the remote technology is employed. The students plan and perform an investigation of series and parallel circuits.

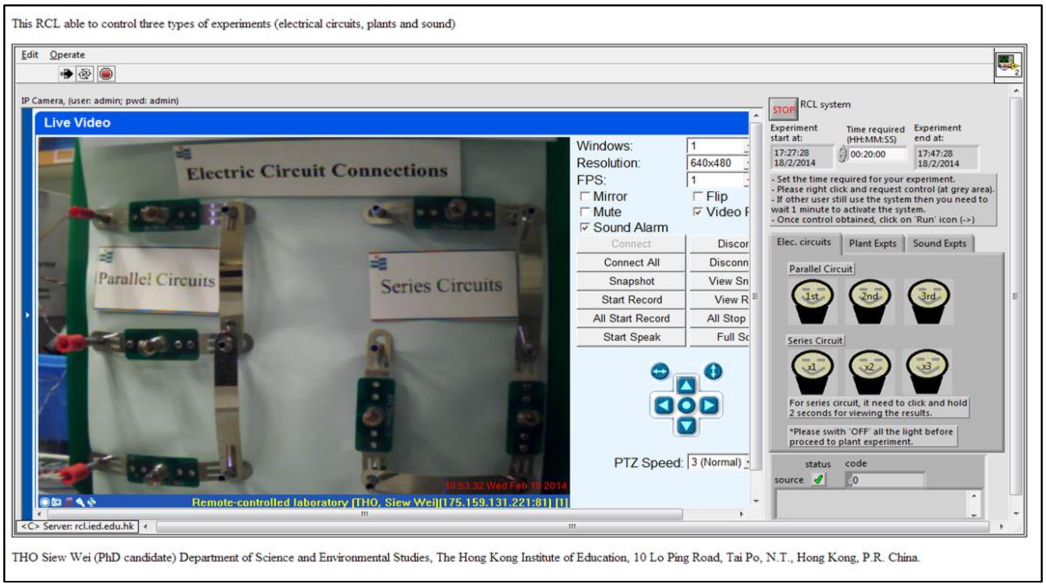



Figure 22 Webpage Display of RCL System: Electrical Circuit Experiment

In this experiment, the students can turn light bulbs in series and parallel circuits on and off. By controlling the circuits, students can observe the brightness of the light bulbs in series and parallel circuit connections. It can be observed that the same brightness of bulbs in parallel circuit is obtained when more light bulbs in a parallel circuit are turned on. Next, it can also be observed that the brightness of light bulbs dims in a series circuit when more light bulbs in a series circuit are turned on. Thus, students can learn about electrical circuit connections in series and parallel circuits.

### 4.4.3 Plant Experiment – Growth Response of Plant to Light Stimuli

The learning objective of the plant experiment involving light stimuli is to investigate plant growth response to external (light) stimuli. Figure 23 shows the webpage for the plant growth–light stimuli experiment; the webpage illustrates how the remote technology is employed. The students plan and execute an investigation of plant growth response to light stimuli, turning on one or two light bulbs. The plants grow towards the light, a fundamental characteristic of plants. The plants can be rotated 180$^{o}$ to a horizontal rotation (or vertical axis of rotation) to observe how they will adjust to grow towards the light again.

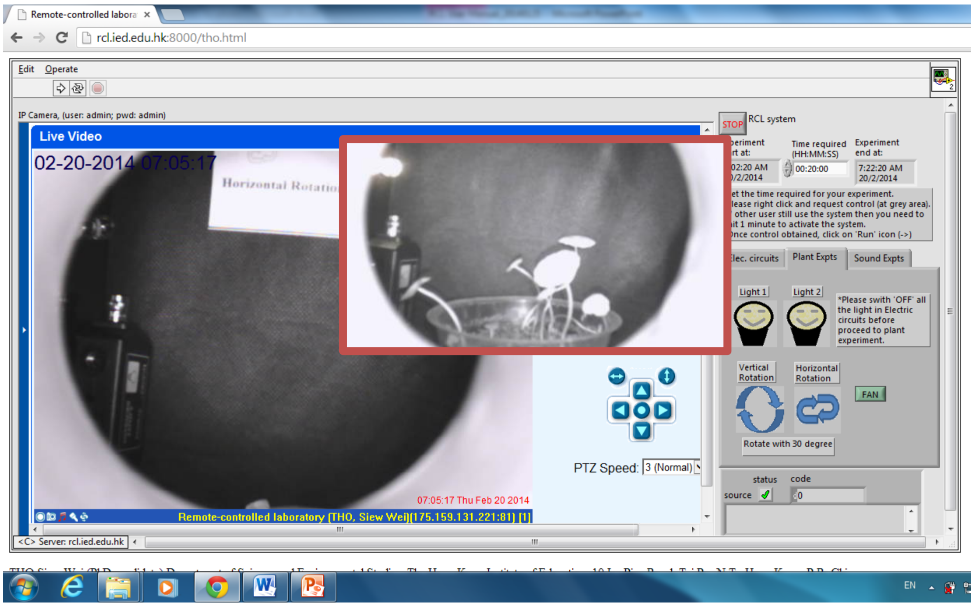


Figure 23 Webpage Display of RCL System: Plant Experiment - Light

In this experiment, the students can turn one or two light bulbs on and off and rotate the pot. According to their adjustments, the students can observe the plant growth towards the light, which can be evaluated by the response time, number of light bulbs, and position of the pot. The plant growth towards the light source can be manipulated by turning on more light bulbs or rotating the position of pot. Thus, the students can learn about *phototropism*, the tendency of plants to grow towards light.

### 4.4.4 Plant Experiment – Growth Response of Plant to Gravity Stimuli

The learning objective of the plant experiment involving gravity is to investigate plant growth response to external (gravity) stimuli. Figure 24 shows the webpage for the plant growth–gravity stimuli experiment; the webpage illustrates how the remote technology is employed. The students plan and perform an investigation of plant growth response to gravity stimuli, rotating the position of the plants to a vertical rotation (or horizontal axis of direction) in the daytime; characteristically, the plants grow upwards. The plants in an upright position are rotated $90^{o}$ to a vertical rotation of direction at night; the plants again grow towards the light because of the gravity stimulation.

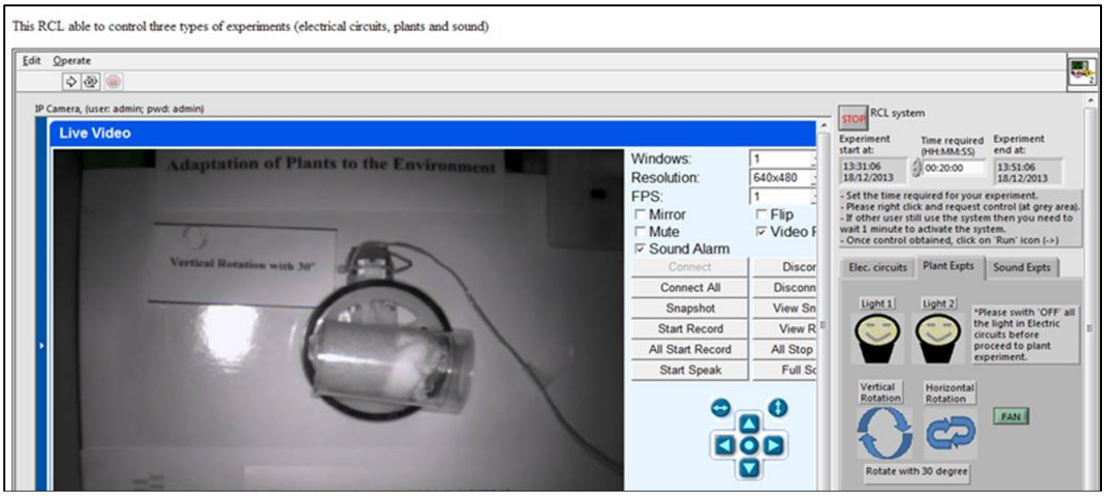


Figure 24 Webpage Display of RCL System: Plant Experiment - Gravity

In this experiment, the students can rotate the position of the plant. By controlling the plant, students can observe the growth response of plants towards gravity, measurable by the response time and position of the pot. The plants grow upwards when the position of the plants is rotated. Thus, the students can learn about *negative gravitropism*, the characteristic of shoots to grow upwards.

4.5 System Performance Evaluation of the RCL Prototype

In late 2013, the first RCL prototype was developed and subjected to a system performance evaluation, during which whether the RCL system could be used by at least five users simultaneously was explored. The RCL system was designed for use by five students per group at one time slot. The performance evaluation revealed that the system could be controlled by one user and four observers simultaneously (Figure 25). The remote panel connection manager, a built-in function of the LabVIEW software that displays access information for all users connected to the RCL system server, was used to monitor the users. During the evaluation, the response time experienced by the controller when performing the remote experiments was acceptable. Thus, no major problems were observed and the RCL system was approved for use in the first iteration of evaluation.

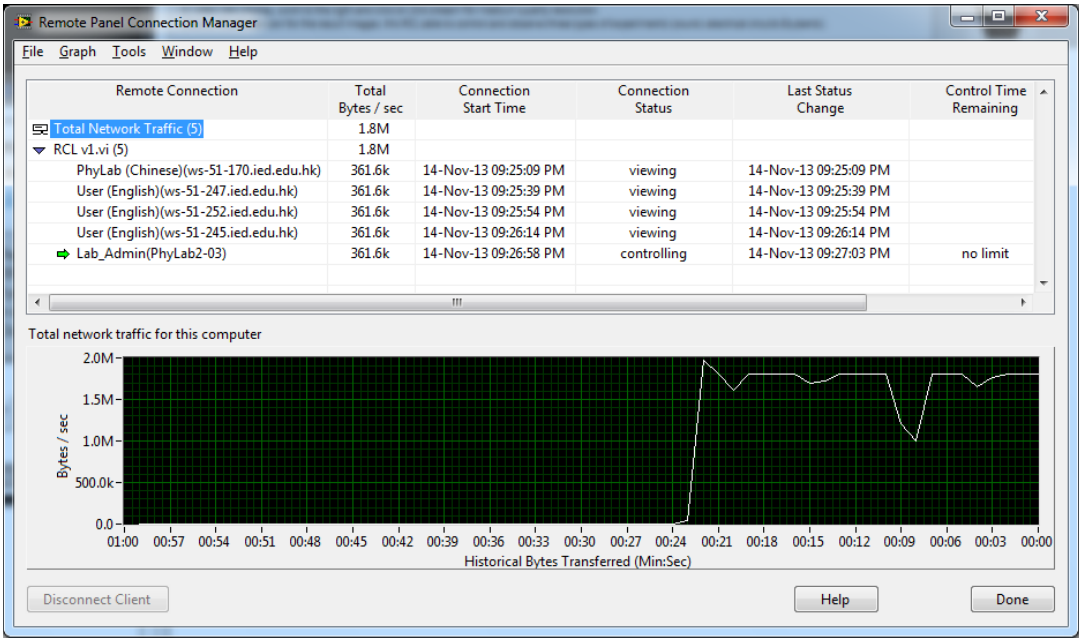


Figure 25 Remote Panel Connection Manager used to monitor the Users' Access Information

## 4.6 Conclusion

According to the literature and practitioners, RCL design principles were designed to develop the novel RCL system. The system, which enabled long-term observation, and four feasible remote experiments that are repeatable at any time or location were firstly developed. Finally, after a system performance evaluation of the first RCL prototype, the system was ready for the first iteration of evaluation.

# CHAPTER 5

# FINDING AND ANALYSIS OF FIRST ITERATIVE CYCLE

This chapter presents the findings, analysis, and discussion of first iteration. Moreover, the details of refinement and the implications are described. A conclusion derived from the first iteration and directions for future study are discussed.

## 5.1 Participants and Pre-survey

This evaluation study was conducted in a tertiary teacher education institution. A total of 69 third-year undergraduate students in two different courses, namely, Course 1 (science and web technology programme majors) and Course 2 (teacher training programme majors), were participated in the evaluation process of the remote-controlled laboratory (RCL) activities. To comply with the educational research code, they were required to complete and sign a consent form indicating voluntary participation in the study. However, data collected from only 64 participants were valid for the subsequent statistical analysis process, and no missing data were found in the valid collected data. Data from the remaining five participants were invalid because the participants had participated in the pilot study and provided incomplete responses to the survey. Table 17 shows the descriptive statistics of the participants' programme and gender.

Table 17
Descriptive Statistics of the Participants in Course Versus Gender Cross-tabulation

| **Class** | **Gender** | | **Total** |
|---|---|---|---|
| | Male | Female | |
| Course 1 | 20 | 10 | 30 |
| Course 2 | 24 | 10 | 34 |
| **Total** | 44 | 20 | 64 |

In addition, the participants provided other information pertaining to their smartphones, tablets, and their current Internet data plan (Table 18). This information is useful for future development of remote experiments using mobile devices (Cui et al., 2012; Tiwari & Singh, 2011). According to the data, most participants had smartphones (98.4%) and a high speed Internet data plan (75%); however, approximately 60% of the participants did not have tablet devices.

Table 18
Descriptive Statistics of the Participants' Mobile Devices Information

| **Item** | **Detail** | **Frequency** | **Percent, %** |
|---|---|---|---|
| Smartphones | Yes | 63 | 98.4 |
| | No | 1 | 1.6 |
| Tablet | Yes | 26 | 40.6 |
| | No | 38 | 59.4 |
| High volume data plan (i.e.500 MB/over per month) | Yes | 48 | 75.0 |
| | No | 16 | 25.0 |

This section also describes an analysis of the pre-survey that assessed participant aspects including present level of scientific knowledge, teaching of science topics, teaching of science using information and communication technology (ICT) tools, ability in conducting scientific experiments, experience in inquiry-based learning, and experience or involvement in RCL activities (Table 19). According to these data, the statistical analysis (i.e., analysis of variance [ANOVA]) was conducted.

Table 19
Descriptive Statistics of the Participants' Perception

| Statements | Detail | Frequency | Percent, % |
|---|---|---|---|
| Please rate how you presently view your own science knowledge level? | High | 11 | 17.2 |
| | Medium | 35 | 54.7 |
| | Low | 18 | 28.1 |
| As a future teacher, please rate how you presently view your own effectiveness in teaching science topic? | High | 9 | 14.1 |
| | Medium | 40 | 62.5 |
| | Low | 15 | 23.4 |
| As a future teacher, please rate how you presently view your own effectiveness in teaching science using ICT tools? | High | 6 | 9.4 |
| | Medium | 36 | 56.3 |
| | Low | 22 | 34.4 |
| How do you rate your ability in conducting scientific experiment? | High | 7 | 10.9 |
| | Medium | 39 | 60.9 |
| | Low | 18 | 28.1 |
| How do you rate your experience on inquiry learning? | A lot | 8 | 12.5 |
| | Medium | 42 | 65.6 |
| | Little | 14 | 21.9 |
| Have you ever been involved in any RCL activity? | Yes | 9 | 14.1 |
| | No | 55 | 85.9 |

## 5.2 The Comparison of Participant Perception between Conventional Science Laboratory and RCL Approaches

Before the laboratory session, participants commented positively and negatively on conventional science laboratories, providing data that were crucial for exploring the current uses of and problems encountered in laboratory learning. The responses reflected that current laboratory learning involved several problems, such as large experimental errors, no possibility to conduct dangerous experiments, and time restrictions when performing practical work (i.e., experimental setup and recording). These comments were subsequently compared with the comments regarding RCLs to obtain a comprehensive view of applying innovative remote experiments into science education (Table 20).

After the laboratory session, participants were also asked to give positive and negative comments on the RCL system. They were interested in the RCL system and by the fact that they could conduct experiments through the Internet anywhere at their leisure. However, the participants could not physically touch the experimental equipment or tools, an aspect that differs substantially from working in a conventional science laboratory. In addition, they encountered problems with Internet connection and setup. Overall, these results were consistent with those obtained by previous researchers, such as Chen et al. (2012), Cooper and Ferreira (2009), and Lowe et al. (2013), who also pointed out some advantages and disadvantages of using RCL from studying their research and participants' work.

Table 20
Participants' Frequently Found Comments on RCL and Conventional Laboratory Work (N=64)

| | **Conventional science laboratory** | **RCL** |
|---|---|---|
| **Positive comments*** | - Able to understand the scientific principles or knowledge<br>- Real hands-on experiments | - Able to conduct experiments at anytime<br>- Able to conduct experiments at anyplace<br>- Able to conduct experiments at real-time via the Internet<br>- RCL is interesting |
| **Negative comments*** | - Certain experiments are dangerous<br>- Large experimental errors<br>- Time consuming for students to setup and record the experiments | - Setup problem<br>- Internet problem<br>- Need time to learn new way of conducting experiment<br>- Cannot touch the equipment or tools |

*Similar comments with occurrences more than ten times were summarised.

5.3 Post-survey and Interview Data

*Samples t test:* Table 21 presents the evaluation data of the independent samples *t* test as obtained from the student survey. For the eight categories on the educational merits of the new RCL approach based on the course of study, the mean scores (with Likert scale 1=strongly disagree, 2=disagree, 3=agree and 4=strongly agree) lay within the range of 2.73 to 3.14, and the score for every category was near 3, indicating agreement with the questionnaire statement. The Cronbach's alpha reliability coefficient of the survey was 0.96. According to these results, the Course 2 participants constantly rated the survey items higher compared with Course 1 participant; however, no significant differences were determined using the independent samples *t* test, except in the motivation stimulation category. The *t* test results also revealed that there was no significant gender difference.

Overall, the survey results from all participants indicated that they agreed with the educational merits in using the RCL system and the manner of performing the Internet-based science experiments. The RCL was perceived to improve their confidence level of teaching (enhancing self-efficacy in learning and teaching, [Bandura, 1977; Schunk, 1991]) and was a useful tool for learning and teaching science. Then, an independent samples *t* test was used to compare the scores given by the students in Courses 1 and 2; a statistically significant difference was observed in the motivation stimulation category at the .05 significance level. Course 2 participants were generally more motivated when conducting experiments during the RCL session than were Course 1 participants (Table 21). Participants who studied fewer ICT courses were predicted to be more motivated in testing and using the RCL system.

Table 21
Mean Scores (with SD in Brackets) and *t* test of Participants' Response on Survey Items as Based on Their Course. N is the Number of Participants

| **Category** | **Course 1 (N=30)** | **Course 2 (N=34)** | **Overall (N=64)** | ***t* statistic** |
|---|---|---|---|---|
| Insight of Science & ICT | 2.91 (.55) | 2.98 (.64) | 2.95 (.60) | -0.46 |
| Operating the RCL system | 2.90 (.50) | 3.06 (.42) | 2.98 (.46) | -1.38 |
| Enriching learning | 2.82 (.89) | 3.03 (.59) | 2.93 (.75) | -1.08 |
| Developing application | 2.78 (.66) | 2.99 (.52) | 2.89 (.59) | -1.42 |
| Stimulating motivation | 2.80 (.78) | 3.14 (.54) | 2.98 (.68) | -2.03* |
| Improving teaching skills | 2.87 (.65) | 3.06 (.45) | 2.97 (.56) | -1.39 |
| Promoting group work | 2.73 (.73) | 2.97 (.57) | 2.86 (.66) | -1.45 |
| Enhancing self-efficacy in learning & teaching | 2.81 (.67) | 2.99 (.45) | 2.90 (.56) | -1.24 |

Note: *p < .05

*ANOVA test:* Table 22 reports the evaluation data of ANOVA as obtained from the student survey based on their present level of scientific knowledge. For the eight categories on the educational merits of the new RCL approach, the mean scores ranged from 2.75 to 3.31 as based on the science knowledge level. Overall, the participants with low levels of scientific knowledge constantly rated the survey items higher than did participants with medium and high levels of scientific knowledge in all categories, except scientific insight and ICT and enhancement of self-efficacy in learning and teaching. An ANOVA test was used to compare the student scores among scientific knowledge level. Unexpectedly, a significant difference was found for the RCL system operation category at the .05 significance level. Participants with low scientific knowledge levels generally found the system to be more easy to use than did participants with medium and high levels of scientific knowledge (Table 22). Consequently, a statistically significant difference was also found for the motivation stimulation category at the .05 significance level: participants with low scientific knowledge level were generally found to be more motivated when conducting RCL experiments than were the participants in the other two level groups (Table 22). The participants who had low levels of scientific knowledge were more motivated and they were more adapt at operating the RCL system.

Table 22
Mean Scores (with SD in Brackets) and ANOVA Test of Participants' Response on Survey Items Based on Their Science Knowledge Level. N is the Number of Participants

| **Category** | **High (N=11)** | **Medium (N=35)** | **Low (N=18)** | ***F* statistic** |
|---|---|---|---|---|
| Insight of Science & ICT | 3.15 (.54) | 2.84 (.64) | 3.04 (.52) | 1.45 |
| Operating the RCL system | 2.88 (.54) | 2.90 (.43) | 3.22 (.41) | 3.60* |
| Enriching learning | 3.09 (.75) | 2.78 (.73) | 3.13 (.76) | 1.62 |
| Developing application | 2.88 (.73) | 2.80 (.58) | 3.07 (.52) | 1.28 |
| Stimulating motivation | 2.85 (.77) | 2.85 (.72) | 3.31 (.40) | 3.28* |
| Improving teaching skills | 2.94 (.53) | 2.90 (.61) | 3.13 (.44) | 1.08 |
| Promoting group work | 2.79 (.75) | 2.75 (.68) | 3.11 (.50) | 1.90 |
| Enhancing self-efficacy in learning & teaching | 3.02 (.51) | 2.83 (.53) | 2.97 (.66) | .61 |

Note: *$p < .05$

The ANOVA tests also revealed that there were no significant differences in present level of science topic taught, teaching of science using ICT tools, ability in conducting scientific experiments, and experience in inquiry-based learning.

*Open-ended questions:* The participant feedback on perceptions of and difficulties encountered when using the RCL system was collected by using the open-ended questions in Table 23.

Table 23
Four Open-ended Questions to Assess Participants' Perception Regarding the RCL System (N=64)

| Open-ended Question | Selected Insightful Comments |
|---|---|
| 1. What have you learned from the inquiry experiments through the use of RCL system? | - They learned how to conduct experiment through RCL system.*<br>- They learned related scientific concepts.* |
| 2. Have you encountered any problems concerning the system equipment while doing the inquiry experiments? | - They faced the Internet problem.*<br>- They faced the setup problem.*<br>- They faced problems of controlling the IP camera with other users. |
| 3. If you were given another chance to do the experiments again, please suggest some ways for improvement? | - They suggested more guide should be given.*<br>- They suggested using high resolution IP camera.*<br>- They suggested using Smartphone. |
| 4. Please suggest a science topic/activity that is possible to apply the inquiry experiments via the use of RCL system. | - They suggested biology topic* (outdoor environment, photosynthesis, plants and animal behaviour).<br>- They suggested physics topic* (electricity and dangerous experiment: heat and radioactivity).<br>- They suggested chemistry topic (chemical reaction). |

*Similar comments given with more than 20% were summarised.

It is noted that a number of negative comments and suggestions were also listed for RCL system refinement. These negative comments or limitations related to the RCL activities were unavoidable, but can be alleviated or resolved with appropriate refinement to the system design and development. Moreover, the study showed that participants required sufficient guidance and training to use the RCL system to optimise its educational value. Nevertheless, some features of the RCL system required amendment, and technical problems had to be overcome to provide a more reliable and robust system. Furthermore, future studies can focus on using a high resolution Internet protocol (IP) camera for observation and developing a simpler and more user-friendly interface that is suitable for secondary school students.

The interview after the laboratory session yielded extensive, meaningful, and more in-depth data (Merging data, [Creswell & Plano Clark, 2011]) about the student's views and suggestions that can be triangulated from the survey (Cameron, 2011; Olsen, 2004). Participants selected for interviews have been pseudo named as A, B, and C for ethical reasons. Table 24 shows the feedback regarding the RCL system obtained during the interviews.

Table 24
Summary of Participants' Feedback about the RCL in the Interviews

| |
|---|
| **Positive comments:**<br>A: "Increase student learning motivation because student can observe and control the remote experiment."<br>B: "For certain night-time science experiment, we can observe it at anyplace."<br>C: "Save time. Previously, we need to stay and wait for recording the whole day science experimental data. But, we can record the data at anytime and anywhere through the use of RCL system." |
| **Negative comments:**<br>A: "Operating the remote experiment is relatively clumsy."<br>B: "The user interface is difficult to control."<br>C: "The lack of real hands-on in remote experiment in comparison with the traditional experiment." |
| **Suggestions:**<br>A: "High resolution of IP camera and high speed of Internet bandwidth are needed."<br>B: "Through an easy user interface, you can control a lot of other parameters."<br>C: "For secondary school, do some radioactivity experiments." |

According to the interviews, participants believed that the RCL system enabled them to clearly understand the importance of remote experiments; moreover, they enjoyed using the RCL system to observe and understand the nocturnal behaviour of plants. In other words, the RCL system can enable overcoming certain problems encountered in practical work, including those pertaining to time and venue.

However, various shortcomings of the RCL were also identified. For example, B mentioned that the RCL operation was clumsy, and C noted that controlling the RCL experiment was difficult. This may be because the plant experiments shared the same tab control. These problems can be solved by creating two tab controls, one for each plant experiment.

In the suggestion section, several shared and valuable comments were received. For example, A suggested increasing the resolution and IP camera and the speed of the Internet; B suggested modifying the user interface and C recommended that dangerous experiments be explored. The suggestions were incorporated into subsequent modifications; for example, the IP camera was switched to a high resolution IP camera and the user interface was modified to provide a more user-friendly control of the remote experiments. A remote radioactivity experiment was recently developed and published (Jona & Vondracek, 2013); therefore, a remote radioactivity experiment was not developed in this study. Instead, an outdoor solar energy remote experiment was developed and added (Tho & Yeung, 2015); performing the experiment conventionally would be potentially uncomfortable or dangerous for students because it requires remaining in the sunlight for long periods. The researcher could have no control over the Internet-related suggestion; for example, Internet speed is affected by the participants' Internet packages or the time at which they accessed the Internet.

## 5.4 Refinements

According to an analysis of the collected data, the RCL system was refined by (a) modifying existing remote experiments; (b) adding feasible remote experiments (topics: plant respiration, battery bank, infrared [IR] night vision, and solar energy); (c) using an IP camera with higher resolution; (d) providing clearer RCL operating guidelines; (e) arranging the time of conducting the remote experiments; and (f) improving collaboration in learning by adding a free synchronous chat box.

## 5.5 The Refined of Remote Experiments

This section describes the refinements of the RCL system, including modifying the existing remote experiments and adding four new remote experiments, namely, plant respiration, battery bank, IR application of night vision, and solar energy. The refined and new remote experiments can be applied to enable students to learn certain scientific concepts involved in various areas of science, including physics and biology. Four new topics, batteries, solar energy, plant respiration, and IR light, were incorporated into the guided-inquiry experiments for use in the RCL system according to several selected topics from the Hong Kong Science Education Key Learning Area Curriculum Guide (CDC, 2002) and Syllabuses for Secondary Schools (CDC, 1998) (Table 25).

Table 25

Integration of the RCL with the Hong Kong Science Education Curriculum

| **Scientific Concepts** | **Topics and subtopics of Science Education Curriculum** |
|---|---|
| Battery | Energy<br>- Different forms of energy: heat, light, sound, kinetic, potential, chemical and electrical energy<br>- Simple energy changes: energy converters, controlled and uncontrolled energy conversion<br>Making Use of Electricity<br>- Current: measurement and its unit<br>- Voltage: measurement and its unit<br>- Power of an electrical appliance |
| Solar energy | Energy<br>- Different forms of energy: heat, light, sound, kinetic, potential, chemical and electrical energy<br>- Simple energy changes: energy converters, controlled and uncontrolled energy conversion<br>Making Use of Electricity<br>- Current: measurement and its unit<br>- Voltage: measurement and its unit<br>- Power of an electrical appliance |
| Plant respiration | Living things: characteristics of living things<br>- Living Things<br>How do green plants obtain energy: photosynthesis<br>- Gaseous exchange in plants: respiration and the release of chemical energy from food |
| IR light | Light, colours and beyond<br>Beyond the visible spectrum<br>- IR radiation and its applications |

A total of eight feasible remote experiments (Table 26), developed with reference to the local school science curricula, can be incorporated into the refined RCL system. Figure 26 outlines the refined RCL system that involves a high resolution IP camera and NI system. The refined RCL system development, including hardware configuration and software development, is detailed in the following sections.

Table 26
The Design and Content of Refined Remote-controlled Experiments

| **RCL Experiment** | **Learning Objective** | **Changing Parameter** |
|---|---|---|
| Centre: Sound as vibration (jumping beans) | Understand the sound as vibration. | Wave type, sound frequency and volume. |
| *L1: Electrical circuit connection (Series & parallel) | Understand the series and parallel circuit connections. | Number of bulbs in series and parallel as well as the $2^{nd}$ removed/burnt |
| L2: Battery bank | Explore the efficiency of the battery bank. | Charging-discharging battery & turn on devices. |
| L3: IR radiation | Explore the IR light application. | Turn on & off the light for observing different colours. |
| #R1: Plant experiment – Growth response of a plant to gravity stimuli | Long-time observation of plant due to effects of gravity. | Plants' position: horizontal axis of rotation |
| R2: Plant experiment – Growth response of a plant to light stimuli | Long-time observation of plant due to effects light source. | Presence of light and plants' position: vertical axis of rotation. |
| R3: Plants respiration | Understand the respiration of plants. | Turn on & off the light for observing plant respiration. |
| Solar energy experiment | Investigate the efficiency of a solar panel. | Changing angle of solar panel. |

*L: Left; #R: Right

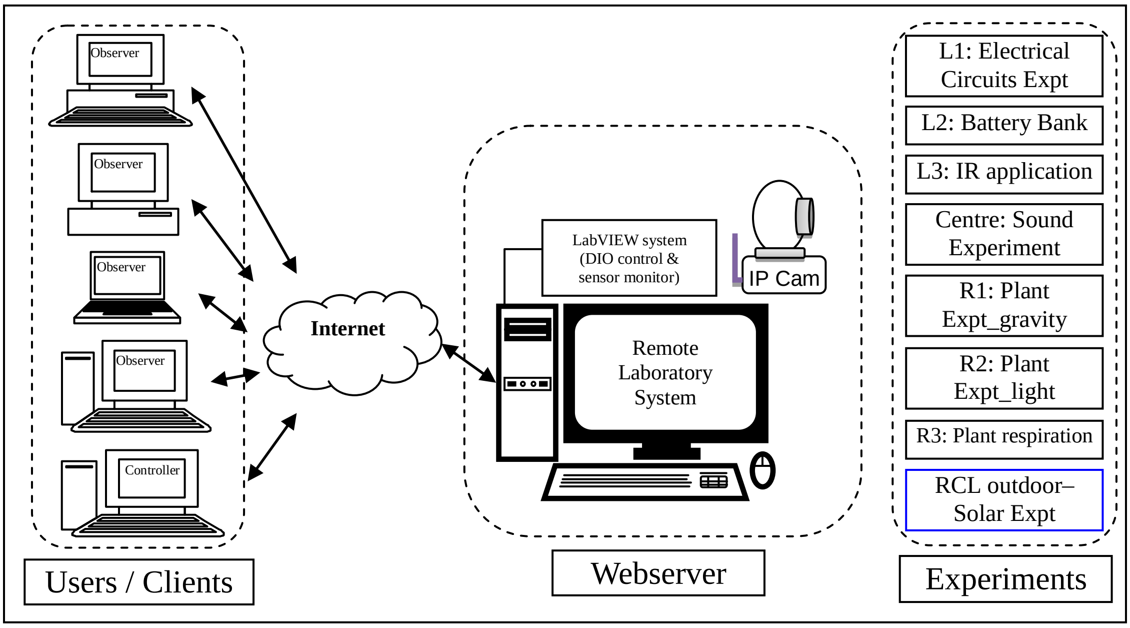


Figure 26 The Structure of Refined RCL System for Performing Science Experiments

Because four new remote experiments were added, the refined RCL system was located in a new location to optimise the use of the IP camera. Therefore, each remote experiment has its own position around the IP camera that can be achievable; the remote experiments are located from right (R3 Plant respiration experiment) to left (L3 IR radiation experiments).

### 5.5.1 Centre: Sound as Vibration

No major modification was made for the sound experiment, except in the position, which was relocated to the centre based on the IP camera (Figure 27).

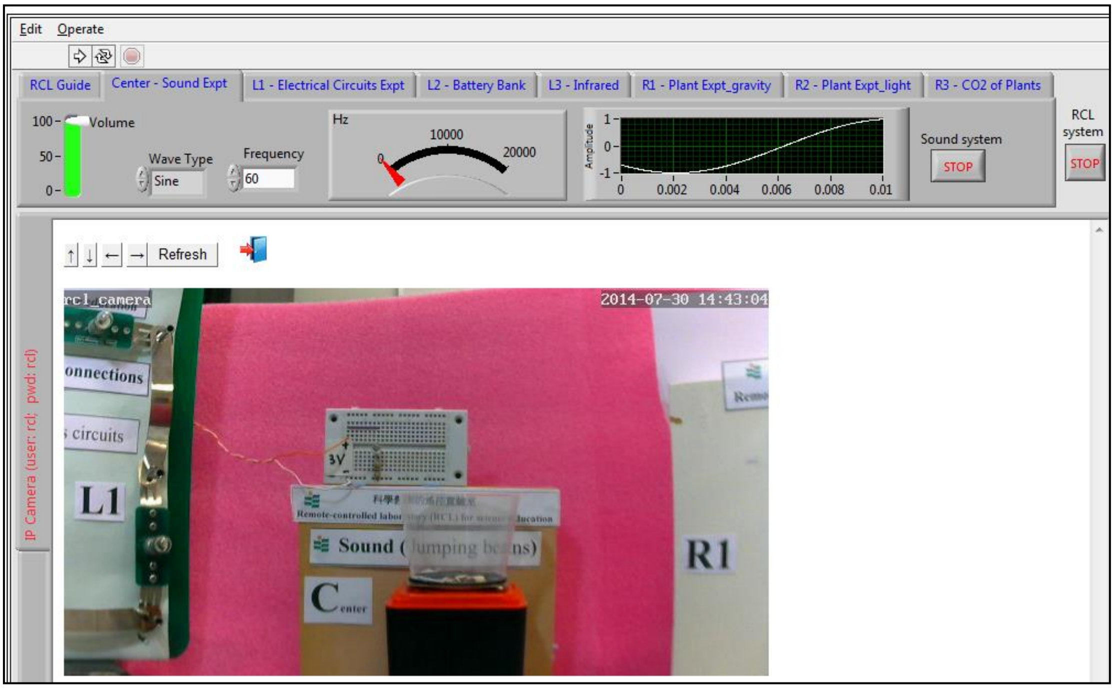


Figure 27 Webpage Display of RCL System: Centre – Sound Experiment

### 5.5.2 L1: Electrical Circuit Connection

A crucial modification was made to the electrical circuit connection experiment. Based on the refinement, the students had to perform two additional remote procedures according to the following questions: (a) In a parallel circuit, if the second bulb is removed from the circuit, do the remaining bulbs light up? (b) In a series circuit, if the second bulb is removed from the circuit, do the remaining bulbs light up? In addition, it was relocated into the new position to the left of the sound experiment setup (Figure 28).


Figure 28 Webpage Display of Refined RCL System: L1 Electrical Circuit Experiment

### 5.5.3 L2: Battery Bank Experiment

The learning objective of the battery bank experiment is to explore the efficiency of the battery bank according to the following guided-inquiry question: Is the capacity of a battery bank or power bank always being true as stated? Figure 29 shows the webpage for the L2 experiment; the webpage illustrates how the remote technology is employed. The students plan and perform an investigation on the efficiency of a battery bank by charging and discharging it. If the power of the battery bank is consumed, then the power output will be equal to the power stated on the product label. In fact, the chemical energy of the battery is converted into electrical energy.

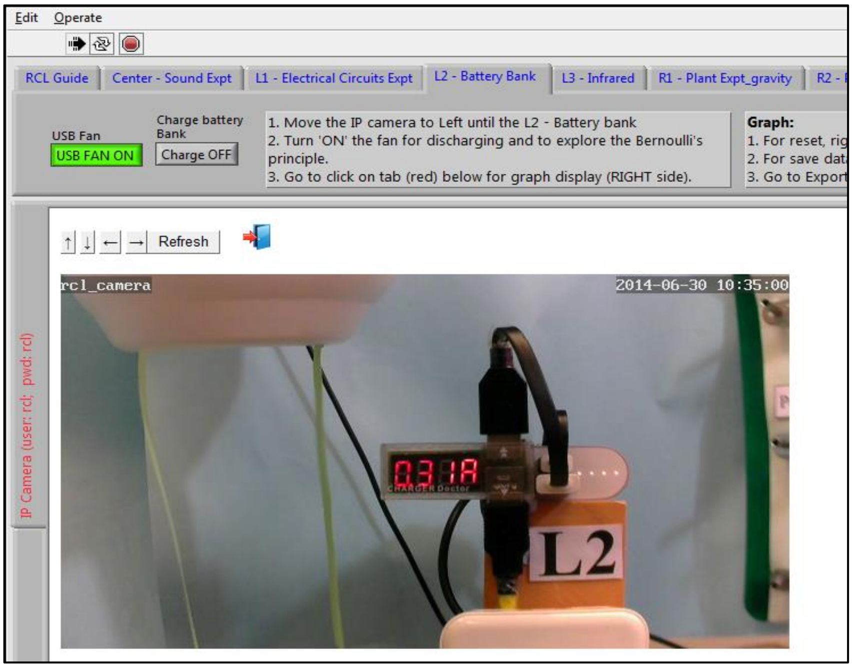



Figure 29 Webpage Display of RCL System: L2 Battery Bank Experiment

In this experiment, the students can charge the battery bank and discharge it by turning on the fan. By controlling the fan, the students can observe the operation of the battery bank. The power consumed is directly proportional to the current and voltage shown by the USB Charger Doctor, which can measure the working current and voltage outputs for any USB devices in the range of 0–3 A and 3.5–7.0 V and can switch between the voltage and current measurements every three seconds. Thus, the students can learn about the power and efficiency of batteries.

### 5.5.4 L3: IR Radiation

The learning objective of the IR radiation experiment is to identify the characteristics of IR night vision by observing colours according to the guided-inquiry question, "What are the colours of objects under the IR light of the IP camera?" Figure 30 shows the webpage for the L3 experiment; the webpage illustrates how the remote technology is employed. The students plan and perform an investigation on identifying the brightness of various colours under the IR light of the IP camera.

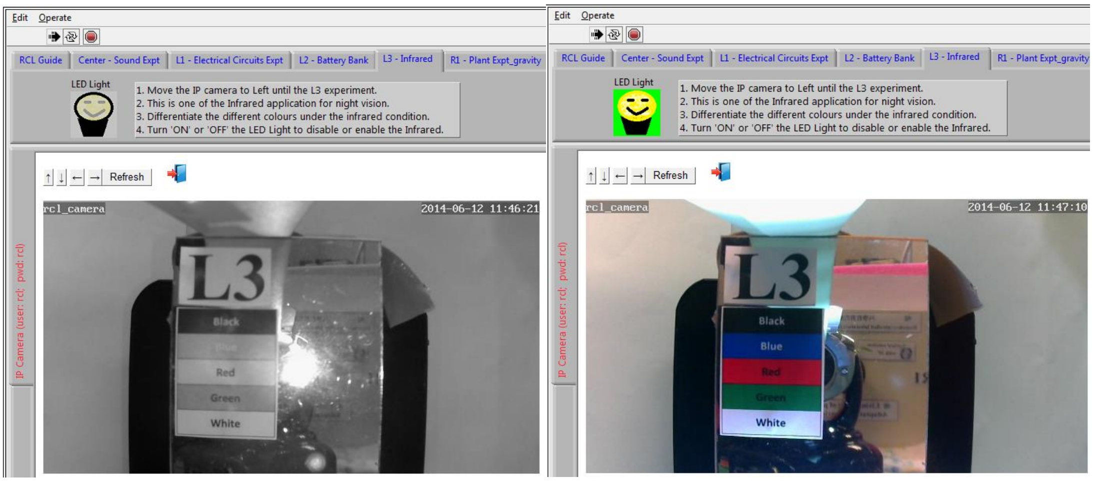


Figure 30 Webpage Display of RCL System: L3 IR Radiation Experiment with IR Radiation (left) and White Light (right)

In this experiment, the students can turn the light on and off to enable and disable the IR radiation. Students can observe the brightness of various colours under IR radiation, thereby learning about IR radiation and its applications.

### 5.5.5 R1: Plant Experiment – Growth Response of Plant to Gravity Stimuli

Two refinements were made to the plant growth–gravity stimuli experiment. First, the shared tab control was dividing into two tab controls to reduce the complexity of the user interface. Second, the R1 experiment was repositioned to the right of the sound experiment setup (Figure 31).

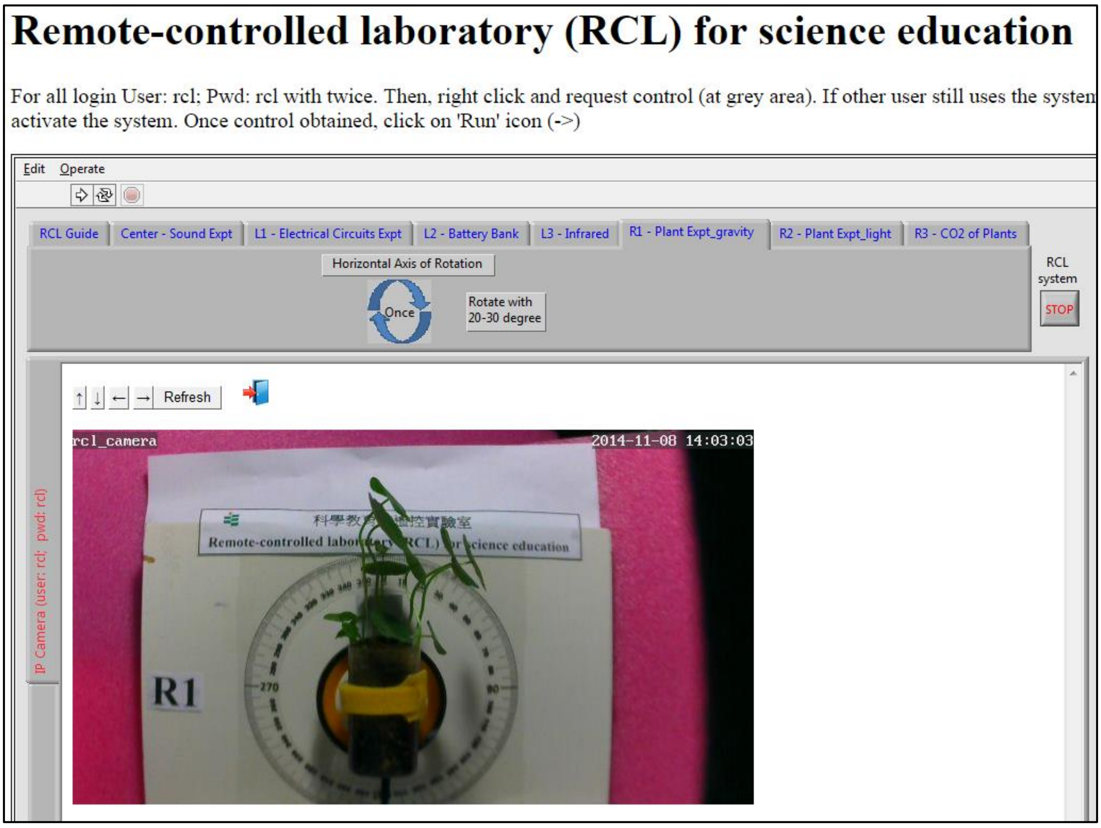


Figure 31 Webpage Display of Refined RCL System: R1 Plant Experiment - Gravity

### 5.5.6 R2: Plant Experiment – Growth Response of Plant to Light Stimuli

Three refinements were made to the plant growth–light stimuli experiment. First, the shared tab control was dividing into two tab controls to reduce the complexity of the user interface. Second, different colours of light were added to improve the changes in variables or parameters. According to this modification, the students could observe how the different colours of light affected the rate of plant growth. Third, the position of the experiment was relocated to the right of the R1 experiment (Figure 32).

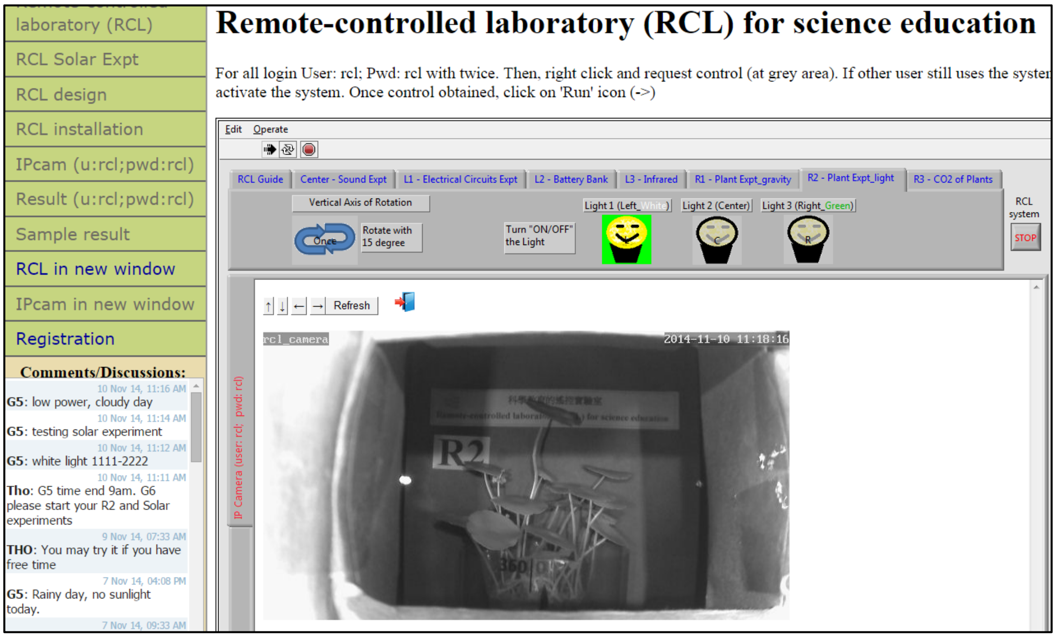


Figure 32 Webpage Display of Refined RCL System: R2 Plant Experiment - Light

### 5.5.7 R3: Plants Respiration

The learning objective of the R3 experiment is to investigate plant respiration according to the guided-inquiry question, “Do plants emit $CO_2$ gas in the dark?” Figure 33 shows the webpage for the R3 experiment; the webpage illustrates how the remote technology is employed. The students plan and perform an investigation on the gas released by plants at night. The plants release $CO_2$, gas which is converted from the consumed oxygen gas.

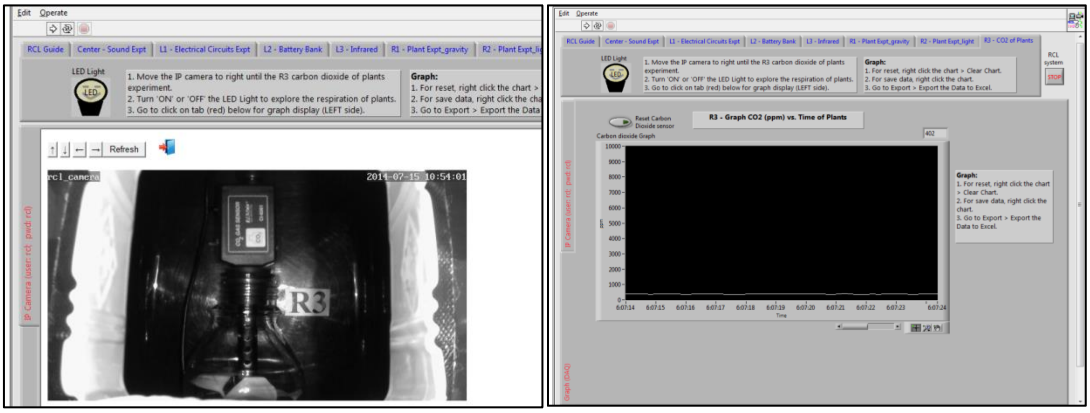



Figure 33 Webpage Display of RCL System: R3 Plant Respiration Experiment (left) and $CO_2$ Rate Graph (right)

In this experiment, the students can enable or disable a light in a box, observing the rate of the $CO_2$ gas through the $CO_2$ sensor. The plants release $CO_2$ gas when the light is disabled for a long period (exceeding ten hours). Thus, students can learn about the process of plant respiration.

### 5.5.8 RCL Outdoor – Solar Experiment

A solar energy experiment was successfully developed, related to the topic of renewable energy and involving the remote control of the setup to enable scientific investigation and long-term observation. The learning objective is to plan and remotely conduct a simple investigation on solar energy by using the IP camera. Solar energy, renewable energy from the sun, is a common topic in junior secondary school science curriculum and is usually taught using the science–technology–society approach (Kumar & Chubin, 2000). However, performing experiments related to this topic is difficult because they involve capturing the maximal amount of sunlight from a single position by manually controlling the angle of a solar panel; this can be uncomfortable for students because they would need to stand in the sunlight for long periods to collect data. Using the RCL system, students can remotely perform real-time solar energy experiments anywhere with Internet access. The real-time videos and pan–tilt–zoom function of the IP camera effectively resolve the aforementioned problems. Figure 34 shows the setup of two IP cameras in a simple remote-controlled experiment located outdoors.

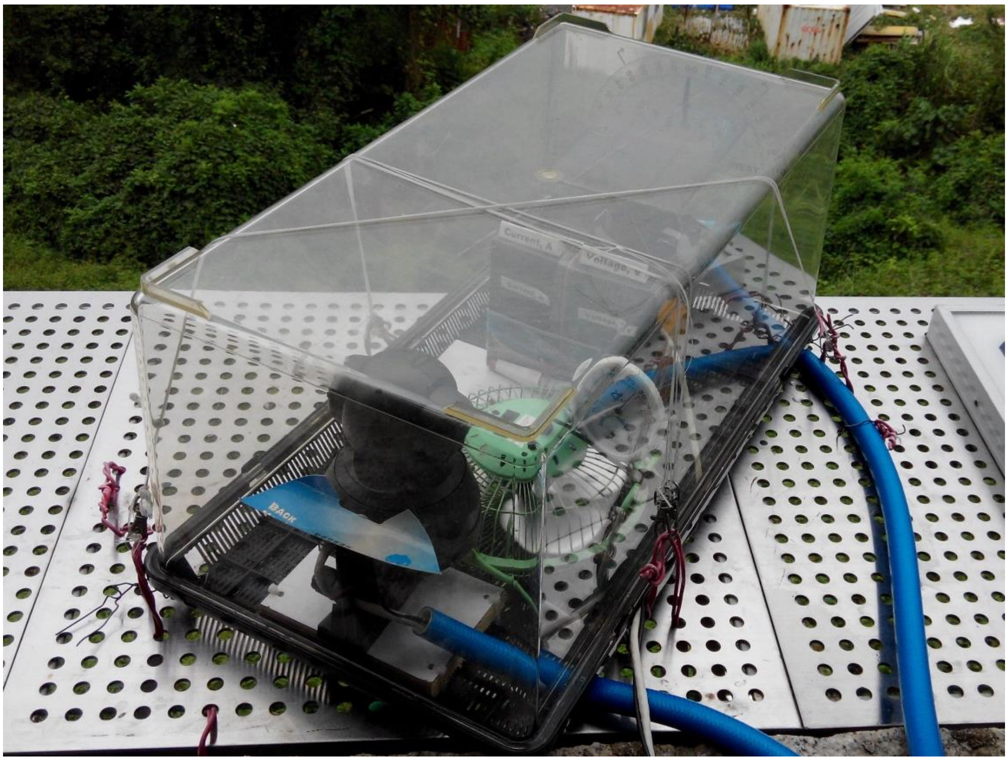



Figure 34 Setup of Two IP Cameras for Remote-controlled Solar Energy Experiment

One camera is used to adjust the tilt angle of the solar panel, and the other camera is used to observe the solar energy reading and the tilt angle of the panel. Both cameras are located outdoors inside a glass container. Figure 35 shows the readings, the panel orientation, and the available control buttons in the web browser for the solar energy experiment.

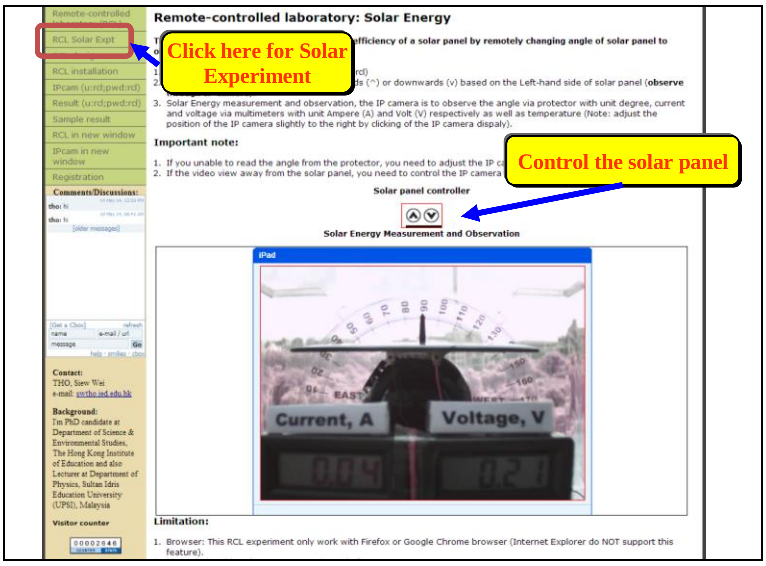



Figure 35 Readings and Control Buttons in the Web Browser of IP Camera-based Solar Energy Experiment

## 5.6 Refinements of RCL System

The refined RCL system primarily depended on LabVIEW software and associated with existing and new NI hardware modules. Another RCL system independent of the LabVIEW software was developed solely for the solar experiment. Hence, the refined RCL system consisted of two major parts: hardware and software.

### 5.6.1 Refinement of Hardware Configurations

The hardware components were refined, as illustrated in Figure 36. Another two slot modules were added to the NI Compact DAQ 9188 Ethernet chassis model, namely, an NI 9401 module with an 8-channel digital input or output (DIO), an NI 9215 module with a 4-channel 16-bit analog-to-digital converters (ADCs), various types of sensors, and IP cameras. Several essential characteristics of the added hardware functions and their applications in science education are explained in the following.

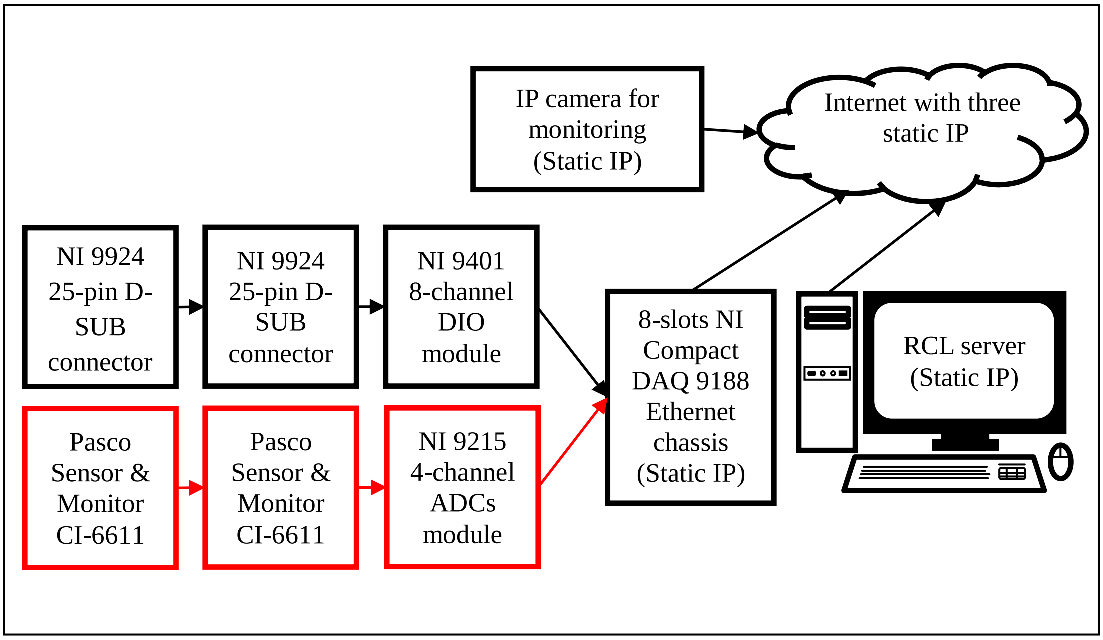



Figure 36 The Refined RCL Hardware Configurations

*Internet:* Another two static IP addresses (Table 27) were requested from the Information Technology Services unit of the Hong Kong Institute of Education (HKIEd) to develop the RCL system for the solar experiment that is independent of the LabVIEW software. These two static IP address were used for the IP cameras.

Table 27
Additional Static IP Address Arrangement

| Device and Location | Static IP address | Port forwarding | Domain Name |
|---|---|---|---|
| IP camera, HKIEd | 175.159.131.223 | 81 | rcl3.ied.edu.hk |
| IP camera, HKIEd | 175.159.131.224 | 81 | rcl4.ied.edu.hk |

*NI 9401 DIO module:* The main purpose of adding another DIO in this study was to increase the number of control functions for controlling the remote experiments.

*NI 9215 ADCs module:* The added NI 9215 ADCs module for the plug-in NI Compact DAQ 9188 chassis contains four simultaneously sampled analog input channels with 16-bit ADCs. According to the NI product description, the module features traceable calibration, a channel-to-earth ground double isolation barrier for safety, noise immunity, and a high common-mode voltage range. The main function of the ADCs in this study was to transform a continuous physical quantity (sensor output voltage) to a digital number that could be identified by the computer.

*Sensor voltage monitor and sensors:* The CI Sensor Voltage Monitor (with model number CI-6611) can supply power to PASCO ScienceWorkshop sensors, enabling the user to obtain the sensor's output voltage. The device can be connected with two digital sensors and three analog sensors and is appropriate for use with all ScienceWorkshop sensors. To measure the sensor's output voltage by using the NI product, the monitor's output terminals are linked to the NI 9215 ADCs module. Subsequently, sensor calibration is required since the output is expressed as a voltage value. For sensor calibration, the sensors detect the physical quantities of an electrical voltage output, which must be calibrated to a specific quantity. In this study, the specific quantities that could be recorded were $CO_2$ (ppm), light intensity (lux), pressure (kPa), and temperature ($^oC$).

*IP cameras:* According to the suggestions from the first iteration of evaluation, a higher resolution IP camera was used to monitor the LabVIEW-based remote experiments. An additional function of this IP camera pertained to the secure digital (SD) card socket used for recording storage. The SD card was added to store or save the motion detection videos and pre-set time recorded images. The existing IP camera was transferred to the solar experiment with a similar IP camera for controlling purposes.

### 5.6.2 Refinement of Software Development

*RCL software:* The RCL software was refined and redesign as a more user-friendly version that provided extra functions. In addition, the software operation flowchart (Figure 37) was refined. To begin, the user selects a "start" box and requests for control, and clicking on "run" to begin the RCL. The inputs are the eight remote experiments, processed and operated by the NI LabVIEW system (NI compact DAQ and LabVIEW software) and IP camera. Real-time data are obtained in the form of images, videos, and $CO_2$ sensor readings (output). Subsequently, the files (i.e., images, videos and $CO_2$ readings in ppm) are saved in the PC or SD card of the IP camera.

After the control process or experiment is completed, the user clicks “stop”, and release the control for other client/user.

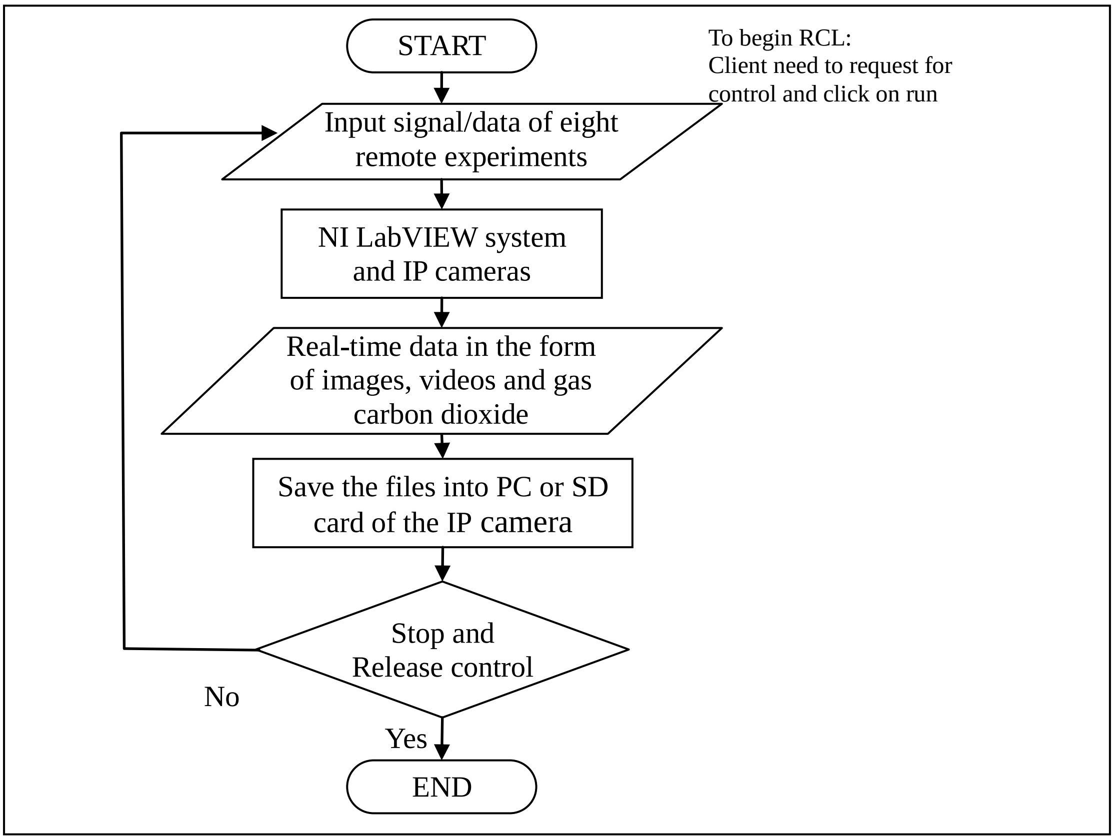
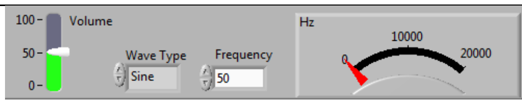
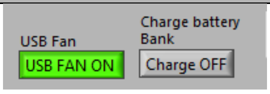
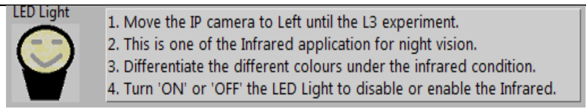
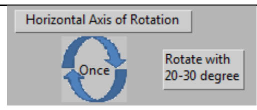
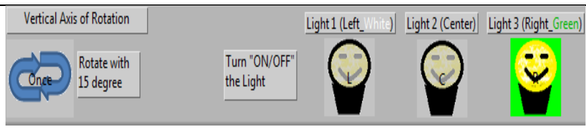
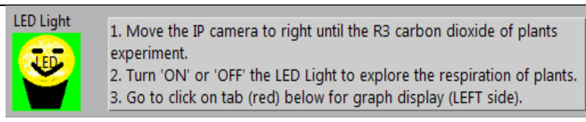



Figure 37 Flowchart of Refined Software Operation

Consequently, several buttons were removed from or added to the software. The control buttons included image buttons, a slider, and text control buttons. Table 28 depicts all buttons in the eight remote experiments.

Table 28

The Control Buttons for Eight Remote Experiments

| **RCL Experiment** | **Changing Parameter** | **Control Button** |
|---|---|---|
| Center: Sound as vibration (jumping beans) | Wave type, sound frequency and volume. |  |
| L1: Electrical circuit connection (Series & parallel) | Number of bulbs in series and parallel as well as the 2nd removed/burnt |  |
| L2: Battery bank | Charging-discharging battery & turn on devices. |  |
| L3: IR radiation | Turn on/off the light for observing different colours. |  |
| R1: Plant experiment – gravity stimuli | Plants' position: horizontal axis of rotation |  |
| R2: Plant experiment – light stimuli | Presence of light and plants' position: vertical axis of rotation. |  |
| R3: Plants respiration | Turn on & off the light for observing plant respiration. |  |
| Solar energy experiment | Changing angle of solar panel. |  |

Next, related buttons and additional DIO and ADC functions were substituted into the refined software program. Figure 38 illustrates the software program execution.

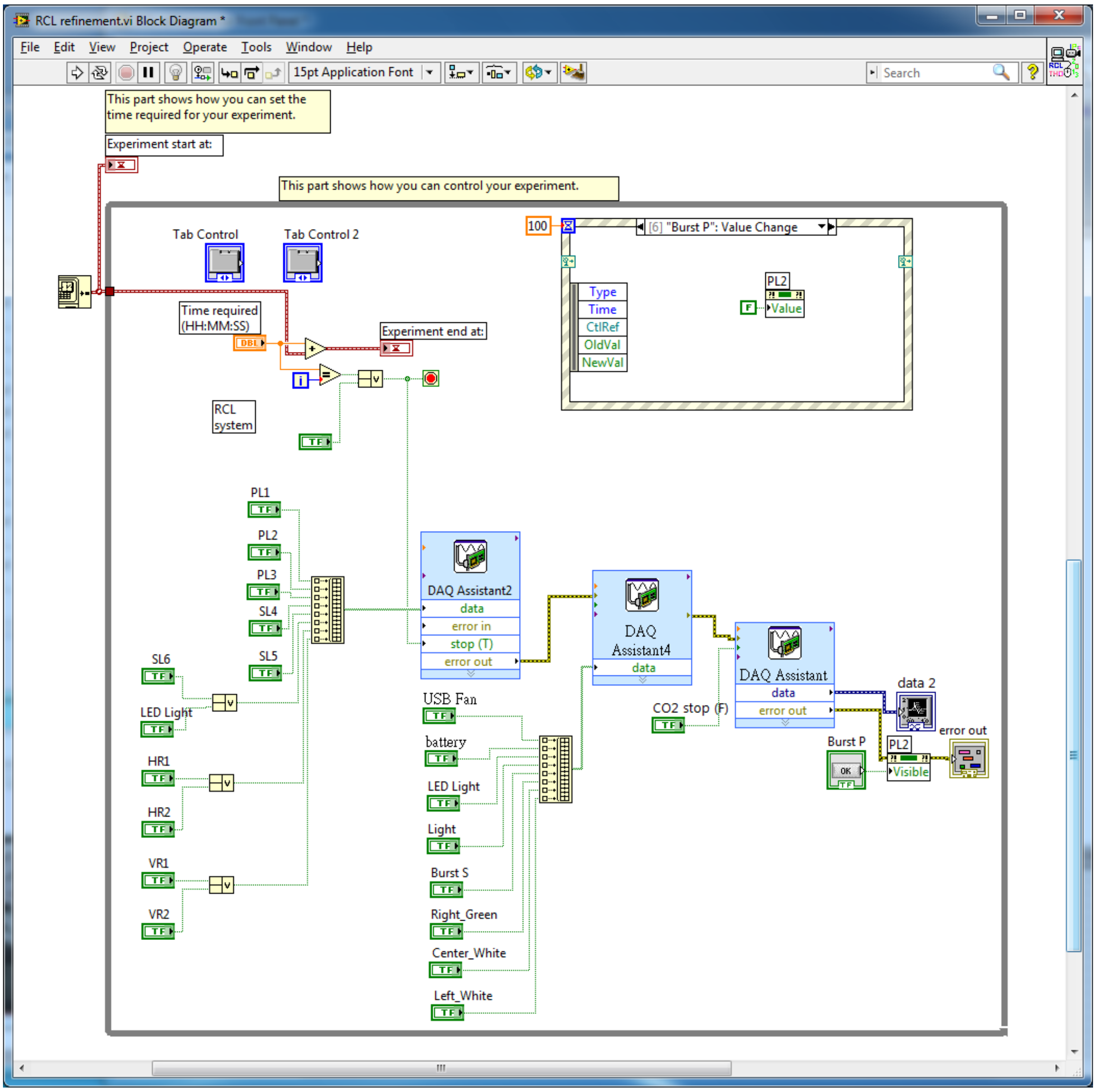



Figure 38 LabVIEW Software Execution of Refined RCL Program

*Chat box*: According to the results from the first iteration of evaluation, a free synchronous chat box function was added to enhance collaboration in learning. Students can use this function to leave comments and particularly discuss RCL settings and findings (Figure 39).

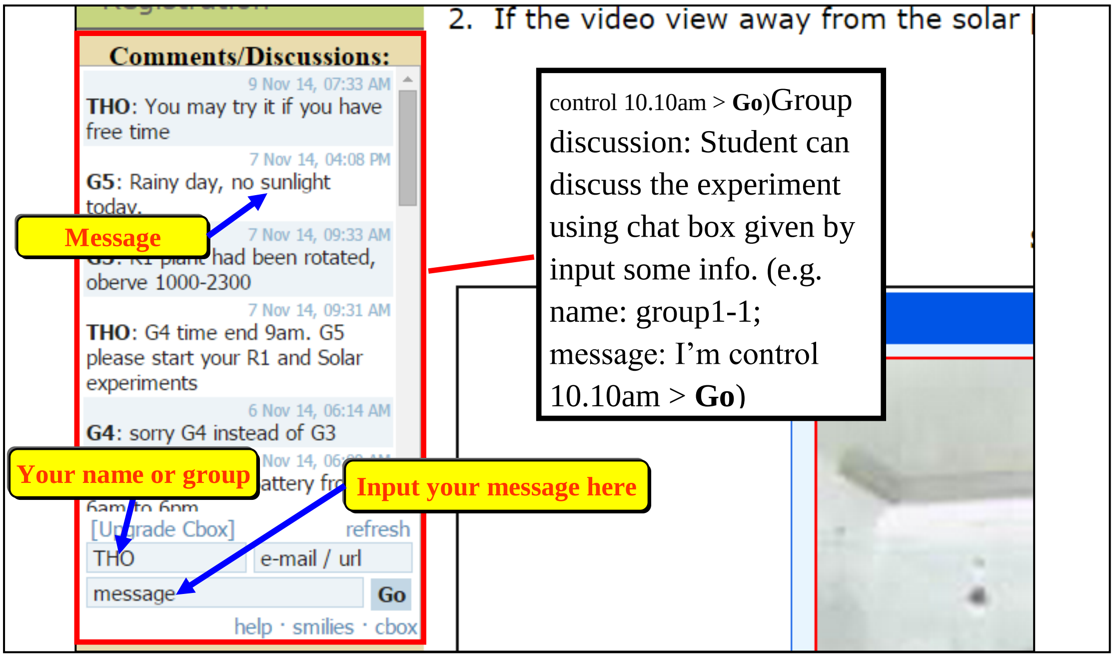



Figure 39 Free Synchronous Chat Box for Comments and Discussions

## 5.7 System Performance Evaluation of Refined RCL System

The performance evaluation of the refined RCL system revealed that the system could be controlled by one user and four observers simultaneously. Moreover, the response time experienced by the controller when performing the remote experiments was acceptable. Adapting the high resolution IP camera caused a 2-second delay; however, this problem could be resolved by setting the camera's video view to mobile. The RCL design principles and reflections are presented in the following section.

## 5.8 Implications

The results of this study revealed that the refined RCL system has great potential for application in school science laboratory learning. According to the results of the analysis and refinement, three key implications can be derived for the future development and school-based implementation of the RCL system. The first of these relates to the system refinement. Various unique or innovative features must be incorporated into the refined RCL system to increase the likelihood of its adoption in the school learning environment: (a) Reliability and robustness of the RCL system must be ensured to ensure that even careless students will not damage the system. (b) Access rights must be properly managed and monitored so that related remote experiments can be shared by the teacher education institution to other schools. (c) The refined RCL system must be space efficient, incorporating remote experiments on eight topics related to various science disciplines.

Second, the refined RCL system and the remote experiments in particular were developed for integration in secondary school science education (physics and biology). Currently, RCL-based experiments in physics are few, and those in biology are non-existent. In the open-ended questions, the participants suggested developing remote experiments related to physics and biology. Remote experiments developed by previous researchers focused mainly on engineering (Barrios et al., 2013; Scanlon et al., 2004), with a few experiments related to secondary school physics (e.g., Schauer et al., 2008).

Last but not least, the survey, open-ended questions, and interviews findings revealed that particular attention must be paid to RCL instruction and guidance (Kirschner, Sweller, & Clark, 2006). The participants demanded clearer RCL operation guidance, probably because of the new RCL approach adopted was unfamiliar. Thus, more detailed RCL operating procedure guidance and student worksheets were developed and refined before the remote experiments were implemented in secondary schools.

## 5.9 Conclusion

In this study, the researcher achieved several major outcomes. First, the RCL system was developed, including innovative science experiments that can be performed indoors or outdoors. The system can be applied in a school environment to enhance science learning, complementing regular classroom teaching. Second, student perceptions of the RCL and conventional science laboratories were compared; yielding data that can be a reference for future development of an educational RCL system. Moreover, comments and suggestions regarding improving the RCL system by changing a high resolution IP camera were collected. The iteration process of data-based research method was applied through design, implementation, analysis, and refinement, enabling the refinement of the RCL system and design principles. Finally, the implications of the refined RCL system were discussed and the system was further tested in a secondary school environment.

In summary, this chapter study recounts the development and design of the RCL system featuring an IP camera successfully developed and evaluated. Furthermore, the design of several feasible experiments involving sound, electric circuit connection, *phototropism*, and day and night-time *gravitropism* are detailed, as is the refinement of such experiments.

# CHAPTER 6

# FINDING AND ANALYSIS OF SECOND ITERATIVE CYCLE

This chapter presents the findings, analysis, and discussion of the second iterative cycle, describing the details of the refinement and the implications. Finally, conclusions from the second iteration and directions for future study are provided. In the second iteration, the refined remote-controlled laboratory (RCL) system was applied in a secondary school classroom (pseudo named as School A) in Hong Kong in early October 2014. A total of Five weeks were allocated for the second cycle. In the first week, students responded to a pre-survey and pre-test. The students learned about the refined RCL system in the second week and conducted the remote experiments according to the guided-inquiry worksheets. In the third and fourth weeks, they had the opportunity to operate the assigned remote experiments at their own pace. In the final week, the related science principles were presented by the researcher and students shared their findings, experiences and feelings about the remote experiments as well as the difficulties encountered. The student responses to the refined RCL system were evaluated by using surveys and a conceptual understanding test. Moreover, student interactions during the classroom lesson were observed and studied, and interviews with the teacher and selected students after the RCL experiment session were conducted. The data collected from the pre-test, post-test, pre-survey, post-survey and interviews were entered into computer files for subsequent qualitative and quantitative analysis.

## 6.1 Participants and Pre-survey

The second iteration of evaluation was conducted in a public secondary school in Hong Kong. A total of 36 junior secondary students at the beginning of their Secondary 3 (Form three, Grade 9) year participated in the evaluation. They had learned about basic scientific concepts, such as those related to living things, energy, and electricity, in their previous class, but they had not learned most of the concepts relevant to the RCL activities. To comply with the educational research code, the students and their parents were required to complete and sign a consent form indicating voluntary participation in the study. However, data collected from only 32 participants were valid for subsequent statistical analysis, and no missing data were found in the pre-test or post-test. Mean substitution was used for missing data on age and from the pre-survey and post-survey. Data from four participants were not valid because the students provided incomplete responses on the survey or were absent during the final lesson. Table 29 shows the descriptive statistics of the participants' gender and their mean age of the participants' was 14.5 years old.

Table 29
Descriptive Statistics of the Participants' Gender

| **Item** | **Detail** | **Frequency** | **Percent, %** |
|---|---|---|---|
| Gender | Male | 15 | 46.9 |
| | Female | 17 | 53.1 |

In addition, the participants were categorised into three science achievement levels (high, medium, and low) according to their last science examination marks. Furthermore, they indicated their present level of ability to conduct scientific experiments and were categorised accordingly as high, medium, or low (Table 30). Statistical analyses (i.e., *t* test and analysis of variance [ANOVA]) were conducted using the obtained data.

Table 30
Descriptive Statistics of the Participants' Knowledge and Experiment Level

| **Item** | **Detail** | **Frequency** | **Percent, %** |
|---|---|---|---|
| Science achievement level based on their examination result | High | 10 | 31.3 |
| | Medium | 11 | 34.4 |
| | Low | 11 | 34.4 |
| How do you rate your personal ability in conducting scientific experiment? | High | 5 | 15.6 |
| | Medium | 17 | 53.1 |
| | Low | 10 | 31.3 |

This section also presents an analysis of the pre-survey evaluating participants' personal interest in science, insight into science experiments, information and communication technology (ICT) learning, and science practices (Table 31). The mean scores for these four categories related to the educational value of using the RCL system (ranked on a 4-point Likert scale ranging from 1 [*strongly disagree*] to 4 [*strongly agree*]) ranged from 2.62 to 2.79.

Table 31
Descriptive Statistics of the Participants' Perception in Pre-survey

| **Category** | **Mean** | **S.D** |
|---|---|---|
| Personal Interest of Science | 2.68 | 0.66 |
| Insight of Science Experiment | 2.79 | 0.57 |
| ICT Learning | 2.63 | 0.76 |
| Science Practices | 2.70 | 0.51 |

## 6.2 Student Conceptual Understanding, Post-survey and Interview Data

*Effects on student conceptual understanding:* Regarding the multiple-choice questions (MCQs) on the pre-test and post-test, each MCQ carries the same scores; participant scores were calculated. Table 32 presents the means, standard deviations (SDs), paired samples *t* test statistics, and effect size of student conceptual understanding, as affected by using the refined RCL system. Based on the paired *t* test of the pre-test and post-test scores for the plant-related remote experiments (biology), a statistically significant difference was observed in the scores at the .01 significance level and for the electricity-related remote experiments (physics), a statistically significant difference was found in the scores at the .05 significance level: the mean post-test scores were higher than the mean pre-test scores in both groups. However, the *t* test results revealed no significant gender difference in the conceptual understanding test scores.

Overall, the results illustrated that using the RCL system in the classroom effectively enhanced student conceptual understanding of relevant plant and electricity topics. According to the values of the effect size, the effect on the students from the plant and electricity remote experiments can be rated as “modest” (Cohen et al., 2007, p. 521). In addition, the overall result of these two groups of remote experiments have a “modest” effect on the participants, and it is well-understood that educational change is a slow process, and prolonged implementation of a novel and refined approach or pedagogy is a prerequisite for achieving a strong effect on student learning outcomes. Therefore, further evaluation must be conducted in future.

Table 32
Pre-test and Post-test of Conceptual Understanding Analyses (N=32)

| **Experiment** | **Pre-test Mean (S.D.)** | **Post-test Mean (S.D.)** | **Paired *t* test** | **Effect Size** |
|---|---|---|---|---|
| Plant | 29.17(12.70) | 43.23(14.27) | -5.3** | -0.46 |
| Electricity | 26.04(13.01) | 34.11(15.46) | -2.6* | -0.27 |
| Overall | 28.13(8.92) | 38.02(11.87) | -5.1** | -0.43 |

Note: *p<.05 and **p <.001

*Post-survey:* In the first part of the post-survey, the participants provided their log-in information, total amount of time spent on RCL activities, and plans for future use of the RCL system in their free time (Table 33). This information was useful for determining students’ interest in RCL activities. According to the data, most participants logged into the RCL system fewer than five times (84.4%) and the total time spent using the system was 1–2 hours (50%). They indicated interest in conducting the remote experiments again if they have the time (approximately 70%).

Table 33
Descriptive Statistics of the Participants’ Knowledge and Experiment Level

| **Item** | **Detail** | **Frequency** | **Percent, %** |
|---|---|---|---|
| How many times you log-in and used the RCL? | ≤ 5 times | 27 | 84.4 |
| | 6 – 10 times | 5 | 15.6 |
| | > 10 times | 0 | 0.0 |
| Total amount of time you spend on the RCL system | ≤ 1 hour | 15 | 46.9 |
| | 1 – 2 hours | 16 | 50.0 |
| | > 3 hours | 1 | 3.1 |
| If you had more free time, would you use (RCL system) more? | Yes | 22 | 68.8 |
| | No | 10 | 31.2 |

The second part of the post-survey pertained to the perception of the participants after performing the RCL activities; aspects evaluated included personal interest in science, insight into the science experiments, operation of the RCL system, motivation stimulation, the promotion of teamwork, the importance of the RCL system, and science practices (Table 34). For these seven categories, the mean scores (rated on a 4-point Likert scale ranging from 1 [*strongly disagree*] to 4 [*strongly agree*]) ranged from 2.94 to 3.14. Based on the data, the mean scores for the two categories, personal interest in science and insight into the science experiments, were near 3, and those for the other five categories exceeded 3, showing agreement with the questionnaire statement.

Table 34
Descriptive Statistics of the Participants' Perception in Post-survey

| **Category** | **Mean** | **S.D** |
|---|---|---|
| Personal Interest of Science | 2.94 | 0.65 |
| Insight of Science Experiment | 2.99 | 0.61 |
| Operating the RCL system | 3.00 | 0.57 |
| Stimulating Motivation | 3.06 | 0.56 |
| Promoting Teamwork | 3.22 | 0.61 |
| Importance of RCL system | 3.12 | 0.45 |
| Science Practices | 3.14 | 0.48 |

According to the results, the students constantly scored higher on the post-survey items in the dimensions of personal interest in science, insights into the science experiments, and science practices compared with on the pre-survey. A paired samples *t* test was subsequently used to compare the scores given by participants on the pre-survey and post-survey; the dimensions of personal interest in science and science practices differed significantly at the .05 significance level. A comparison of the pre-survey and post-survey results indicated that students were more interested and had higher science practices after the RCL experiment session (Table 35). Thus, apparently, students had positive attitudes and were interested in science and science practices when using the RCL system to learn.

Table 35
Mean Scores (with SD in Brackets) and Paired-samples *t* test of Participants' Response on Survey Items as Based on Their Pre and Post survey

| **Category** | **Pre-survey** | **Post-survey** | **Paired *t* test** |
|---|---|---|---|
| Personal Interest of Science | 2.68 (0.66) | 2.94 (0.65) | -2.20* |
| Insight of Science Experiment | 2.79 (0.57) | 2.99 (0.61) | -1.42 |
| Science Practices | 2.63 (0.76) | 3.14 (0.48) | -4.64* |

Note: *p < .05

An independent samples *t* test was used to compare the student scores as affected by gender; the results revealed no significant gender difference. Furthermore, the ANOVA test, applied to compare the student scores in the post-survey categories based on science achievement level, revealed no statistically significant science achievement level difference.

Part of the survey was designed to compare the RCL experience and school science practical work in general (Table 36). The participants compared the two on the basis of reliability of observations, ease of gathering data, personal involvement, personal motivation, ease of learning new things, and teamwork or collaboration in learning (ranked on a 5-point Likert scale ranging from 1 [*school practical work is much better*] to 5 [*the RCL system is much better*]). Table 36 shows the distribution of the participant feedback. The overall mean score was 3.38, close to 3, indicating that the RCL is equally as good as school practical work. This result was supported by those of previous studies, in which remote experiments were determined to be equally as educational as hands-on experiments (Corter et al., 2007; Gustavsson et al., 2009). Thus, the remote experiments can complement conventional laboratory due to the additional benefits of RCL system (e.g. experiments for long-term & distance places).

Table 36
Descriptive Statistics of the Participants' Perception in Post-survey (N=32)

| **Statement** | **Mean** | **S.D** |
|---|---|---|
| Reliability of observations | 3.34 | 1.05 |
| Ease of gathering data | 3.69 | 1.04 |
| Personal involvement | 3.25 | 1.34 |
| Personal Motivation | 3.31 | 1.33 |
| Ease of learning new things | 3.66 | 1.13 |
| Teamwork/collaboration in learning | 3.03 | 1.18 |
| Overall | 3.38 | 0.93 |

*Open-ended questions:* In the second iteration, participant views of and difficulties encountered when using the RCL system were collected and summarised from open-ended questions, shown in Table 37.

Table 37
Three Open-ended Questions to Assess Participants' Perception Regarding the RCL System (with Number of Responses in Brackets)

| **Open-ended Question** | | **Comments** |
|---|---|---|
| 1. What have you learned from the RCL guided inquiry experiments? | - | They learned related scientific concepts (14) |
| | - | They learned how to conduct remote experiments (7) |
| 2. Have you encountered any problems concerning the RCL programme and the equipment while doing the remote experiments? | - | No difficulty encountered (21) |
| | - | They faced the Internet problem (3) |
| | - | They faced the setup or installation problem (2) |
| | - | They faced problem but not mentioned about the problem (2) |
| | - | They faced the English problem (1) |
| 3. If you were given another chance to do the RCL again, please suggest some ways for improvement? | - | They suggested to develop more interesting remote experiments (6) |
| | - | They suggested more easy to install the RCL (6) |
| | - | They suggested more detailed of how to use RCL (5) |
| | - | They suggested to include Chinese words (3) |
| | - | They suggested using Smartphone (1) |
| | - | They suggested to include games (1) |
| | - | They suggested more attractive interface (1) |

*The above representative points (N=32) were summarised and sorted from most common to least common.

A few negative comments were received, and several suggestions were provided to improve the RCL system. The majority of the participants did not experience difficulties (21 responses); difficulties related to or negative comments about the RCL activities were unavoidable. For example, Internet problems (3 responses) may have been caused by the Internet package used. Installation (2 responses) and English problems (1 response) could be resolved by refining the lesson presentation for the next implementation (i.e., the teacher or instructor could use Cantonese to teach the lesson and explain the installation steps). These results were consistent with those obtained during the first iteration of evaluation (Merging data, [Creswell & Plano

Clark, 2011]): participants must receive sufficient guidance and training in using the RCL system to optimise the system's educational values. Furthermore, the suggestions given by the participants were general and expected; for example, they wanted more interesting remote experiments (6 responses), simpler RCL installation (6 responses), and more details of how to use the RCL system (6 responses), and these may relate to the language used for teaching and guiding (3 responses) and relate to attractive interface (1 response). Two particularly insightful suggestions were received for future development: more remote experiments should be controllable by using smartphones (1 response) and related educational games should be included (1 response). One of the added remote experiments, the solar experiment, can be conducted using a smartphone or tablet device. Therefore, the participant who made this suggestion may want more remote experiments that can be controlled using smartphones or tablet devices. Overall, the responses to the open-ended questions were consistent with the survey results. The students acknowledged the value of the RCL system; however, several suggestions were made and common difficulties were encountered.

*Student interview data*: The student interviews after the RCL session also yielded extensive, meaningful, and more in-depth data (Merging data, [Creswell & Plano Clark, 2011]) about student views and suggestions on using the refined RCL system that can be triangulated from the survey (Cameron, 2011; Creswell & Plano Clark, 2011; Olsen, 2004). Participants in the interviews have been pseudo named S1 (low achievement and interest in science), S2 (medium achievement and high interest in science), and S3 (high achievement and interest in science) for ethical reasons. Table 38 shows the interview feedback on the RCL system and activities.

Table 38

Summary of Students' Feedback about the RCL in the Interviews

| |
|---|
| **Positive comments:**<br>S1: "For those experiment need longer duration of time, school may not be able to provide enough time for us"<br>S2: "Experiment that needs a lot of time to do it and this (RCL) could help save the time for us… Other than that, we can do a lot of the experiment together."<br>S3: "Yes, it is easy to work with," |
| **Negative comments:**<br>S1: "It needs English… we do not do it by our self, then it is not that clear."<br>S2: "But we have to install software before we do the experiment; it is a little bit difficult."<br>S3: "Not familiar with some English, yes, a bit hard, and won't contact much in the daily life. Other than English, this experiment requires computers… maybe it is hard for others to install, as others who don't know may ask me." |
| **Suggestions:**<br>S1: "Don't conduct it (experiment) by using the computer"<br>S2: "Maybe the experiment has to be more fit to the students, don't be too complicated because some experiments are comparatively complicated."<br>S3: "it (RCL installation) needs a lot of time for preparation, which you have to prepare to open the computer, and leads to a fewer time for doing experiment… if the network is not stable then experiment could not be done." |

According to the interviews, participants believed that the revised RCL system was easy to operate (S3), and that using the RCL system to observe and understand experiment that require longer periods are difficult to perform in school laboratories was favourable (S1 and S2). Thus, the RCL system can promote student-centred learning because it can be used by students at convenient locations such as at home, and it can resolve certain practical work problems, including those related to time and venue. These results were consistent with those from the post-survey; students agreed with the questionnaire statements.

However, various shortcomings of the RCL system were also identified. For example, S1 mentioned that the English-mediated instructions were difficult to follow and hands-on experiments are preferred. Student S3 also mentioned the difficulty in understanding certain English words and in installing the RCL system (S2 mentioned this as well).

Several common suggestions were received. For example, S1 suggested conducting hands-on experiments, which were more familiar. S2 suggested simplifying the RCL installation, as did S3, who also recommended resolving the network problem. These problems and suggestions were incorporated to further modification of the system for the third iteration; more detailed instruction for RCL installation was provided in English and Chinese. However, the suggestion regarding the Internet network could not be incorporated by the researcher. As mentioned, Internet speed problems may have been caused by the Internet package used or the time of Internet access.

*Teacher interview data*: Because teachers are close to students, they can provide professional feedback on student performance and attitudes according to their observations during school practical work and the RCL activities (Connecting and Merging data, [Creswell & Plano Clark, 2011]). For ethical purposes, the science teacher was named T3. From the teacher interview, several crucial points were identified and three related themes were derived: the Hawthorne effect, RCL approach, and self-efficacy.

Hawthorne effect—Some research bias is unavoidable; for example, the Hawthorne effect (also known as the novelty effect) "occurs when students are stimulated to greater efforts simply because of the novelty of a treatment" (Bayraktar, 2001, P. 182). However, this bias can be reduced by asking a question related to the normal practice in science learning and teaching (i.e., "Have you used any ICT tools to assist student learning when conducting school practical work? Is it common for students to use ICT when learning?"). T3 mentioned that technological tools are applied in science learning and teaching, such as CD-ROM animations or simulations for computer demonstrations, online images related to science (videos from YouTube and photos) and data loggers in field studies (pH, $CO_2$, and $O_2$ sensors). These data revealed that the students were familiar with using ICT tools in science learning; therefore, the Hawthorne effect could be reduced when conducting the remote experiments.

RCL approach—The most common observations or opinions were that the RCL system can complement the science practical work in school. T3 explained, "if it [science experiment] takes more than 50 minutes, then we have to use the RCL method or some of the experiments couldn't be done in the school laboratory, we can only use the RCL system”. Furthermore, using the RCL system enhanced the self-learning aspect: “This could lead to an increase of [science] learning for the students who are interested in”. T3 also remarked that the plant topic was too in-depth and is more suitable for senior secondary level students, particularly those in a biology class; however, biology teachers will not perform the plant experiment that requires longer time. “Yes, the plant [experiment] for IS [integrated science] is not that in-depth, they will do it at the Biology in form 4 or form 5. However, biology teachers would not do this similar experiment due to the time limit”. Interestingly, the comments by the teacher were similar to the feedback from the students and the results of the first iteration of evaluation.

However, various shortcomings were identified by the teacher, who noticed that the participation of the students was normal, possibly because of the complexity of the RCL software. “Maybe the students have to go through a lot of steps in order to do what they have to do: open the computer when they back home, download [install] the software. Therefore, there is some possibility for a lot of students that they cannot do it successfully”. Furthermore, because the students want increasingly more guidelines, seek direct experimental results, and are unwilling to explore the work, “you [teacher] have to do a lot of preparation, and the responsibility has become the teacher’s, not the student’s, to solve the problem”. This is consistent with the negative comments provided by the students that they want more guided instructions and instructions in Chinese, even though the science subject was English-mediated instruction.

Self-efficacy—Regarding self-efficacy, T3 would feel confident operating the RCL system in the classroom if the RCL interfaces were simpler and there were less initial access control (i.e., request control and run the software). However, T3 felt confident that using the RCL system could increase student motivation to learn science: “Yes, at least you have provided the opportunities for them to interact with it [RCL], like for some students who are interested in it. I believe the students would pick the science stream afterwards. It is good for them, keeping them to learn Integrated Science”. Besides, T3 added that time is essential for students to explore the RCL:

"They might not perform well for their first time, but there will be improvement afterwards. Time is needed, to continually do the activity from this aspect".

## 6.3 Refinements

According to the analysis of the collected data, the RCL system was refined by (a) modifying the presentation of the remote experiments; (b) providing clearer RCL system operating guidelines with Chinese translations; and (c) focusing the remote experiments on electricity (electrical circuits, battery bank, and solar energy) during the subsequent implementation.

First, the presentation of the RCL system and remote experiments were modified. The results from and observations during the RCL lesson indicated that Chinese instructions should be considered. The instructor should use English and Cantonese when presenting the RCL system.

Second, detailed RCL system operating guidelines with Chinese translations were developed (Appendix L), particularly explaining how to conduct remote experiments in the LabVIEW interface (Figure 40).

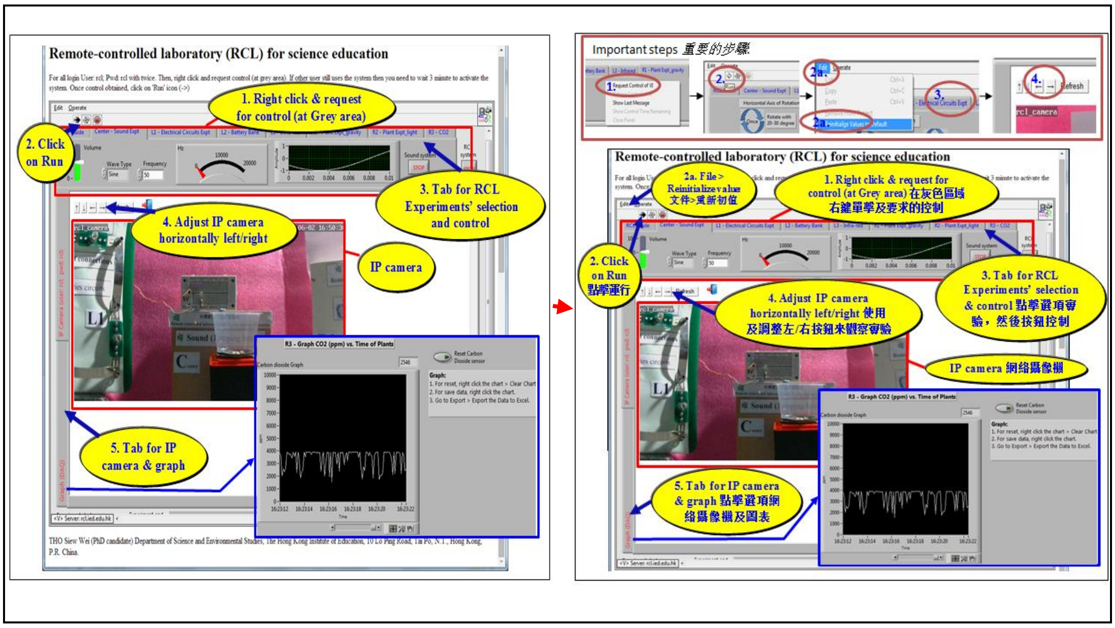



Figure 40 Part of the RCL Operating Guidelines Before (left) and After (right) Refinement

Finally, the remote experiments conducted by students in the third iteration were related to electricity (i.e., electrical circuits, battery banks, and solar energy). However, the remote experiments related to plants, sound, and IR radiation was also presented to the students as a teacher demonstration. The experiments were restricted to the topic of electricity for three main reasons: (a) to test the refined RCL system, particularly the presentation and guideline aspects, (b) to focus on one major topic, particularly electricity-related remote experiments, and (c) as requested by the related teacher. Thus, students answered the electricity-related MCQs, but not the entire post-test (Appendix H) in the third iteration.

## 6.4 Implications

According to the results obtained from using the refined RCL system, the refined RCL system received positive feedback and should be further applied in science education. Therefore, no major refinement was made to the refined RCL system. The results from the second iteration revealed that the refined RCL system had the advantages of promoting remote experiments in a secondary school learning environment. Two main implications can be derived from the results, analysis, discussion, and refinement of the second iteration.

The first implication relates to the educational value of the refined RCL system. According to the pre-test and post-test results, the students significantly improved after using the RCL system and expressed positive views regarding it. The open-ended question responses in the post-survey, the interview data, and classroom observation indicated that students can actively participate in the RCL activities. Furthermore, the teacher and students also claimed that the RCL system can complement school science practical work. This result is similar to those from a systematic review, which revealed that remote experiments were deemed equally good as hands-on experiments (Corter et al., 2007; Lang et al., 2007; Nickerson et al., 2007; Tzafestas et al., 2006). In addition, the students wanted to continue exploring the RCL activities when they had time (approximately 70%). However, several negative comments and shortcomings were identified by the students; some of the feedback was expected, such as complaints about Internet problems (Gillet et al., 2005). Nevertheless, several valuable suggestions were received; some of them were refined and others may be considered for future development.

Second, regarding the refinement of the RCL system, the two minor aforementioned modifications were necessary for enhancing the possibility of Hong Kong secondary students exploring the remote experiments further. The modifications included the RCL operating guidelines and the way of presenting the remote experiments as well as focus on the electricity-related remote experiments for the third cycle of iteration.

## 6.5 Conclusion

The second iteration also yielded various essential outcomes. First, the RCL system as applied in a secondary school was effective, according to the conceptual understanding achievement and survey results. Second, the results of the second iteration were consistent with those of the first iteration. Third, the results were consistent with those of previous RCL studies in school learning environment conducted by Kong et al. (2009) and Lowe et al. (2013). The school students acknowledged the educational value of the RCL system.

According to teacher and student feedback, the RCL system promoted a student-centred learning approach, particularly for students interested in science, through the effective use of innovative experiments. Therefore, further developing and evaluating the RCL system is crucial for science experiments and demonstration kits. It can be a resource for future science teaching and learning, particularly as a complement to conventional science experiments in school.

In conclusion, this chapter reports the refinement of the RCL system and the development of several new feasible remote experiments that were implemented and evaluated in a secondary school. Thus, this refined RCL system can be applied in secondary school science education. However, the RCL system must be tested and evaluated by another school to verify usability and reliability. Therefore, a third iteration of evaluation was conducted and is described in the following chapter.

# CHAPTER 7

# FINDING AND ANALYSIS OF THIRD ITERATIVE CYCLE

This chapter presents the findings, analysis, and discussion of third iteration of evaluation, detailing the refinement and implications. In third iteration, the refined remote-controlled laboratory (RCL) system was applied again in another secondary school, pseudo named as School B, in Hong Kong at the end of November 2014. A period of four weeks was allocated for the third cycle because the students needed to complete the electricity-related remote experiments. In the first week, the students responded to the pre-survey and pre-test, and were introduced to the refined RCL system. In the second and third weeks, they conducted the assigned remote experiments at their own pace. The related science principles were presented in the fourth week and the students shared their experiences and feelings about the remote experiments as well as the difficulties encountered. The refined RCL system was evaluated by assessing the student responses to the same survey and conceptual understanding test that were applied in the second iteration. The student interactions in the classroom were observed, and the teacher and selected students were interviewed after the RCL activities concluded. Thus, the data collected from the pre-test, post-test, pre-survey, post-survey, and interviews were entered into computer files for subsequent qualitative and quantitative analysis.

## 7.1 Participants and Pre-survey

The third iteration of evaluation was conducted in another public secondary school in Hong Kong. A total of 40 junior secondary students in the middle of their Secondary 2 (Form two, Grade 8) year participated. They had learned related basic scientific concepts, such as those related to living things, energy, and electricity, in previous science classes, but they had not learned most of the science concepts related to the

RCL activities. To comply with the educational research code, the students and their parents completed and signed a consent form indicating voluntary participation in the study. However, only data collected from 35 students were valid for the subsequent statistical analysis process and no missing data were found in the pre-test and post-test. Mean substitution was used for the missing data on age and in the pre-survey and post-survey. Data from five participants were invalid because they were absent during either the first or last class of the RCL lessons, and thus left incomplete responses in the surveys and conceptual understanding test. Table 39 shows the descriptive statistics of the valid participants' gender and their mean age of the participants' was 13.8 years old.

Table 39
Descriptive Statistics of the Participants' Gender

| **Item** | **Detail** | **Frequency** | **Percent, %** |
|---|---|---|---|
| Gender | Male | 13 | 37.1 |
| | Female | 22 | 62.9 |

The participants provided their last science examination marks and were categorised accordingly into three science achievement levels: high, medium, and low. Moreover, they indicated their present ability level in conducting scientific experiments and were categorised as high, medium, or low accordingly (Table 40). According to these data, the statistical analyses (i.e., *t* test and analysis of variance [ANOVA]) were conducted.

Table 40
Descriptive Statistics of the Participants' Knowledge and Experiment Level

| **Item** | **Detail** | **Frequency** | **Percent, %** |
|---|---|---|---|
| Science achievement level based on their examination result | High | 11 | 31.4 |
| | Medium | 13 | 37.1 |
| | Low | 11 | 31.4 |
| How do you rate your personal ability in conducting scientific experiment? | High | 3 | 8.6 |
| | Medium | 30 | 85.7 |
| | Low | 2 | 5.7 |

This section described the analysis of the pre-survey pertaining to participant personal interest in science, insight into science experiments, information and communication technology (ICT) learning, and science practices (Table 41). The mean scores of these four categories (ranked on a 4-point Likert scale ranging from 1 [*strongly disagree*] to 4 [*strongly agree*]) ranged from 2.62 to 2.79.

Table 41
Descriptive Statistics of the Participants' Perception in Pre-survey

| **Category** | **Mean** | **S.D** |
|---|---|---|
| Personal Interest of Science | 2.79 | 0.62 |
| Insight of Science Experiments | 3.02 | 0.49 |
| ICT Learning | 2.61 | 0.46 |
| Science Practices | 2.61 | 0.38 |

## 7.2 Student Conceptual Understanding

*Effects on student conceptual understanding:* Table 42 presents the mean values, standard deviations (SDs), paired samples *t* test statistic, and effect size of the conceptual understanding of the participants, as affected by the refined RCL system. On the pre-test and post-test, each electricity-related multiple choice question (MCQ) carried the same scores. After the score for each participant was determined, the mean values and SDs for the 35 participants were calculated. According to the paired *t* test for the pre-test and post-test scores of only the electricity-related remote experiments (physics), the mean scores differed significantly: the post-test mean scores were higher than the pre-test mean scores. Thus, the refined RCL system applied in the classroom learning environment effectively enhanced the students' conceptual understanding of relevant electricity topics. According to the value of the effect size, the effect on the participants from participating in the RCL electricity-related learning activities was "modest" (Cohen et al., 2007, p. 521). However, a longer period of testing and evaluation is required for determining whether the RCL system is truly useful and beneficial to science learning and teaching.

Table 42
Pre-test and Post-test of Conceptual Understanding Analysis (N=35)

| **Experiment** | **Pre-test Mean (S.D.)** | **Post-test Mean (S.D.)** | **Paired *t* test** | **Effect Size** |
|---|---|---|---|---|
| Electricity-related remote experiments | 42.62(14.26) | 49.29(12.84) | -2.7* | -0.27 |

Note: *p<.05

In addition, the independent samples *t* test was applied to analyse the participant scores in terms of gender; the results revealed that there were significant gender differences (Table 43). The boys scored significantly higher than did the girls on the related conceptual understanding test. After the refinement in the second iteration, the boys were predicted to be more interested the remote experiments. However, this prediction needed to be triangulated with other analysis data particularly that gathered from the surveys and interviews, to confirm the data reliability.

Table 43
Mean Scores (with SD in Brackets) and *t* Test of Participants' Response on Post-Test as Based on Their Gender. N is the Number of Participants

| **Experiment** | **Male (N=13)** | **Female (N=22)** | **Overall (N=35)** | ***t* statistic** |
|---|---|---|---|---|
| Electricity-related remote experiments | 56.41 (11.86) | 45.07 (11.69) | 49.29 (12.84) | 2.76* |

Note: *p < .05

According to the teacher interviews, both groups of students had experienced using ICT as a tool of science learning. Therefore, it is anticipated they have same comparable ICT competence. Thus, the analysis of covariance (ANCOVA) was performed as described in the abovementioned methodology (section 3.5.4.3) to compare the data from the conceptual understanding tests of School A in the second iteration with those of School B in the third iteration (Table 44). This analysis is crucial for comparing the participants' conceptual understanding before and after the RCL system refinement. The results revealed that after controlling for the initial ability of the participants, the post-test scores differed significantly between the two schools, $F(1, 64) = 5.94$, $p < .05$. Thus, the refinement was a considerable improvement.

Table 44
ANCOVA Tests of Between-Subjects Effects
Dependent Variable: Post-test

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared |
|---|---|---|---|---|---|---|
| Corrected Model | 5322.127[a] | 2 | 2661.064 | 14.754 | .000 | .316 |
| Intercept | 7904.957 | 1 | 7904.957 | 43.827 | .000 | .406 |
| Pre-test | 1474.623 | 1 | 1474.623 | 8.176 | .006 | .113 |
| school | 1071.352 | 1 | 1071.352 | 5.940 | .018 | .085 |
| Error | 11543.545 | 64 | 180.368 | | | |
| Total | 135277.778 | 67 | | | | |
| Corrected Total | 16865.672 | 66 | | | | |

a. R Squared = .316 (Adjusted R Squared = .294)

The profile plot indicated that the refined RCL system enabled higher achievement scores after the initial ability of the participants was controlled for (Figure 41).

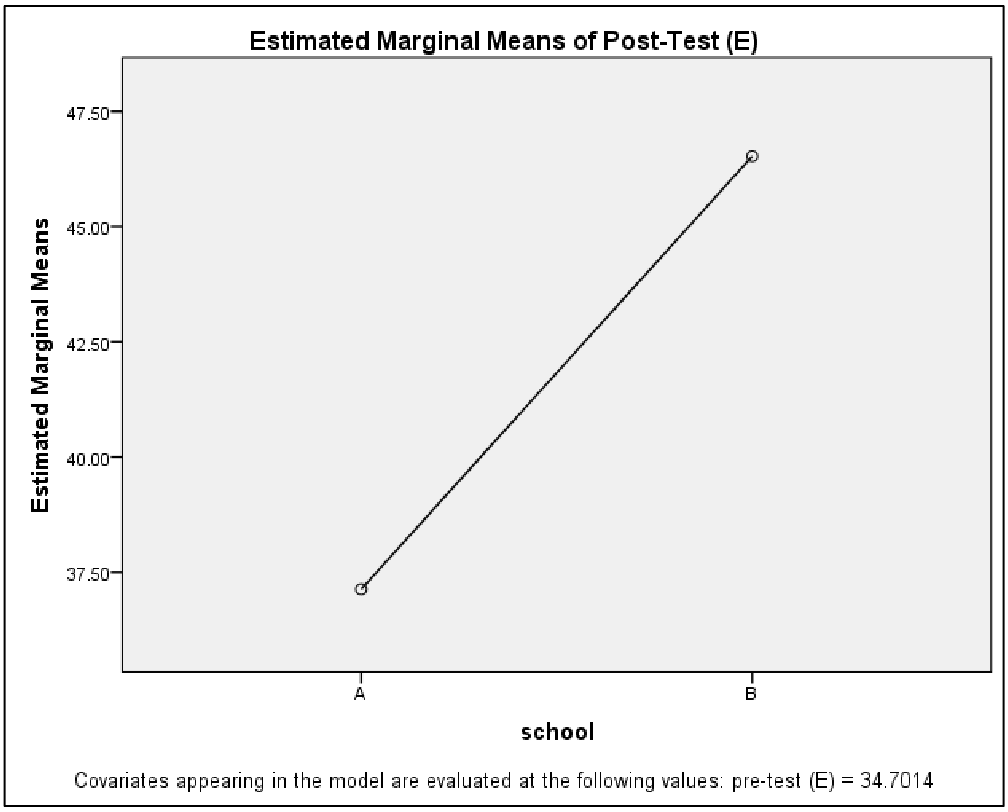



Figure 41 Profile Plot

## 7.3 Post-survey and Interview Data

*Post-survey:* The participants provided their log-in data, total time spent on RCL activities, and intentions to use the RCL system in their free time (Table 45). This data were useful for determining the level of interest the students had towards the refined RCL system and activities. According to the data, most participants logged into the RCL system fewer than five times (68.6%) and spent a total of less than one hour (65.7%) using it. This is an acceptable value because they merely conducted three electricity-related remote experiments. They indicated the desire to conduct the remote experiments again (approximately 60%) if they had more free time.

Table 45
Descriptive Statistics of the Participants' Knowledge and Experiment Level

| **Item** | **Detail** | **Frequency** | **Percent, %** |
|---|---|---|---|
| How many times you log-in and used the RCL? | ≤ 5 times | 24 | 68.6 |
| | 6 – 10 times | 8 | 22.9 |
| | > 10 times | 3 | 8.6 |
| Total amount of time you spend on the RCL system | ≤ 1 hour | 23 | 65.7 |
| | 1 – 2 hours | 11 | 31.4 |
| | > 3 hours | 1 | 2.9 |
| If you had more free time, would you use (RCL system) more? | Yes | 20 | 57.1 |
| | No | 15 | 42.9 |

The second part of the post-survey was used to assess the personal interest in science, insight into the science experiments, operation of the RCL system, motivation stimulation, teamwork promotion, importance of the RCL system, and science practices after the RCL activities. Table 46 presents the evaluation data of the independent samples *t* test on the post-survey data. For the seven categories related to the educational value of the refined RCL system based on the course of study, the mean scores (rated on a 4-point Likert scale ranging from 1 [*strongly disagree*] to 4 [*strongly agree*]) ranged from 2.55 to 3.15, and the score for every category was near 3. The boys (with comparatively lower SDs) constantly provided higher ratings for the survey items compared with the girls. The independent samples *t* test was subsequently used to compare the student scores in terms of gender; the results revealed that there were statistically significant gender differences in three survey categories, namely, personal interest in science, operation of the RCL system, and science practices.

Overall, the survey findings from all participants in third iteration showed that they acknowledged the educational value of the refined RCL system and the methods of performing the web-based science experiments. According to the independent samples *t* test results, the refined RCL system increased the boys' personal interest in science and improved their ability to conduct science remote experiments. The boys were generally more interested and had higher practices in the RCL session than did the girls (Table 46). Moreover, the boys operated the RCL system more easily than did the girls, because in general, boys are more interested in science subjects and technology (Chang, Yeung, & Cheng, 2012) and occupations related to science, technology, engineering, and mathematics (STEM) than are girls (Beede, Julian, Langdon, McKittrick, Khan, & Doms, 2011; Sadler, Sonnert, Hazari, & Tai, 2012). Interestingly, the survey data analysis results were consistent with those of the conceptual understanding achievement test. Therefore, the boys were more interested and motivated in testing and using the refined RCL system.

Table 46
Mean Scores (with SD in Brackets) and *t* test of Participants' Response on Survey Items as Based on Their Gender. N is the Number of Participants

| **Category** | **Male (N=13)** | **Female (N=22)** | **Overall (N=35)** | ***t* statistic** |
|---|---|---|---|---|
| Personal Interest of Science | 3.15 (.44) | 2.64 (.65) | 2.83 (.63) | 2.54* |
| Insight of Science Experiment | 3.05 (.40) | 2.67 (.68) | 2.78 (.57) | 1.84 |
| Operating the RCL system | 2.90 (.28) | 2.55 (.57) | 2.68 (.51) | 2.43* |
| Stimulating Motivation | 2.96 (.45) | 2.61 (.63) | 2.74 (.59) | 1.73 |
| Promoting Teamwork | 2.97 (.35) | 2.71 (.70) | 2.81 (.60) | 1.26 |
| Importance of RCL system | 3.03 (.38) | 2.76 (.45) | 2.86 (.47) | 1.67 |
| Science Practices | 3.14 (.33) | 2.68 (.47) | 2.85 (.48) | 3.09* |

Note: *p < .05

The ANOVA test was applied to compare the student scores from the post-survey categories in terms of science achievement level; no significant difference was determined. The boys not only rated items higher in the survey, but also scored higher on the conceptual understanding test after using the refined RCL system.

Furthermore, the post-survey items scored were constantly higher than those of the pre-survey in the personal interest in science and science practices. However, the paired samples *t* test comparing the pre-survey and post-survey scores revealed a statistically significant difference only for the science practices category at the .05 significance level; participants generally scored higher in the science practices on the post-survey after the RCL session (Table 47). Students apparently had positive attitudes, in terms of science practices, towards the RCL system.

Table 47
Mean Scores (with SD in Brackets) and Paired-samples *t* test of Participants' Response on Survey Items as Based on Their Pre and Post Survey

| **Category** | **Pre-survey** | **Post-survey** | **Paired *t* test** |
|---|---|---|---|
| Personal Interest of Science | 2.79 (0.62) | 2.82 (0.63) | -0.53 |
| Insight of Science Experiment | 3.02 (0.49) | 2.81 (0.62) | 1.93 |
| Science Practices | 2.61 (0.38) | 2.85 (0.48) | -3.43* |

Note: *p < .05

Moreover, part of the survey was used to compare using the RCL system and performing school science practical work (Table 48). The participants compared the RCL system and practical work according to the reliability of observations, ease of gathering data, personal involvement, personal motivation, ease of learning new information, and teamwork and collaboration in learning (rated on a 5-point Likert scale ranging from 1 [*school practical work is much better*] to 5 [*the RCL system is much better*]). Table 48 shows the distribution of the participant feedback. The overall mean score was 2.89, which is near 3, indicating that the RCL was equally as educational as school practical work. This result is consistent with those of the second iteration and previous studies, in which remote experiments were found to be equally good as hands-on experiments (Corter et al., 2007; Gustavsson et al., 2009; Lang et al., 2007; Nickerson et al., 2007; Tzafestas et al., 2006). Therefore, the remote experiments can complement school science experiments due to the additional benefits of RCL system including long-term and night-time and distance outdoor experiments.

Table 48
Descriptive Statistics of the Participants' Perception in Post-survey

| Statement | Mean | S.D |
|---|---|---|
| Reliability of observations | 2.89 | 1.05 |
| Ease of gathering data | 3.09 | 1.04 |
| Personal involvement | 2.86 | 0.97 |
| Personal Motivation | 2.83 | 1.00 |
| Ease of learning new things | 3.14 | 1.04 |
| Teamwork/collaboration in learning | 2.51 | 1.04 |
| Overall | 2.89 | 0.80 |

Overall, the participants in the third iteration rated the survey items lower than did participants in the second iteration; however, this was the trend of participant responses in the third iteration and of female students in particular. This trend can be explained by the overall pre-survey and post-survey responses. In addition, because of the relatively fewer participants in this study, this result could not be reliably confirmed from the statistical tests.

*Open-ended questions:* In the third iteration, the participants' views of and difficulties encountered in using the RCL system were also collected and summarised by using open-ended questions (Table 49). According to the responses, the students learned about the remote experiments and related scientific concepts. Most of the participants did not encounter any major difficulties (approximately 50%); however, two problems were indicated, namely, Internet problems (14 responses) and RCL system setup and installation problems (6 responses). The large number of participants who logged in before the last lesson on December 9, 2014, eventually caused the numerous negative comments regarding Internet problems (Figure 42), which are unavoidable if students wait until the last minute to perform the experiments, even though allotted times for performing the experiments have been assigned. Therefore, an effective log-in arrangement, reward educational system, and multiple RCL system, as well as a log-in monitoring system (also mentioned by T4), must be considered to resolve Internet problems. These problems were consistent with those indicated in the first and second iterations, implying that students must receive guidance and training to use the refined RCL system to optimise its educational value.

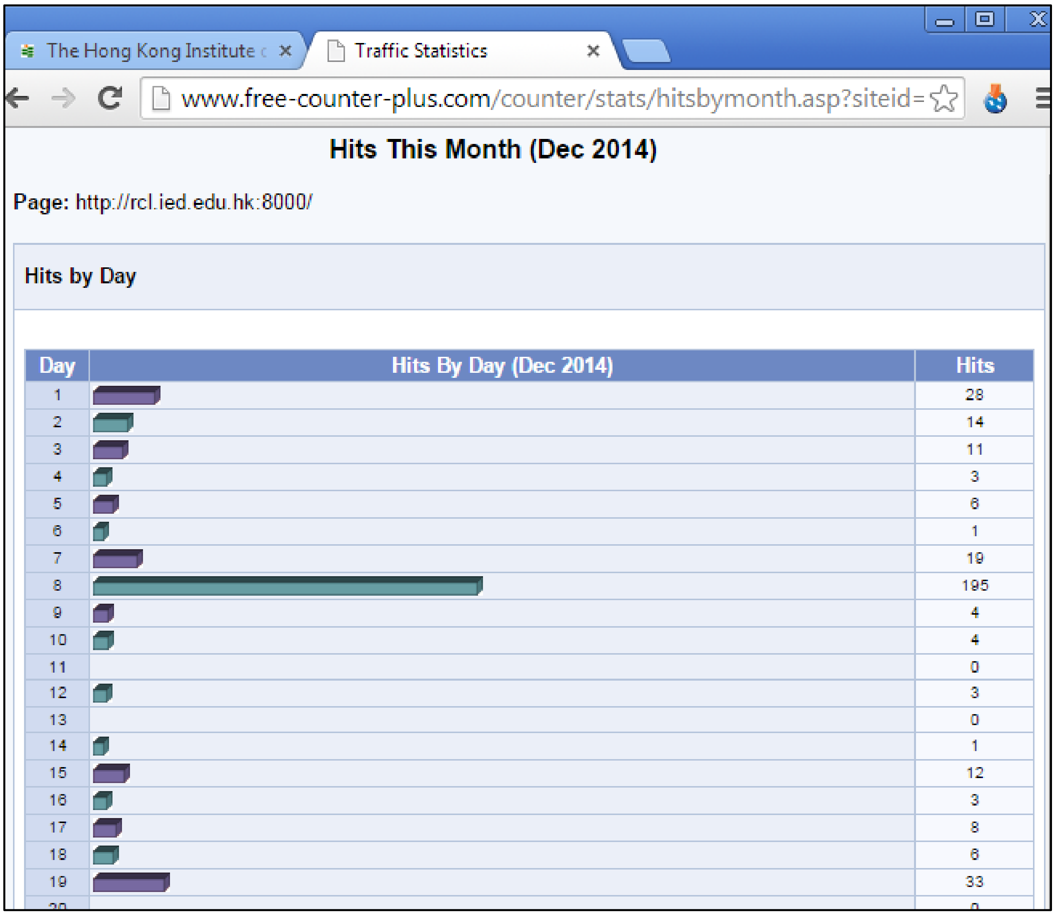



Figure 42 The Statistics of RCL Website's Visitors (Created from http://www.free-counter-plus.com/)

Moreover, the suggestions given by the participants were common and expected, similar to those in the first iteration; they want more remote experiments (9 responses), simpler RCL installation (8 responses), resolution for Internet problems (6 responses), added Chinese translations (1 response), and a more attractive interface (1 response). Nevertheless, two suggestions previously unmentioned in the second iteration were received for consideration in future RCL development: creating remote experiments involving chemical reactions (1 response) and explosions (dangerous experiment, 1 response).

Table 49
Three Open-ended Questions to Assess Participants' Perception Regarding the RCL System (with Number of Responses in Brackets)

| **Open-ended Question** | | **Comments** |
|---|---|---|
| 1. What have you learned from the RCL guided inquiry experiments? | -<br>-<br>- | They learned how to conduct remote experiments (14)<br>They learned electricity-related remote experiment (13)<br>They learned related scientific concepts (8) |
| 2. Have you encountered any problems concerning the RCL programme and the equipment while doing the remote experiments? | -<br>-<br>-<br>-<br>- | No difficulty encountered (17)<br>They faced the Internet problem (14)<br>They faced the RCL setup or installation problem (6)<br>They faced problem but not mentioned about the problem (1)<br>The interface is not clear (1) |
| 3. If you were given another chance to do the RCL again, please suggest some ways for improvement? | -<br>-<br>-<br>-<br>-<br>-<br>-<br>- | They suggested to develop more remote experiments (9)<br>They suggested more easy to install the RCL (8)<br>They suggested to solve the Internet related problems (6)<br>They suggested to increase the teamwork in RCL (5)<br>They suggested more attractive interface (1)<br>They suggested to include Chinese words (1)<br>They suggested to Chemistry experiment (1)<br>They suggested to explosion experiment (1) |

*The above representative points (N=35) were summarised and sorted from most common to least common.

*Student interview data*: The student interviews after the third iteration of RCL evaluation yielded extensive, meaningful, and in-depth data (Merging data, [Creswell & Plano Clark, 2011]) about student views and suggestions that can be triangulated with the survey results. The interviewees were denoted S4 (low achievement and interest in science), S5 (medium achievement and high interest in science), and S6 (high achievement and interest in science) for ethical reasons. Table 50 shows the interview feedback regarding the refined RCL system.

In the interview, participants reflected that they learned about applying state-of-the-art technology in science education (S4 and S5). The RCL system is simple and convenient to use (S5 and S6). S6 added that the RCL system enables observing science experiments that need a longer amount of time (S6) and are difficult to perform at school. These results are consistence with those from the post-survey and the second iteration.

However, several negative comments and shortcomings of the RCL were also identified. The three interviewees claimed that the English hindered them from understanding the RCL system through the Internet. Moreover, S5 and S6 mentioned the problematic Internet access; S4 remarked that “it is not smooth when I used it yesterday; I have used for a long time to do it”. Two reasons may have caused the Internet access problems: (1) too many users logging in simultaneously, or (2) the Internet package used. In addition, S5 felt that performing the long-term experiment was boring. This response may be because conventional science experiments in school are relatively short and student is not familiar with this experimental method. In fact, this is the advantage of the remote experiment, which the students do not need to remain and wait for the experimental results. Finally, S6 also found the installation of the plug-in problematic.

Several suggestions were identified. Three of the students suggested including Chinese translations on the RCL website even though the RCL guidelines were supplemented with Chinese translations and the students received English-mediated instruction in the science class. They recommended developing more remote experiments, particularly those related to biology (S4 and S6). S5 suggested revising the user interface because was unattractive, and S6 added the need to overcome network problems. However, as mentioned the first and second iterations, the network problems were beyond the control of the researcher.

Finally, S5 and S6 claimed that the remote experiments can complement school science experiments, a response that is consistent with the results of the survey. However, S4 preferred conventional school experiments, but added, “I hope the RCL system and school practical work can coexist”. In summary, the problems and suggestions were incorporated into further modification, which is detailed in Section 7.4; in particular, Chinese translation was added to the RCL website.

Table 50
Summary of Students' Insightful Feedback about the Refined RCL in the Interviews

| |
|---|
| **Positive comments:**<br>S4: "It could help us to know more about the technology of science, and then need no to buy the external equipment; you have to know where to access the internet, which is to do the experiment through internet."<br>S5: "Yes, the operation interface is simple, I can understand, and it is quite user-friendly… it is different with the practical work at school. It is something new for me."<br>S6: "Yes, because it is much more convenience, like we have to do for a longer duration time of experiment… the experiment we usually do need to take a lot of time, school cannot be done." |
| **Negative comments:**<br>S4: "I was using the Internet (RCL system) yesterday, which I don't quite understand about it. Yes, maybe it is because of the English, I don't quite understand"<br>S5: "(1) the worksheet which has given to me is in English. Maybe I really understand about it. (2) Also the duration of the experiment is quite long, it is quite boring in the middle, as it has to be waited. (3) Sometimes it cannot be connected, couldn't find the website, and couldn't get access to it."<br>S6: "(1) For the program (RCL), which is the one cannot be opened, because it needs the plug-in. (2) Yes, you might also not be able to access the website when you first try, you have to reload to access." |
| **Suggestions:**<br>S4: "For the internet, I hope the difficult English words could have bracket, to include the Chinese explanation, to let those Chinese and non-Chinese students understand it. Other than that, there could be a slightly more experiments, which are about biology."<br>S5: "The colour of the interface is quite dark, couldn't attract the people to do it. Also it could try to add some Chinese"<br>S6: "(1) I hope there will be Chinese, a Chinese explanation, and then it will be less troublesome. (2) For the server which sometimes cannot access. (3) … more experiments (RCL)" |

*Teacher interview data*: As mentioned, the teacher can provide professional feedback on student performance and attitude according to personal observations in school practical work and the RCL activities (Connecting and Merging data, [Creswell & Plano Clark, 2011]). For ethical purposes, the science teacher was named T4. The interview with the teacher yielded several major points and four related themes, namely, the Hawthorne effect, the RCL approach, self-efficacy, and e-learning.

Hawthorne effect—As mentioned in Section 6.2, the Hawthorne effect can be reduced by asking a question related students' normal practice in science learning and teaching, such as what ICT tools they use in science learning, teaching, and practical work. T4 stated that the ICT tools used for science learning and teaching including a computer, projector, and iPad tablet, as well as a data logger for performing the science experiments. Thus, students are familiar with using ICT tools in science learning, particularly when performing science experiments; therefore, the Hawthorne effect could be reduced when conducting the remote experiments.

RCL approach—The most emphasised opinion by the teacher was the convenience of being able to perform the remote experiments anytime and at anyplace. Furthermore, T4 stated that the RCL system is suitable for use with long-term science experiments, particular those related to biology. For example, T4 mentioned that "we would like to see From 2 students do an experiment on photosynthesis. However, our school will only provide the result of the experiment… [The experiment] requires waiting for two to three days". Overall, the refined RCL system was understandable; however, T4 suggested replicating the remote experiments in several set of RCL system to enable several groups of students to perform the experiments simultaneously. Regarding student sharing and presentation, T4 stated that "they [the students] are willing to share about their own experience and participation". Therefore, these interview data were similar to the data obtained from the student interviews, surveys, and first and second iterations.

However, a problems identified by T4 was related to technical difficulties; for example, "they [the students] have asked me about the problem, but it was about something technical— they could not open the interface, because they needed to use a Google browser". Then, the students solved the problem by using a smartphone equipped with a Google Chrome browser. In other words, the students were interested in the remote experiments, attempted to solve a problem by asking the teacher, and ultimately overcame the problem by themselves. For the suggestion, T4 hoped to monitor the students' log in record. The students will need to be monitored by the teacher if the RCL system is actually adopted by the school.

Self-efficacy—Concerning self-efficacy, T4 felt highly confident about using the RCL system in the classroom because "I don't oppose the things of ICT, and also e-learning". Moreover, T4 added that using the RCL activities can increase student motivation to learn science. However, the RCL interface must be designed according to student ability: “For the junior form, the interface might need to be simpler, like there would be all the icons, and you click one, making it more user-friendly. For the senior form, that would be a different design”.

E-learning—E-learning is an approach used to overcome the difficulties created by the varied ranges of learner ability. T4 added that the learner ability should be taken into consideration: “Education has always emphasised educational diversity, the catering to learning diversity, and I think e-learning is one of the methods that can be used to achieve it, to cater to students from different achievement levels”. Furthermore, the RCL activities are “more beneficial for self-study”, (T4) particularly for students who are interested in science. T4 indicated this strength of the RCL system, saying, “I think it is a good progress as it can stimulate the students with the strengths. They will try to do the experiment when they are at home. I think it is a bit like self-study because there is no teacher to monitor the students, which make me think that for those who are interested in science, they will get more from it”.

## 7.4 Refinements

According to the results and analysis in the third iteration, the refined RCL system was positively received by the participants and the entire system as retained. However, part of the RCL website was refined by adding a dual language format, particularly to enhance the directions for conducting the remote experiments. This revision was in response to the feedback that even though Chinese translation was added to the RCL guidelines, the students indicated in the interviews that more Chinese should be added to the RCL website. The researcher anticipates that the refined RCL system will be accepted by Hong Kong secondary students and will require no further refinement. This refinement is supported by Tannhäuser and Dondi (2011), who suggested developing RCL system in different languages. However, adding the Chinese was not a critical refinement, because it caused a problem for non-Chinese users or Chinese users who want to use an English version.

Therefore, the existing RCL website was retained and another RCL website featuring a combination of Chinese and English was developed (http://rcl.ied.edu.hk:8000/rcl_chi.html), particularly focusing on the LabVIEW interface of the remote experiments (Figure 43).

Figure 43 New RCL Webpage Display with Chinese Translation

However, Windows operating system users must switch the current language for non-Unicode programs to Chinese (Traditional, Hong Kong SAR, Taiwan, or Macau SAR) before logging in to the new RCL website with Chinese translations of certain difficult words.

In effect, this revision caused problems for non-Chinese users or users who wanted to use the English version. When the users did not change the language settings as mentioned, then garbled text was displayed, as shown in Figure 44.

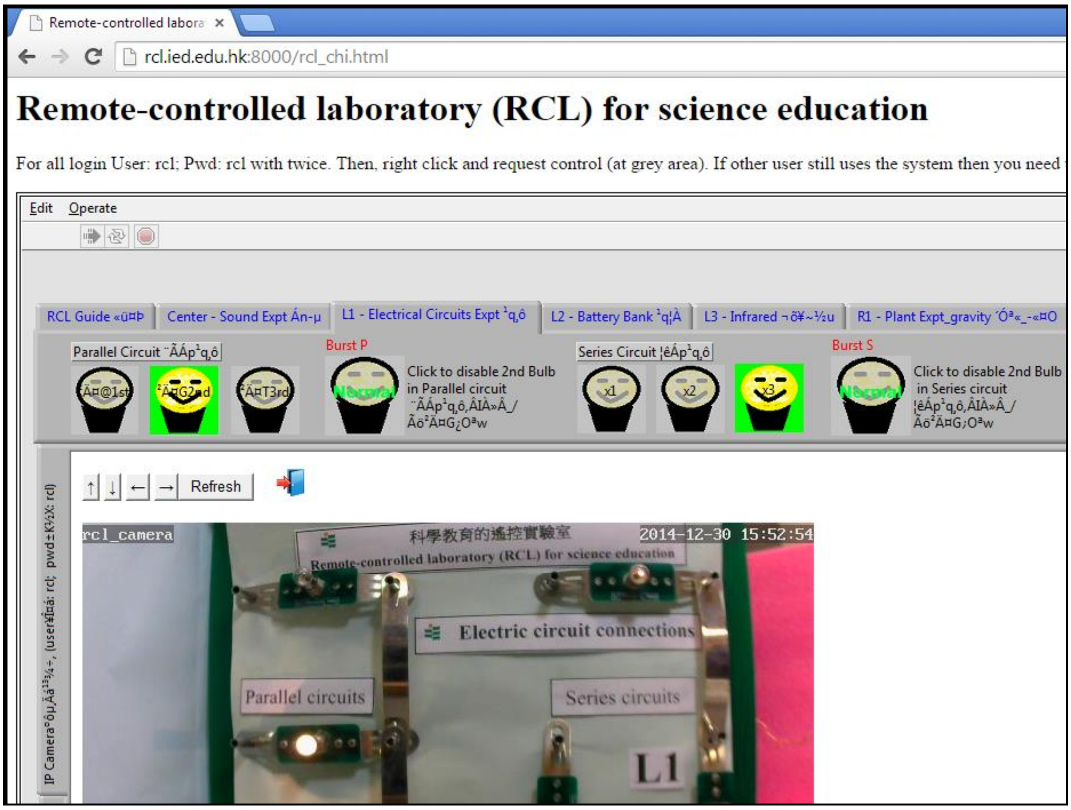


Figure 44 New RCL Webpage Display without Changing the Language Settings

## 7.5 Final System Performance Evaluation

The final performance evaluation of the refined RCL system revealed that the refined system still could be controlled by one user and four observers simultaneously, which was consistent with the system performance evaluation described in Section 5.7. Similarly, the response time experienced by the controller for performing the remote experiments was acceptable.

## 7.6 Implications

The third iteration revealed that the refined RCL system was promising and should be retained. Nevertheless, a new RCL website with Chinese translation was added, particularly for users who wanted Chinese instruction. Again, the results from the third iteration showed that the refined RCL system could potentially promote the use of remote experiments in a secondary school learning environment. According to the findings, analysis, discussion, and minor refinement, three main implications for the refined RCL system were derived.

The first implication is related to the constructivist approach to science teaching and learning. As abovementioned, the construction of knowledge is related to secondary students acquire and construct knowledge by themselves through the RCL system (Abdulwahed & Nagy, 2011; Torre et al., 2013). During RCL implementation, students were required to gather information and performed the remote experiments related to the assigned work and time as they were randomly divided into small groups of five members. Therefore, this direct implication of RCL and constructivist learning is that students' prior knowledge influence how they develop new scientific knowledge and skills through teamwork and the use of this technology. In this study, participants acknowledged the educational potential of RCL in the development of their science knowledge and skills (based on survey, open-ended questions and interview), particularly RCL system had features of long-time observation, real-time controlling and interactive (Cooper & Ferreira, 2009; Scanlon et al., 2004; Tho & Yeung, 2015).

The second implication is related to the educational value of the refined RCL system. The results indicated that the RCL system improved the learning outcomes more than in the second iteration. Furthermore, the remote experiments can be considered complementary to school science laboratory work (Fabregas et al., 2011). After the manner in which the remote experiments were presented was refined, the boys seemed substantially more interested in the RCL system; however, because of the relatively small number of participants in this last iteration, conclusions drawn from this observation are unreliable.

The third implication is related to the language used in the RCL lesson and system. The interview data showed that students suggested English is used with Chinese terms provided for difficult words. The RCL website was refined and a new website was developed in response to this suggestion. However, this refinement was not optimal for overcoming the problem, because it is unsupported by previous studies, which indicated that students' science achievement is negatively affected by using Cantonese in teaching and English in reading and writing for English-mediated science classes (Yip et al., 2003). In addition, this type of practice may reduce the English standards of Hong Kong students (Li, 1998). Therefore, teaching students to change their attitudes (according to teacher interview data in second iteration) by exploring the related science experiment and information by themselves is a more suitable practice to address the language problems encountered. Thus, the existing RCL website was retained for conducting the remote experiments.

## 7.7 Conclusion

This chapter described the third iteration of evaluating the refined RCL system based on the first and second iterations. First, the refined RCL system was effective, according to the analysis and data received; in particular, it enabled more favourable student learning outcomes, as assessed through the conceptual understanding test. In other word, the refined RCL system substantially increased the related conceptual understanding of the secondary students in the third iteration.

Second, several essential outcomes were gathered. The RCL system was positively received when applied in a secondary school, according to survey and interview data obtained. These meaningful data collected from students and a science teacher were triangulated with the results from the conceptual understanding test. Thus, the results from the third iteration were consistent with those of the second iteration and previous studies (Kong et al. 2009; Lowe et al., 2013). Using this RCL system can be considered an effective and innovative approach in a school learning environment.

Finally, science teaching and learning is shifting towards a more student-centred approach, facilitated through the effective use of digital technology, particularly for conducting science experiments. Recent educational reforms have identified the importance of technology-enhanced science learning, which can be achieved in science education by using the RCL system (Lowe et al., 2013). Therefore, the development of RCLs becomes a critical aspect of science practical work; RCLs can also be used as demonstration resources for future teaching and learning, especially for experiments that are impossible to implement in traditional school learning environments.

The Venn diagram in Figure 45 was used to compare and contrast the three iterative cycles of evaluation and refinement to enable readers to understand the overall of these cycles of developments and findings.

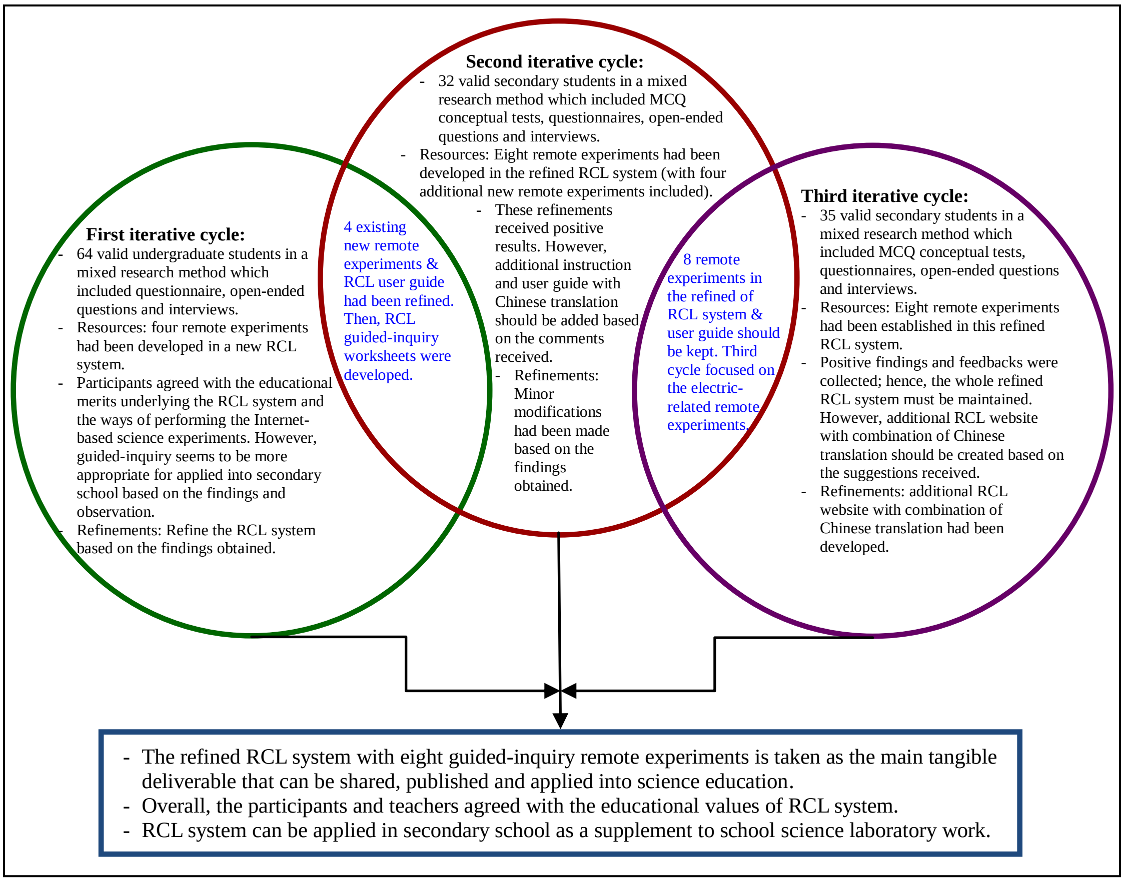



Figure 45 Venn Diagram of Iterative Cycles of Evaluation and Refinement

# CHAPTER 8

# CONCLUSIONS

This chapter first presents the final set of remote-controlled laboratory (RCL) design principles. Then, the research questions are answered and reflections on the entire study are reported. The limitations are indicated, and finally, future research directions and a conclusion are offered.

## 8.1 Final Set of RCL Design Principles

The refined RCL system was successfully developed for application with eight innovative science experiments that can be used both inside and outside the classroom to enhance science learning; the system complements the general practices of science learning and teaching. In other words, the refined RCL system can be shared, published, and applied in science education, particularly at the secondary level. In addition, this system can be used as a learning and teaching tool or resource for laboratory work and demonstrations to enrich and extend science teaching and the learning process.

In addition, this study also improved upon RCL design principles. Four RCL design principles were developed, as mentioned in Chapter 4. According to the three iterative cycles of evaluation, two additional RCL design principles were considered crucial to the development of a novel RCL system for science education, namely, collaboration in learning and RCL instruction. For collaboration in learning, the RCL system must incorporate a synchronous chat and messaging function that can promote student teamwork (Cooper & Ferreira, 2009). For RCL instruction, the RCL system must have clear RCL operating guidelines and worksheets to enhance the understanding of the remote experiments (Kirschner et al., 2006; Tiwari, & Singh, 2011).

Thus, the final set of RCL design principles can also be adopted and shared for future remote laboratories developed for use in secondary education. In other words, these design principles cannot be generalised, because the “generalization of design-based research is rather limited” (Herrington et al., 2007, p. 4095); however, these principles can have a developmental reference. These design principles can be categorised into six domains or aspects of consideration: (a) integration with science education curriculum, (b) interactive learning, (c) learner engagement, (d) a wide-range of learner ability, (e) collaboration in learning, and (f) RCL instruction.

Table 51 shows the final set of RCL design principles and its pedagogical values, a reference for science teachers/educators/researcher/policy maker who aim to develop RCL system for use in secondary science education. The description of these design principles is based on the three iterative cycle results and the literature review. In addition, suggestions for the future consideration of each principle have been added and arranged according to importance.

Table 51
Final Set of RCL Design Principles

| **Design Principle** | **Description of the principle** |
|---|---|
| Integration with the science education curriculum | The Hong Kong science education (or any subjects) curriculum (CDC, 2002) is a well-organised and updated guiding document that including the related knowledge, skills and attitudes for learning. In this study, the new RCL system is developed and refined based on the related science curriculum.<br><br>In future, developing new learning activities or approaches that connected RCL are encouraged to integrate with the suggestions in the curriculum for achieving the learning goals. |
| RCL instruction | Instruction manual is known as the essential information that directs the users or learners on how to use certain software or device particularly for introducing a new system, a clear operating instruction is definitely needed. In this study, the RCL system must provide a clearer RCL operating guidelines and worksheets for better understanding of the remote experiments. |

| | |
|---|---|
| | In addition, certain English words with Chinese translation in bracket are provided in related guideline and worksheets.<br><br>In future, it is important to create an awareness of teachers and students to the essential of web security and software plug-in as well as additional step (i.e. request for control) before they want to use any special designed educational software in the Internet through the guideline and operating manual. |
| Interactive learning | "Interaction is an essential ingredient of any learning environment" (Woo & Reeves, 2007, p. 15). This interaction between the learner with their group members and science experiment can be also performed via the Internet (i.e. simulation or remote experiments). Therefore, this interaction is essential element of the social constructivist. In this study, the RCL activities are interactive and real-time experiments. Student can perform and repeat the real-time remote experiments via the Internet at anytime and anyplace. The learner can interact with their group members and remote experiments through the Internet and perform the real-time with longer science experiments at anytime and anyplace which is difficult in their normal school practical work.<br><br>In future, the field trip can be organised to visit the remote experimental venue and server. Student can observe the technology used and acquire the extension knowledge how the RCL system being developed. |
| Learner engagement | Leaner engagement known as the learner actively participates in the learning activities to "describe, interpret and explained concepts" (Buncick, Betts, & Horgan, 2001, p. 1238). In this study, the RCL activities are able to engage the learner actively participate in technology-enhanced inquiry with motivation. Student can conduct remote experiments, analyse and interpret experimental results and present their findings with others. The |

| | |
|---|---|
| | presentation of the findings is important evidence to show their engagement in the remote laboratory activities. Again, this RCL approach can provide the constructivist learning.<br><br>In future, the student monitoring system that can be integrated with this RCL system should be added to record their log-in information. |
| Wide-range of learner ability | Developing new learning activities or approaches via the Internet are encouraged to ensure it can help wide-range of learner ability. In this study, the RCL activities are appropriate for wide range of learner ability and it is available at any time as well as anywhere. Therefore, learner can acquire the knowledge and perform the remote experiments based on their convenience time.<br><br>In future, different levels of online quizzes that can be integrated with this RCL system should be created to check their understanding. |
| Collaboration in learning | Teamwork in science practical work is normally practiced for helping each other to achieve certain learning goals. In this study, the RCL system must also provide collaboration in learning. Then, it come together with any synchronous chat and messaging functions that can promote students' teamwork. Through this function, leaner can collaborate with their group members in their free time at convenience place via the use of chat box in the RCL website.<br><br>In future, the improvement to attract the student actively participate and collaborate should be considered via the use of reward system (i.e. token will be given to most active group). |

## 8.2 Publications and Conference Presentations

In this study, research outputs in the form of journal articles and conference presentations were produced. Research output is an essential element in data-based research (DBR) or any research in which the researchers must regularly present and publish findings at conferences and in journals. Thus, journal articles and conference proceedings, including articles under review, as well as conference presentations, are listed as follows:

*Journal Articles, Conference Proceeding and Newsletter*

Tho, S. W., & Yeung, Y. Y. (2014). Remote laboratory (RL) system for technology-enhanced science learning: The design and pilot implementation in undergraduate courses. *Proceedings of the 22nd International Conference on Computers in Education, ICCE 2014*, 260-262.

Tho, S. W., & Yeung, Y. Y. (2015). Innovative IP camera applications for scientific investigation. *School Science Review, 96*(356), 58-62.

Tho, S. W., Yeung, Y. Y., So, W. M., & Lee, Y. C. (2015). Remote-controlled Laboratory for Science Education. *The Newsletter of The East-Asian Association for Science Education, 8-10*. Retrieved from http://new.theease.org/read.php?bdid=2&page=1&msid=210&st=

Tho, S. W., & Yeung, Y. Y. (2014). Technology-enhanced science learning through remote laboratory: System design and pilot implementation in tertiary education. *Australasian Journal of Educational Technology* (Published 2016 – doi: 10.14742/ajet.2203).

Tho, S. W., Yeung, Y. Y., Wei, R., Chan, K. W., & So, W. M. (2014). A systematic review of remote laboratory work in science education with the support of visualizing its structure through the *HistCite* and *Citespace* software. *International Journal of Science and Mathematics Education* (Published 2017 - doi: 10.1007/s10763-016-9740-z).

Tho, S. W., & Yeung, Y. Y. (2018). An implementation of remote laboratory for secondary science education. *Journal of Computer Assisted Learning* (Accepted 2018 – doi: 10.1111/jcal.12273)

*Conference Presentations*

Tho, S. W. (2014). The effectiveness of remote-controlled laboratory. Poster presented in the *East-Asian Association for Science Education Winter School 2014*, Ewha Womans University, Seoul, Korea, January 12 – 18, 2014.

Tho, S. W. (2014). Remote laboratory for science education: An innovative use of IP camera for monitoring science experiments. Paper presented in the *International Postgraduate Research Conference and Summer School (IPRCSS) 2014.* The Hong Kong Institute of Education, Hong Kong, China, July 4 – 5, 2014.

Tho, S. W., Yeung, Y. Y., So, W. M., Wei, R., & Chan, K. W. (2014). A systematic review of laboratory work in science education by visualizing its history with *HistCite* and *Citespace* software. Paper presented in the *Asia Pacific Educational Research Association International Conference 2014,* The Hong Kong Institute of Education, Hong Kong, China, November 19 – 21, 2014.

## 8.3 Responses to Research Questions

To guide the reader, findings or assertions that were used to answer the research questions are written in **boldface** type. Discussions are provided in normal font.

### 8.3.1 Response to Research Question 1

1. What forms of novel RCL system incorporating guided inquiry can be developed to enhance science education?

*1.1 What feasible guided-inquiry experiments can be incorporated into the RCL system?*

Eight remote experiments in the refined RCL system, together with Internet protocol (IP) cameras and a teachers' guide and users' guide, were successfully developed (Appendices F and G). **These innovative experiments feature long-term observation and are repeatable anytime and anywhere; they pertain to topics**

**from different science disciplines, including physics and biology.** First, four feasible remote experiments were developed (Appendix A), and an initial iteration of evaluation was conducted in a tertiary teacher education institution to obtain comments and suggestions from practitioners who have received related teacher education training and web technology courses. According to the participants' comments and suggestions, the system was refined, and four more remote experiments were developed. A total of eight remote experiments were readied for use and evaluation in a secondary school through second and third iterations. The remote experiments pertained to the topics of sound, electric circuits, battery bank, solar energy, infrared (IR) application, *phototropism*, day and night-time *gravitropism*, and plant respiration.

*1.2 How can the RCL system be implemented in a school environment for use by students inside and outside of the classroom?*

One of the vital requirements for successful implementation of RCL system is about the pedagogy, or how learning takes place online via RCL system. In practice, however, this is usually the forgotten part in any effort to implement RCL. Here, the RCL efforts are focused on student-centred learning, scientific investigation, collaborative learning, informal science learning, e-learning and constructivist learning because it is remarkable that the RCL system could make science learning and teaching more resourceful, meaningful and practice-oriented, for instance, it can motivate and foster secondary students to actively participate in the process of science learning. **With proper systematic arrangement, the novel refined RCL can be implemented in the school environment.** After the first iteration, the refined RCL system was readied for implementation in a secondary school. The reliability and robustness of this system was verified to ensure that even careless students cannot destroy it. The access rights were subsequently managed and monitored to facilitate the sharing of the remote experiments from the teacher education institution to various secondary schools (Abdulwahed & Nagy, 2011; Leleve et al., 2003). Additionally, the RCL system is space efficient, involving eight remote experiments. Therefore, students can perform the remote experiments at their convenience anywhere with Internet access. However, students and science teachers (i.e. professional development efforts) must receive appropriate RCL instructions before using the unfamiliar RCL system to prepare science teachers, particularly in implementing technology-enhanced and learner-centred learning.

*1.3 What are the major problems encountered in the system development process and in the implementation stage? How can such problems be resolved?*

Before RCL system development, the researcher attended a series of workshops and performed a systematic review of RCL-related literature. **According to the literature, few studies investigated RCL application in secondary education.** Therefore, few examples of RCL research studies in school learning environment could be referenced. However, previous studies on developing and evaluating related technology-enhanced learning, namely, developing an open source data logger for a microcomputer-based laboratory (Tho & Hussain, 2011), developing innovative science experiments for smartphones (Tho & Yeung, 2013, 2014a; Zhang et al., 2014), and evaluating a technology-enhanced physics programme for community-based science learning (Chan et al., 2014; Tho et al., 2013; Tho et al., 2015), formed a foundation on which to develop a novel RCL system for secondary school science education.

Because the primary researcher was not a Hong Kong permanent resident, **another major problem encountered was finding a secondary school for RCL system implementation.** Fortunately, two local postgraduate students helped solve this problem by introducing secondary school principals for further discussion of RCL system implementation. The principals agreed and signed a school consent form for participation in evaluating the refined RCL system during the second and third iterations.

### 8.3.2 Response to Research Question 2

2. How can the RCL system be designed to influence student learning effectiveness in a guided-inquiry learning environment?

*2.1 What science learning outcomes did using the developed RCL system produce (in terms of student conceptual understanding and perception)?*

First, **the findings can be inferred from the effects on student conceptual understanding in the second and third iterations of evaluation**. Indeed, the pre-test and post-test (multiple choice question [MCQ] conceptual understanding test) were used to assess participant understanding of the related science principles in the second and third iterations (Kong et al., 2009; Nickerson et al., 2007). However, no achievement test was used in the first iteration because the undergraduate students' cognitive understanding of the related science concepts was not suitable.

Therefore, the secondary student learning outcomes revealed by the conceptual understanding test corresponded to the plant-related experiments (biology) and electricity-related experiments (physics). In the second iteration, the paired samples *t* test was used to examine the mean scores of the pre-test and post-test, and the independent samples *t* test was used for analysing the gender difference. The results indicated significant differences in the scores; the mean post-test scores were higher than the mean pre-test scores in both the plant-related experiments (biology) and electricity-related experiments (physics). The students had a more advanced understanding of the related science topics. However, there was no significant gender difference in the results of the conceptual understanding test.

For the third iteration, the paired samples *t* test was used to examine the mean scores of the pre-test and post-test in the third iterative cycle and the independent samples *t* test was used to assess the gender difference; the analysis of covariance (ANCOVA) test was also used for comparing the conceptual understanding test results from the second and third iterations, particular those pertaining to the electricity-related experiments. The results of the paired samples *t* test revealed that the scores differed significantly; the mean post-test scores were higher than the mean pre-test scores in the electricity-related experiments (physics). Moreover, the results indicated that after controlling for initial ability of participants, the differences in the post-test scores of third iteration were significantly higher than those of the second iteration; therefore, the novel RCL system is effective and the refinements were an improvement. Then, the boys scored significantly higher than did the girls on the related conceptual understanding test, as determined by the independent samples *t* test. Thus, the boys were predicted to be more interested the remote experiments after the refinement in the second iteration.

Second, **the findings can be inferred from the survey results in the second and third iterations.** In the second iteration, the secondary students differed significantly in term of personal interest in science and science practices according to the paired samples *t* test on the pre-survey and post-survey results. Thus, student attitudes and science practices were affected positively after using the guided-inquiry remote experiments. In the third iteration, the students showed significant difference in the science practices, indicating that their science practices were also positively affected after using the guided inquiry remote experiments. According to the results of the second and third iterations, more than half of the students want to conduct more remote experiments if they have the free. This means that the students feel positively towards science learning incorporating the RCL system.

*2.2 What are the strengths and weaknesses of the RCL system in the real school environment?*

**Based on the results and literature review, several strengths and weaknesses of the RCL system in the real school environment were identified.** Numerous positive comments about the strengths of novel RCL system were received through the open-ended questions and interviews. The most common comments received pertained to the ability to use the system anyplace and anytime. According to the implementation, the RCL system can be used to conduct long-term experiments that cannot be performed in a school laboratory. The students were amazed at how a real-time remote experiment can be conducted through the Internet. In the interviews, the teachers expressed interest in the RCL system, and they added that it can facilitate practicing the e-learning concept currently stressed by the Education Bureau (EdB; 2009).

However, several weaknesses of RCL system were identified. First, the plug-in installation and the initial steps before performing the remote experiments were difficult to follow. Second, the students could not conduct the remote experiments simultaneously because the system can only support a limited number of users. Currently, only one RCL system is used for seven remote experiments; another RCL system was developed for controlling the solar energy experiment. Third, the maintenance for the RCL system was fairly problematic. For example of the plant experiments, the researcher or laboratory assistant had to care for the plants, providing water and sunlight. For the solar energy experiment, the researcher or laboratory assistant needed to check the wire regularly because the entire system was located outdoors.

### 2.3 *What are the major problems encountered in implementing the RCL system in classrooms? How can such problems be resolved?*

The major problems in implementing the RCL system in real classrooms can be divided into two aspects, namely, **(a) informing students about the importance of web security and the plug-in installation, and (b) encouraging student participation.**

First, it is challenging to inform students about the importance of web security (Leleve et al., 2003) and installation of the related RCL plug-in. According to the findings of the second iteration, the students and teacher felt the installation and initial steps before using the RCL system was complex. To resolve this problem, an instruction manual with a Chinese translation of difficult words was developed and included directions on how to install the LabVIEW runtime engine (plug-in) and how to run the remote experiments.

The second problem is related to student participation. In fact, engaging active student participation after school hours is difficult. This task was more challenging because the researcher was not their teacher; therefore, the school science teacher played a pivotal role in guiding and tracking student participation. In the second iteration, the teacher indicated two critical factors affecting the difficulty of implementing the RCL in a school environment. First, the RCL system is complex. Second, the students are too dependent on an exam-oriented system. T3 stated that teachers nowadays need to prepare a lot of work to “feed” to the students, which may cause problems in attitudes towards science. Therefore, creating awareness of student responsibility to explore and investigate scientific knowledge is essential; exploring and investigating is equally crucial for receiving scientific information in class to achieve higher marks on examinations.

In the third iteration, T4 also noticed that monitoring student activities is essential because students require monitoring, possibly because of their attitudes. For example, they may ask why they need to do extra work that is unrelated to exams. Some students may take advantage when not monitored and perform the task given. Therefore, student monitoring system that can be integrated with the RCL system should be added to record log-in information. In addition, rewards also can be given for those who achieve a certain grade or level; these rewards may encourage students to participate in the given task.

*2.4 How can the teacher and student opinions be used to improve the RCL system in the school environment?*

**Overall, most participants in the three iterations commented favourably and unfavourably and they presented essential suggestions for further refinement of the RCL system.** In the first iteration, the undergraduate students provided a number of essential comments and suggestions that were useful for further developing new remote experiments appropriate for use in a secondary school. Thus, the main purpose of the first iteration was to determine the perception of participants and gather meaningful comments and suggestions for refinement.

The main purpose of the second iteration was to evaluate the refined RCL system in a secondary school learning environment and improve the system if necessary. The students and teacher provided common and expected comments. The feedback indicated that the refined RCL system positively affected the conceptual understanding and science-related attitudes of the students. However, two minor modifications were performed according to the results obtained.

In the third iteration, the refined RCL system with minor modification was evaluated again in a different secondary school. According to the data analysis, the refined RCL system is effective and the entire system must be retained. However, an additional RCL website with Chinese translation was developed on the basis of suggestions received.

### 8.3.3 Response to Research Question 3

3. What are the educational implications of the research findings for future RCL implementation?

The findings of this study reveal that the RCL system has potential as a complement to school science laboratory work. Therefore, the educational implications of this study can be divided into four major parts: (a) promoting e-learning through the use of the RCL system, (b) applying it in other levels or subjects, (c) applying and developing it in other countries, and (d) developing new technological innovation by using the DBR method.

**Promoting e-learning through the use of the RCL system**—In general, e-learning is related to online courses through learning management system for documentation, administration, student management and online lesson with assessment function via tests and discussions (Govindasamy, 2001; Lee & Lee, 2008; Moore, Dickson-Deane, & Galyen, 2011). Besides that, e-learning is essential to facilitate and supplement regular classroom learning and teaching particularly in the paperless and self-learning aspect (EdB, 2009, 2014). However, it is seldom that students learned and used the e-learning to perform real-time applications especially doing real-time science experiments. In this study, this RCL system can potentially be integrated with existing e-learning methods (i.e., massive open online courses and mobile learning), which are essential in distance education. Using this approach may improve student motivation as well as e-learning practices and usability. In science education, science educators and teachers can use the RCL system as an e-learning tool; for instance, they may use the RCL system to address problems related to low science motivation and can engage their students in science learning, particularly by conducting science experiments that are dangerous or require longer periods. In addition, professional development for applying this RCL system into classroom practice may be required because the RCL system is new to science teachers and part of the system requires plug-in installation.

**Applying it in other levels or subjects**—The application of this RCL system can be expanded in the science learning and teaching for other levels of education, such as primary school or even kindergarten. However, the system should be carefully developed for use in such levels (i.e., the interface must be attractive and easy to use). Moreover, the system application can be expanded into the other secondary-level subjects, such as Information Technology (IT) subject, to teach students how to use and develop remote technology; in geography classes, students can remotely observe and change parameters for observing the natural environment after they initially visit a location.

**Applying and developing the RCL system in other countries or areas**—For other countries, this RCL system can act as a network or collaboration tool for performing remote experiments in different locations and conditions; for example, another solar remote experiment can be developed in Malaysia or Australia and then Hong Kong secondary students can perform three remote experiments simultaneously to observe the power generated by solar panels that is affected by the position of the sun and the weather conditions. For other areas, schools in rural areas may lack resources or facilities (Gulati, 2008; Panizzon, 2012; Truscott & Truscott, 2005); for example, students may not have the chance to conduct science experiments or travel far distances. Therefore, this system may enable these students to explore science experiments and state-of-the-art technology.

**Developing new technological innovation by using the DBR method**—Finally, the DBR method appears to be appropriate for designing technological innovations for use in school learning environments (Amiel & Reeves, 2008; Kong et al., 2009; Nelson et al., 2005), such as the novel RCL system for secondary science education (Lowe et al., 2013; Tho & Yeung, 2014c). This paper discusses practitioners' contributions in the form of valuable ideas and suggestions for developing and refining the RCL system. Therefore, this study may be a reference for researchers who want to use the DBR method.

## 8.4 Limitations and Delimitations of the Study

### 8.4.1 Limitations of the Study

Limitations of the study can be divided into four parts: (a) budget and system limitations, (b) sample limitations, (c) observation limitations, and (d) time limitations.

Because of budget and system limitation as well as the high cost of hardware and proprietary software, only one RCL system with seven remote experiments and another solar remote experiment were developed. Additionally, the LabVIEW runtime engine lacks a support or plugin for mobile devices, particularly when using the Web Publishing Tool function of the LabVIEW software. Therefore, applying and evaluating the RCL system using a large scale sample was difficult. Similar to previous studies mentioned in the literature review, RCL-related studies have normally involved small scale samples. Hence, this factor caused the following limitation.

An experimental group only (without a control group) was included because testing and improving the RCL system was the primary focus. Moreover, the samples were limited to two classes in a tertiary teacher institution in the first iteration and two classes of secondary school students, one in each of the second and third iterations. However, participants in the first cycle were undergraduate students instead of secondary school students and therefore their background, knowledge, skills and attitudes would be substantially different. Consequently, it is difficult to generalise the findings of this studies to other large contexts because of the small scale sample (Creswell, 2009). However, the findings from these three iterations of evaluation revealed educational values for policy makers and science teachers, educators, and researchers who are involved in developing RCL system in future studies.

Regarding video recordings, the recordings in this study were limited to capturing student RCL activities or work in the classroom only. Videos of students performing the remote experiments at home were unobtainable. Therefore, a visitor counter was applied for counting the student log-in activities. This technique is not ideal for recording student activities because of the limited log-in information. Recommendations for future studies regarding this technique are offered in Section 8.5.

Finally, the findings may have been affected by the Hawthorne effect, caused by the novelty of the approach and short duration of implementation. Therefore, this effect can be assessed by conducting a longitudinal study to track the effectiveness of the approach on the same sample over a period of time using different RCL activities.

### 8.4.2 Delimitations of the Study

The scope of the hardware used in the research was delimited to the use of NI products, LabVIEW software, and IP cameras. Additionally, the findings and refinements focused only on the eight developed remote experiments included in the refined RCL system. Hence, other potential remote experiments were excluded in this study.

## 8.5 Recommendations for Future Studies

The educational software and hardware developed in this study enables conducting eight remote experiments pertaining to different science topics. However, because of budget and time limitations, many features and improvements remain for future investigation. Several suggestions are provided as follows:

**Develop an economical RCL system**—The main hardware used in this study was purchased from NI, and the price was relatively high. Hence, using local or other brands of remote products could lower the price of hardware. For instance, a researcher from the Internet School Experimental System (Schauer, Lustig, Dvořák, & Ožvoldová, 2008) were contacted and other open-source platforms for remote techniques (i.e., Arduino and LabVNC) were reviewed for future plans. In future studies, other platforms can be used as a viable alternative to the expensive and proprietary nature of NI hardware and LabVIEW software. In addition, the installation step can be performed easily and more experimental apparatus and interesting remote experiments can be purchased and developed (as suggested by the participants in the three iterative cycles). In other words, the remote experiments can be expanded to other types, such as environmental-related remote experiments (i.e., solar energy experiment) and dangerous experiments (i.e., involving heat and explosions).

**Allocate the novel RCL system to various locations**—Now that the innovative RCL system has been developed, it can be duplicated and located in other regions or areas, particularly to facilitate environmental-related remote experiments (Lang et al., 2007). For example, the solar remote experiment can be performed by incorporating other regions or countries, enabling students to simultaneously observe how the power of the solar panel is affected by the position of the sun and the weather.

**Improve the RCL software by providing more features**—Currently, the RCL system has the basic features required to assist learners using the system. However, unique features can be integrated into the system to enhance the learning aspect, interest, and user-friendliness. Some suggestions are provided as follows:

(a) **Integrated pre-test functions**—A pre-test function in the program could assess student understanding; they would need to achieve a certain grade before they could proceed to perform the remote experiments. With this function, learners with basic knowledge and skills can perform remote experiments according to their own pace.

(b) **Sharing, discussion, and reflection forum**—Integrating the system with certain existing web application, such as wiki, would be beneficial. With this additional function, students and their group members can share and edit related search information, work, and reflections through wiki sites (Chu, 2008; Lai & Ng, 2011; Ng & Lai, 2012).

(c) **Game features**—Adding related educational game features would enable learners to become more engaged. While they are waiting for long-term remote experiments, the learners could play the educational games. However, the programmers and designers must avoid adding too many game features that may distract the learners' concentration and thus, hinder the educational goals (Hung, 2011).

(d) **Student monitoring system**—A monitoring system can be integrated with the RCL system to record student log-in information (Kong et al., 2009; Tannhäuser & Dondi, 2011, 2012). Using appropriate username and password arrangement, the learners can register a personal account in the monitoring system. The log-in data and important information must include information such as the location (determined according to the IP address) time, date, and duration for performing the remote experiments, as well as which remote experiment they conducted.

**Perform a large scale study over a longer time to evaluate the effectiveness of the RCL System**—This study applied the mixed method, revealing the importance of and further refinements required for the RCL system in three iterations. However, it was a small scale study. Therefore, a large-scale quasi-experimental study with control group and a longer duration should be performed using mixed methods. Such a study can be generalised to a larger population, resolve the Hawthorne effect, and obtain more meaningful data to verify the effectiveness using the RCL system over the Internet for teaching and learning. In addition, this study can be performed in collaboration with researchers in other countries to evaluate the RCL system and maximise its usability and impact in science education.

**Integrate with engineering practices**—Part of the student evaluation was focused on their science practices, assessed using a survey in the second and third iterations. Integrating science and engineering practices while developing RCL activities and evaluation should be considered in future studies.

In conclusion, the researcher does not need to be the programmer or developer in the future study (Herrington et al., 2007). Some of the research funding can be applied to support the innovative ideas mentioned. Thus, RCL system improvement that is difficult or beyond the researcher's ability can be outsourced to a third party to facilitate actualising innovative ideas.

## 8.6 Reflections

As practitioners and researchers in RCL research and development, the researchers noticed that the development of this novel RCL system was a complex process; the researchers needed to develop a reliable RCL system for science education and evaluate it using various types of research instrument, thereby determining the students' conceptual understanding (second and third iterations), perceptions, and attitudes towards the RCL learning and teaching processes.

Fortunately, most of the participants in the three iterative cycles could identify both favourable and unfavourable aspects of the novel RCL system. On the favourable side, the undergraduate participants acknowledged the educational value of the RCL system and felt confident to use it in their future learning and teaching. In the second and third iterations, the refined RCL system improved student conceptual understanding and attitudes towards science learning, particularly in the science practices. The related science teachers also felt confident to use the RCL system in their teaching. Therefore, these findings are encouraging, because the RCL system is not just promoting innovative remote experiments, but also enables exploring learning, perceptions, and future teaching experiences (for both undergraduate students and science teachers), particularly in laboratory work.

By contrast, the unfavourable comments from the undergraduate participants (i.e., Internet, setup, and visual problems) drove the researcher to refine the RCL system and design activities that are closely related to the secondary science curriculum. Several negative comments from the secondary school participants and teachers (i.e., the Internet problem [Gillet et al., 2005], Chinese translations for difficult English words, complexity of installation and initial step before performing the remote experiment) also motivated the further refinement of the RCL system, especially in the operating and guiding RCL activities. The negative comments were expected because some participants were not interested in using information and communication technology (ICT) for learning; the laboratory work incorporating the RCL system was new and challenging; and only a short time was allocated to complete the required activities during the laboratory session in first iteration.

Several helpful suggestions were obtained from the iterations, such as the use of a high resolution camera (especially in the first iteration), more user guidelines, the design of dangerous or uncomfortable experiments, and Chinese translations for difficult English words (particularly in the second and third iterations). The collection and analysis of these valuable comments and suggestions was one of the major purposes of piloting the RCL research in a tertiary teacher education institution and implementing it in two secondary schools. All participants facilitated future large-scale implementation of the refined RCL system in more secondary schools.

Finally, prior experiences of science and physics learning; teaching, research, and development of mobile learning activities for science experiments; developing and evaluating physics programmes for an amusement park at *The Hong Kong Institute of Education* (HKIEd) (Appendix M2); developing open-source MBL activities at the

*Universiti Pendidikan Sultan Idris* (UPSI) enabled developing the innovative remote experiments in the current study. These studies are crucial to enhance the future teaching and research when returning to the workplace. In the future, the researcher will continue researching related technology-enhanced science learning and other related science education topics, as well as network with supervisors and other researchers met during the doctoral study.

## 8.7 Conclusion

In conclusion, developing and evaluating the effective RCL system was challenging. The refined RCL system featuring eight guided-inquiry remote experiments is taken as the main tangible deliverable that can be shared, published, and applied in science education, particularly in secondary schools. The results revealed that the refined RCL system enabled achieving the learning outcomes by assisting the secondary school participants in developing their understanding. Overall, the survey questionnaires showed positive feedback from all participants. According to the open-ended questions and the interviews, some recommendations for improving the weaknesses and some suggestions from the participants were obtained and the RCL system was refined. Thus, “satisfactory outcomes have been reached by all concerned” (Reeves, 2006, p. 59). The developed RCL system can potentially be used for laboratory work and demonstrations or as teaching resources for enriching and extending science teaching and learning. For developing this RCL system, a set of design principles was adopted and can be shared to facilitate future laboratory work development in secondary school. The RCL design principles can be categorised into the six domains or aspects of (a) integration with the science education curriculum, (b) RCL instruction, (c) interactive learning, (d) learner engagement, (e) wide-range of learner ability, and (f) collaboration in learning.

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## Appendix A: Four New RCL Inquiry Worksheets

**Student worksheet:**
**The closed, parallel and series electrical circuit connections**

**What is the remote-controlled laboratory?**

Remote-controlled laboratory is a real-time experiment that can be controlled or monitored by user from their computer through the Internet browser. It is also known as the Web-Based Laboratory.

The RCL system is commonly divided into two major parts, namely, hardware and software. The hardware part consists of the data acquisition system, digital input or output (DIO), camera, and various types of sensors. The software part executes data logging as well as controls and displays the real-time experiment on the computer screen via the Internet.

Thus, the RCL activity enables more flexible delivery (anytime), distance education (anyplace) and new visualization possibilities (interactivity).

**Background:**

Electricity plays a vital role in our daily life, such as light, computer, mobile devices, refrigerator or even air-conditioner. Basically, it needs to complete an electric circuit for activating the electrical devices. The electric circuit is a path connected by wire for the flow of electrons. Therefore, an electric source is needed for the movement of electrons like a battery or other power source. These movements of the electron will make the device work. Normally, a switch is attached to the devices for turning 'ON' or 'OFF' process. In this activity, a battery, wire and a bulb are needed for the basic circuit connection to light up a bulb. To complete a circuit, you need to make a connection from positive terminal of battery to positive terminal of a bulb and from negative terminal of the bulb to negative terminal of the battery.

With additional bulbs connected to a battery, you can get another two types of circuit connections called as series and parallel circuits' connection. In a series circuit connection, all the devices are connected from one to the others. If you put more bulbs into a series circuit, the bulbs will be dimmer than before. In a series circuit connection, all the devices are connected from one to the others (see Figure 1). If you put more bulbs into a series circuit, the bulbs will become dimmer. In a parallel circuit connection, all the devices are connected in parallel (see Figure 2). If you put more bulbs into a parallel circuit, the bulbs will keep the same brightness.

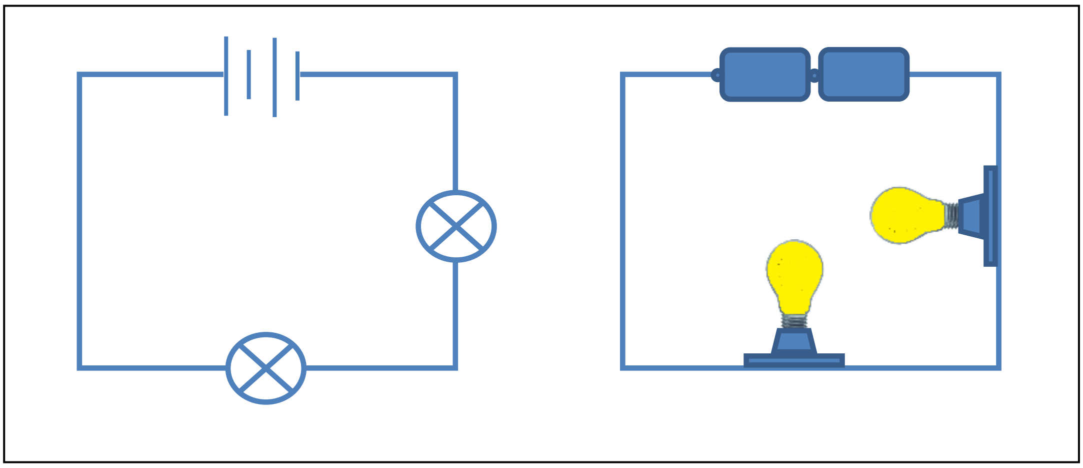


**Figure 1.** Series Circuit Connection

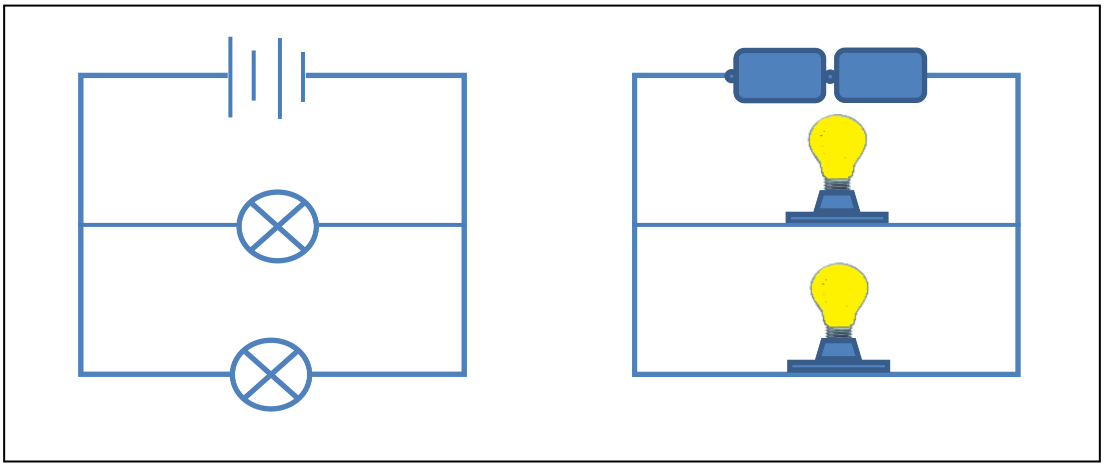


**Figure 2.** Parallel Circuit Connection

**Basic Facts and Supplemental Information:**

1. Electricity is generated by the flow of electrons.
2. There are two types of current: direct current (DC) and alternating current (AC).
3. In DC, electrons move in a single direction
4. In AC, the electrons change directions, switching between backwards and forwards.
5. The electricity use at home is AC but DC comes from all forms of batteries.
6. Two types of circuit connections called as series (Figure 1) and parallel (Figure 2) circuits' connection.
7. In parallel circuits, the bulbs will keep same brightness.
8. In series circuit, the bulbs will be dimmer with additional of bulbs.

**Student will need:**

1. Computer
2. Internet
3. RCL User Manual

**What to do:**

1. To plan and investigate the influence of simple changes in electrical components on different types of circuits using inquiry plan
2. To learn and conduct the remote-controlled experiment
3. To present their findings through the experimental report and oral presentation

**Electrical circuit connections: Inquiry Plan***

I wonder (my question is) ______________________________________________

I predict (my hypothesis is) ______________________________________________

The manipulated variable is ______________________________________________

The responding variable is ______________________________________________

The controlled variables are ______________________________________________

The steps I follow are (The procedures are)

i. ______________________________________________

ii. ______________________________________________

iii. ______________________________________________

The observations I made are (The data are)

______________________________________

The patterns or relationships I found are (The data are organized on a chart or graph)

______________________________________________________

The answer to my question (my conclusion) is

___________________________________

**電路：探究計畫***

我想知道（我的問題是）______________________________________________

我預測（我的假設是)______________________________________________

操縱變數是______________________________________________

反應變數是______________________________________________

控制變數是______________________________________________

我的步驟（程式）

i. ______________________________________________

ii. ______________________________________________

______________________________________________

我所做的觀察（我的資料是）______________________________________________

我發現/找到的模式或關係（圖表或圖形上的資料）________________________

我的答案是（我的結論是）______________________________________________

*This inquiry plan is adapted from Llewellyn (2007).

**Student worksheet:**
**The Fun with Plant Growth due to Light Stimuli**

**What is the remote-controlled laboratory?**
Remote-controlled laboratory is a real-time experiment that can be controlled or monitored by user from their computer through the Internet browser. It is also known as the Web-Based Laboratory.

The RCL system is commonly divided into two major parts, namely, hardware and software. The hardware part consists of the data acquisition system, digital input or output (DIO), camera, and various types of sensors. The software part executes data logging as well as controls and displays the real-time experiment on the computer screen via the Internet.

Thus, the RCL activity enables more flexible delivery (anytime), distance education (anyplace) and new visualization possibilities (interactivity).

**Background:**
Tropism is a growth response between a plant and an external stimulus. The stimulus could be the weather, touch, time, gravity or light. A positive response is indicated by growth toward a stimulus and a negative response is indicated by growth away from the stimulus.

Light is a stimulus that plants respond to. This is called *phototropism* (photo= light). Plants usually display a positive phototropic response to light, which means they grow toward a light source. Plant hormones called auxins play a part in *phototropism*. Auxin is a plant growth hormone. When light is shined on one side of a plant the auxins move to the dark side of the plant. The hormones stimulate the cells on the dark side of the plant to elongate, while the cells on the light side of the plant remain the same. This elongation on one side and staying the same on the other causes the plant to bend in the direction of the light. This bending allows more light to reach more cells on the plant that are responsible for conducting photosynthesis.

**Basic Facts and Supplemental Information:**
- When school plants are placed near windows they should be turned occasionally to prevent one-sided growth.
- The tendency of plants to grow towards light is called "phototropism".
- When moths are attracted to light, this too, is called "phototropism".
- Light is essential to plants.
- Plants use light in the process of photosynthesis.
- The word "photosynthesis means putting together by light.
- Plants take carbon dioxide and water in the presence of sunlight make glucose a simple sugar.
- Plants also give off oxygen in the process of photosynthesis.
- The chemical equation for photosynthesis is;
- $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6+6O_2$

**Student will need:**

1. Computer
2. Internet
3. RCL User Manual

**What to do:**

1. To plan and investigate the plant tropism using inquiry plan
2. To learn and conduct the remote-controlled experiment
3. To present their findings through the experimental report and oral presentation
4. To log on hourly to record their observation and change the plant position if necessary

**Fun with Plant: Inquiry Plan***

I wonder (my question is) ______________________________________________

I predict (my hypothesis is) ____________________________________________

The manipulated variable is ____________________________________________

The responding variable is _____________________________________________

The controlled variables are ____________________________________________

The steps I follow are (The procedures are)

i. ________________________________________________________________

ii. ________________________________________________________________

iii. ________________________________________________________________

The observations I made are (The data are)

______________________________________

The patterns or relationships I found are (The data are organized on a chart or graph)

______________________________________________________

The answer to my question (my conclusion) is

___________________________________

**有趣的植物：探究計畫***

我想知道（我的問題是）________________________________________

我預測（我的假設是)__________________________________________

操縱變數是__________________________________________________

反應變數是__________________________________________________

控制變數是__________________________________________________

我的步驟（程式）

i. ________________________________________________________________

ii. ________________________________________________________________

iii. ________________________________________________________________

我所做的觀察（我的資料是）________________________________________

我發現/找到的模式或關係（圖表或圖形上的資料）______________________

我的答案是（我的結論是）__________________________________________

*This inquiry plan is adapted from Llewellyn (2007).

**Student worksheet:**
**The Fun with Plant Growth due to Gravity Stimuli**

**What is the remote-controlled laboratory?**

Remote-controlled laboratory is a real-time experiment that can be controlled or monitored by user from their computer through the Internet browser. It is also known as the Web-Based Laboratory.

The RCL system is commonly divided into two major parts, namely, hardware and software. The hardware part consists of the data acquisition system, digital input or output (DIO), camera, and various types of sensors. The software part executes data logging as well as controls and displays the real-time experiment on the computer screen via the Internet.

Thus, the RCL activity enables more flexible delivery (anytime), distance education (anyplace) and new visualization possibilities (interactivity).

**Background:**

Do the stems always grow upward? Tropism is the ordinary growth response of a plant to external stimuli. The stimuli can be light (*phototropism*), touch (*thigmotropism*), chemical (*chemotropism*) or gravity (*gravitropism* or *geotropism*). The positive response is directed by growth toward a stimulus and the negative response is indicated by growth away from the stimulus. In this case, *gravitropism* is the directional growth of a plant in response to gravity, and the response is negative.

**Basic Facts and Supplemental Information:**

- This attribute of stems which always seeking to grow upward is called negative “gravitropism”.
- This means that plants grow toward light.
- Roots have the opposite tendency. They always seek to grow downward. This attribute is called “geotropism” or “gravitropism”.
- This means that roots tend to grow toward the centre of the Earth, and stems tend to grow away from the centre, toward light.

**Student will need:**

1. Computer
2. Internet
3. RCL User Manual

**What to do:**

1. To plan and investigate the plant tropism using inquiry plan
2. To learn and conduct the remote-controlled experiment
3. To present their findings through the experimental report and oral presentation
4. To log on hourly to record their observation and change the plant position if necessary

**Fun with Plant2: Inquiry Plan***

I wonder (my question is) ___________________________________________

I predict (my hypothesis is) ___________________________________________

The manipulated variable is ___________________________________________

The responding variable is ___________________________________________

The controlled variables are ___________________________________________

The steps I follow are (The procedures are)

i. ___________________________________________________________

ii. ___________________________________________________________

iii. ___________________________________________________________

The observations I made are (The data are)

_______________________________________

The patterns or relationships I found are (The data are organized on a chart or graph)

________________________________________________________

The answer to my question (my conclusion) is

____________________________________

**有趣的植物2：探究計畫***

我想知道（我的問題是）_________________________________________

我預測（我的假設是)_____________________________________________

操縱變數是_____________________________________________________

反應變數是_____________________________________________________

控制變數是_____________________________________________________

我的步驟（程式）

i. ___________________________________________________________

ii. ___________________________________________________________

iii. ___________________________________________________________

我所做的觀察（我的資料是）____________________________________

我發現/找到的模式或關係（圖表或圖形上的資料）______________________

我的答案是（我的結論是）______________________________________

*This inquiry plan is adapted from Llewellyn (2007).

**Student worksheet:**
**Fun with Sound - Have you ever seen Beans Dance?**

**What is the remote-controlled laboratory?**

Remote-controlled laboratory is a real-time experiment that can be controlled or monitored by user from their computer through the Internet browser. It is also known as the Web-Based Laboratory.

The RCL system is commonly divided into two major parts, namely, hardware and software. The hardware part consists of the data acquisition system, digital input or output (DIO), camera, and various types of sensors. The software part executes data logging as well as controls and displays the real-time experiment on the computer screen via the Internet.

Thus, the RCL activity enables more flexible delivery (anytime), distance education (anyplace) and new visualization possibilities (interactivity).

**Background:**

Human beings have five senses, namely, hear, see, smell, taste and touch. Sound is parts of our daily sensory experience and our ears are important for sound detection. Sound is generated by vibration of an object through a medium from one site to another. This vibration allows you to hear sound.

Noise is also parts of sound and it is known as undesirable sound. However, to categorize a sound as noise may depend on the listener such as Rock music can be pleasurable for somebody but also annoying for others. If a person exposed to loud sound for a long period of time, it can be harmful to his or her hearing ability. Thus, personal hearing protection is important particularly for noise workplace like construction area.

**Basic Facts and Supplemental Information:**

1. Sounds are produced by vibrations.
2. You can sense the vibration by putting your fingers on your throat and talk.
3. Human beings able hear the range frequency from 20 Hz up to 20,000 Hz
4. Hearing frequency may difference between individuals (range declines with age), especially at high frequencies, where a ongoing decline with age is reflected as normal.
5. Noise is unwanted sound.
6. Sound level and its duration may cause hearing loss or damage.
7. Thus, we must protect our hearing system

**Student will need:**

1. Computer
2. Internet
3. RCL User Manual

**What to do:**

1. To plan and investigate the sound as vibration using inquiry plan
2. To learn and conduct the remote-controlled experiment
3. To present their findings through the experimental report and oral presentation

**Fun with Sound: Inquiry Plan***
I wonder (my question is) ______________________________________
I predict (my hypothesis is) ____________________________________
The manipulated variable is _____________________________________
The responding variable is ______________________________________
The controlled variables are _____________________________________
The steps I follow are (The procedures are)

i. ___________________________________________________
ii. ___________________________________________________
iii. ___________________________________________________

The observations I made are (The data are)
_________________________________
The patterns or relationships I found are (The data are organized on a chart or graph)
_______________________________________________
The answer to my question (my conclusion) is
______________________________

**有趣的聲音：探究計畫***
我想知道（我的問題是）___________________________________
我預測（我的假設是)______________________________________
操縱變數是_____________________________________________
反應變數是_____________________________________________
控制變數是_____________________________________________
我的步驟（程式）

i. ___________________________________________________
ii. ___________________________________________________
iii. ___________________________________________________

我所做的觀察（我的資料是）___________________________________
我發現/找到的模式或關係（圖表或圖形上的資料）___________________
我的答案是（我的結論是）_____________________________________
*This inquiry plan is adapted from Llewellyn (2007).

# Appendix B: New RCL User Guide

Remote-Controlled Laboratory (RCL) System
for Science Education

THO, Siew Wei
PhD Candidate,
SES Department, HKIEd

## Contents



2

## What is Remote-controlled Laboratory?

- Also known as Web-Based Laboratory.
- Real-time experiments that can be controlled or monitored by user from their own computer through the Internet browser.
- The RCL system is commonly divided into two major parts, namely, hardware and software.
- Hardware: data acquisition system, digital input or output (IO), camera & various types of sensors.
- Software: executes data logging as well as controls & displays the real-time experiment on the computer screen via the Internet.

3

## Target Group

- Remote-controlled laboratory (RCL) package is specifically designed and developed to employ technology-enhanced inquiry for those related to science education.
- The application of the RCL system is aimed at studying certain scientific principles that related to topic "plants" and "electrical circuit connection" and " sound" by conducting inquiry experiments through the RCL system.

4

## Operating System Requirement

**The computer operating system must meet the following specifications:**

- Windows 7 32-bit/64-bit;
- Windows Vista 32-bit/64-bit;
- Windows XP 32-bit;
- Windows Server 2008 R2 32-bit/64-bit.

5

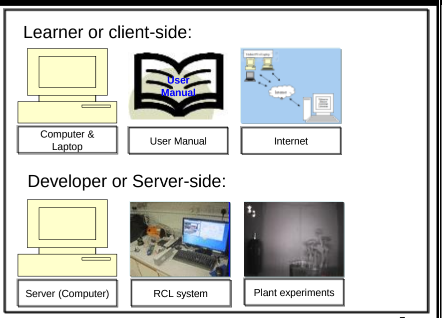
## Installation of Software

**Open the http://rcl.ied.edu.hk:8000/index.html, with simple installation as order shown:**

1. First, install google chorme web browser: http://rcl.ied.edu.hk:8000/run_engine/ChromeStandaloneSetup.exe
2. Then, install the plugin of LabVIEW Run-Time Engine 2011: http://rcl.ied.edu.hk:8000/run_engine/LVRTE2011min.exe
3. Finally, click on remote-controlled laboratory link (at top-left corner of main website) http://rcl.ied.edu.hk:8000/tho.html

6

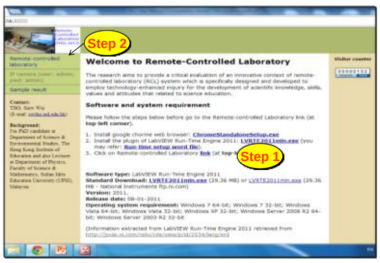
## Hardware Requirement




7

## RCL Software

1. With simple Installation (Step 1), and then click on Remote-controlled laboratory (Step 2).




8

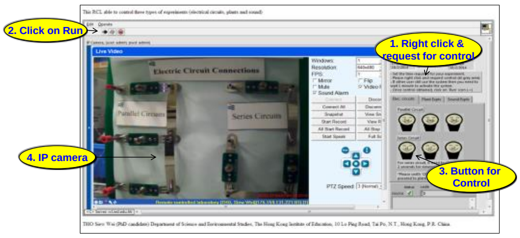
## RCL Software

2. The main window is shown once the RCL is clicked. Login the IP camera with user: admin, password: admin.


9

## RCL Software

3. Right click & request for control (at grey color area & wait for **1 minute** if other still controlling it) > click on Run > Button for control > observe & control via IP camera > save the data & graph.




10

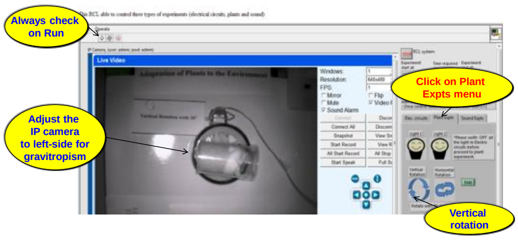
## RCL Software

4. Once control is obtained > Electrical circuits interface > Button for control to control the light bulbs.


11

## RCL Software

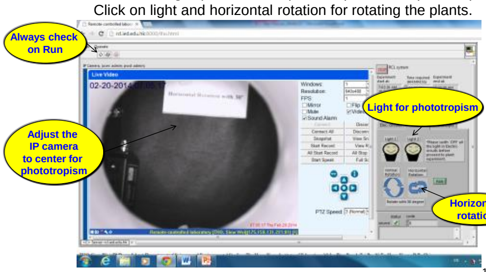
5. Plants experiments > Plant Experiment - Gravity > just click on vertical rotation to rotate the plant




12

## RCL Software

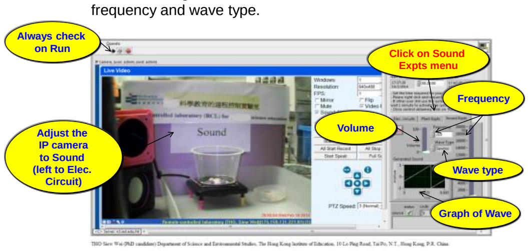
6. Plants experiments > Plant Experiment - Light > remember to turn off the light (Elec. Circuits) before proceed to plant expts. > Click on light and horizontal rotation for rotating the plants.




13

## RCL Software

7. Once control is obtained > Sound interface > put the volume to maximum for good result > Button for control to control the frequency and wave type.




14

## Inquiry Experiment via RCL

1. Read the Student worksheet and start your experiment (e.g. The Fun with Plant by Tropism).

**Student worksheet:**
**The Fun with Plant Growth due to Gravity Stimuli**

**What is the remote-controlled laboratory?**

Remote-controlled laboratory is a real-time experiment that can be controlled or monitored by user from their computer through the Internet browser. It is also known as Web-Based Laboratory.

The RCL system is commonly divided into two major parts, namely, hardware and software. The hardware part consists of the data acquisition system, digital input or output (DIO), camera, and various types of sensors. The software part executes data logging as well as controls and displays the real-time experiment on the computer screen via the Internet.

Thus, the RCL activity enables more flexible delivery (anytime), distance education (anyplace) and new visualization possibilities (interactivity).

**Background:**

Do the stems always grow upward? Tropism is the ordinary growth response of a plant to

15

## Inquiry Experiment via RCL

2. The figure of RCL learning environment flow.

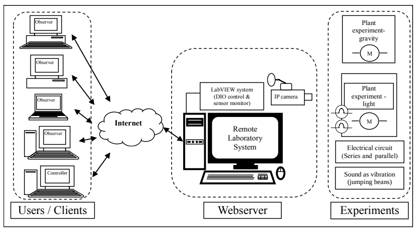



Figure: RCL Environment for performing Plants Experiments with the Labview System

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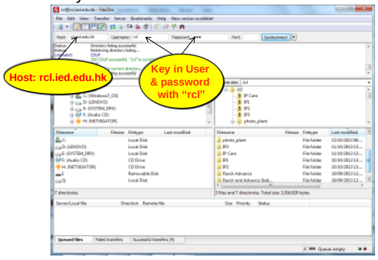
## Inquiry Experiment via RCL

4. Then, plant experiment – light may get the result as shown in the figure (e.g plant point towards light source).

17

## Inquiry Experiment via RCL

5. The data can be saved into ftp and then download the photos via ftp client software. The photos can be further analysed to make a movie.




18

## Analysis Results using Movie

1. Then, combine a number of photo into a movie.

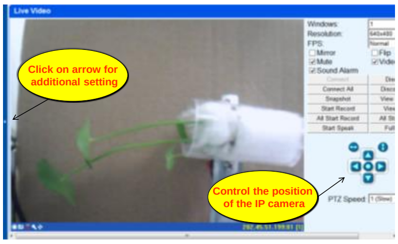
Time_04.24.2013 13_57_pm Time_04.24.2013 14_07_pm Time_04.24.2013 14_17_pm

Time_04.24.2013 14_27_pm Time_04.24.2013 14_37_pm Rotate the plants

19

## Additional Functions of IP Camera

1. IP camera can be freely rotated to the position you want for observing more than one experiments.




20

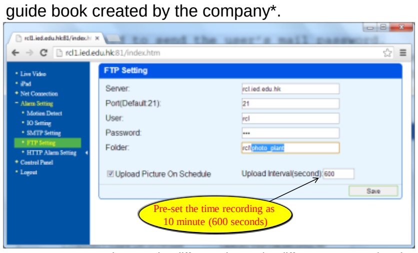
## Additional Functions of IP Camera

2. The moving objects will be automatically detected for video capturing, send out with alert email & uploaded the photo to the ftp server.


21

## Additional Functions of IP Camera

3. You are able to preset the time recording as shown below. For further clarification, you may refer to the guide book created by the company*.




*But, IP camera setting may be different due to the different company/product.

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## Technical Support

It is acknowledged that the technical support by laboratory technician of Science and Environment Studies (SES) department and Information technology services (ITS) for network support.

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The Hong Kong Institute of Education 香港教育學院


Prepared by THO, Siew Wei, PhD Candidate, and supervised by Prof. YEUNG, Yau Yuen, SES Department, HKIEd


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## Appendix C: Undergraduate Student's Pre-Survey

**The Effectiveness of Remote-Controlled Laboratory System for Science Education**

**Undergraduate Student's Pre-Survey**

The data and information obtained from this survey will be kept **confidential** and it will be used only for the purposes of evaluation and related research. Answer **all items** to the best of your perception. Please do not skip any item as your views are important to us, avoid guessing and plan to finish the survey in 5 minutes. Your responses should reflect what **you** actually and honestly think and there are no correct or incorrect answers.

**Personal particulars:**

| |
|---|
| **Student No.:** ☐ **Gender**：☐ Male ☐ Female (please '☑') |
| **Program:** ☐ BScEd (SWT) ☐ BEd (GS) ☐ PGDE (Pri./Sec.) ☐ other: __---___(please '☑') |
| **Year:** ☐1st ☐2nd ☐3rd ☐ 4th ☐ 5th (please '☑') |
| Birth of **Year** & **Month**：☐☐☐☐-☐☐ (yyyy-mm) |
| **Public Examination Level (highest one):** ☐ HKALE ☐ HKDSE ☐ HKCEE (please '☑')<br>**#Result(s)/Grade(s):** ☐Physics ☐Chemistry ☐Biology ☐Computer/ICT ☐Liberal studies<br>☐Other science subject (please specify):_____________ (please 'B' / '4' )<br>(#You may give more than one subject result(s), please write your grade: 'A-F or 1-5**') |

**Other personal information/prior experiences:**

| No. | Statements | Circle your response | | |
|---|---|---|---|---|
| 1 | Do you have a smart phone (e.g. iPhone, Samsung Galaxy…)? | Yes | | No |
| 2 | Do you have a tablet (e.g. iPad, Samsung Galaxy Tab…)? | Yes | | No |
| 3 | Do you have a high volume data plan (i.e.500 MB or over per month) for your phone or other mobile devices? | Yes | | No |
| 4 | Please rate how you presently view your own science knowledge level? | High | Medium | Low |
| 5 | As a future teacher in primary or secondary school, please rate how you presently view your own effectiveness in teaching science topic? | High | Medium | Low |
| 6 | As a future teacher in primary or secondary school, please rate how you presently view your own effectiveness in teaching science using ICT tools? | High | Medium | Low |
| 7 | How do you rate your ability in conducting scientific experiment? | High | Medium | Low |
| 8 | How do you rate your experience on inquiry learning? | A lot | Medium | Little |
| 9 | Have you ever been involved in any remote-controlled laboratory (RCL) activity? (RCL: you are able to control a real-time experiment through the Internet browser.) | Yes | | No |

**The previous experience in conducting conventional scientific experiment**

Based on your previous experience in conducting the conventional scientific experiments or science practical work in school or other science course, list out the advantages and disadvantages in the following tables and please do not skip any item as your views are important to us:-

| **Conventional Scientific Experiment** | |
|---|---|
| Advantages (please provide at least **TWO**): | Disadvantages (please provide at least **TWO**): |

**Thanks for your participation.**

## Appendix D: Undergraduate Student's Post-Survey

**The Effectiveness of Remote-Controlled Laboratory System for Science Education**

**Undergraduate Student's Post-Survey**

The data and information obtained from this survey will be kept **confidential** and it will be used only for the purposes of evaluation and related research. Answer **all items** to the best of your perception. Avoid guessing and plan to finish the survey in 15 minutes. Your responses should reflect what **you** actually and honestly think and there are no correct or incorrect answers.

**Personal particulars:**

**Student No.:** ☐ **Gender**： ☐ Male ☐ Female (please '☑')

**The experience on conducting Remote-Controlled Laboratory (RCL)**

Based on your current experience in conducting the experiments using RCL system, list out the advantages and disadvantages for both approaches in the following tables and please do not skip any item as your views are important to us:-

| **Remote-control laboratory** | |
|---|---|
| Advantages (please provide at least **TWO**): | Disadvantages (please provide at least **TWO**): |

**Survey items:** Circle **only one** answer per item.

| Strongly Disagree | Disagree | Agree | Strongly Agree |
|---|---|---|---|
| ☹☹ | ☹ | ☺ | ☺☺ |
| 1 | 2 | 3 | 4 |

| No. | Statement | ☹☹ | ☹ | ☺ | ☺☺ |
|---|---|---|---|---|---|
| 1 | I like science more than any other subjects. | 1 | 2 | 3 | 4 |
| 2 | Studying science with Information and Communication Technology (ICT) will increase my learning motivation. | 1 | 2 | 3 | 4 |
| 3 | I enjoy using ICT tools (e.g data-logger and computer) in conducting science experiments. | 1 | 2 | 3 | 4 |
| 4 | The Remote-controlled Laboratory (RCL) software interface and features are easy to work with. | 1 | 2 | 3 | 4 |
| 5 | The advantages of conducting the RCL system will be greater than any technical challenges of its use. | 1 | 2 | 3 | 4 |
| 6 | Browsing and controlling a real-time experiment with the online laboratory are easy to work with. | 1 | 2 | 3 | 4 |
| 7 | RCL can assist me to develop a better understanding of the science concepts in these experiments. | 1 | 2 | 3 | 4 |
| 8 | My experience in RCL can enhance my interest in the course. | 1 | 2 | 3 | 4 |
| 9 | I prefer to use the RCL system for learning in my future/other science course. | 1 | 2 | 3 | 4 |

| No. | Statement | ☹☹ | ☹ | ☺ | ☺☺ |
|---|---|---|---|---|---|
| 10 | RCL helped me to better understand how to connect the ICT with real-world applications. | 1 | 2 | 3 | 4 |
| 11 | I can connect the science concepts learnt from RCL experiments with what happens in the real world. | 1 | 2 | 3 | 4 |
| 12 | RCL experiments can relate to what I experience in the real world. | 1 | 2 | 3 | 4 |
| 13 | My experience in RCL increases my interest to conduct experiment in my future class. | 1 | 2 | 3 | 4 |
| 14 | I will recommend the RCL system to other students/teachers. | 1 | 2 | 3 | 4 |
| 15 | The advantages of the RCL system worth the extra time and effort for us to learn it. | 1 | 2 | 3 | 4 |
| 16 | I believe that the use of RCL system can improve my future teaching. | 1 | 2 | 3 | 4 |
| 17 | The RCL activity increases the confidence of my future teaching. | 1 | 2 | 3 | 4 |
| 18 | The RCL activity increases my capabilities to conduct scientific investigation in school. | 1 | 2 | 3 | 4 |
| 19 | This inquiry through RCL system can promote collaborative learning. | 1 | 2 | 3 | 4 |
| 20 | The use of RCL system for inquiry learning assists me to interact more with other students. | 1 | 2 | 3 | 4 |
| 21 | RCL assists me to actively participate in the group discussions. | 1 | 2 | 3 | 4 |

If you have a chance to teach primary/secondary students after graduation, are you confident enough to apply the RCL approach in primary/secondary schools?

| No. | Statement | ☹☹ | ☹ | ☺ | ☺☺ |
|---|---|---|---|---|---|
| 22 | I feel confident that primary/secondary students can easily work with the RCL system. | 1 | 2 | 3 | 4 |
| 23 | I feel confident that primary/secondary students will have greater motivation to learn science through the use of RCL system. | 1 | 2 | 3 | 4 |
| 24 | I believe that the RCL activity can increase primary/secondary students' science knowledge and skills. | 1 | 2 | 3 | 4 |
| 25 | I believe that the RCL activity can promote inquiry-based learning amongst my future primary/secondary students. | 1 | 2 | 3 | 4 |
| 26 | I feel confident that the use of inquiry through RCL can promote collaborative learning among primary/secondary students. | 1 | 2 | 3 | 4 |
| 27 | I feel confident to guide primary/secondary students to conduct scientific investigations (e.g. to engage in developing inquiry planning skills, carry out investigations, control variables, interpret results and draw conclusions) through the RCL activity. | 1 | 2 | 3 | 4 |

**Open-ended question –** Write down your opinion(s) in either English or Chinese and please do not skip any item as your views are important to us:-

28. What have you learned from the inquiry experiments through the use of RCL system?

| |
|---|
| |

29. Have you encountered any problems concerning the programme and the equipment while doing the inquiry experiments? If so, briefly describe the problem(s).

| |
|---|
| |

30. If you were given another chance to do the experiments again, please suggest some ways for improvement?

| |
|---|
| |

31. Please suggest a science topic or activity with a brief design that is possible to apply the inquiry experiments through the use of RCL system.

| |
|---|
| |

**Thanks for your participation.**

## Appendix E: Undergraduate Student's Interview

**The Effectiveness of Remote-Controlled Laboratory System for Science Education**

**Undergraduate Student's interview**

All data are **confidential.** Your identity will not be disclosed to any party.

Student ID:_______________ Gender：Male / Female,

Date：__________ Venue：__________________ Time-Start：____________

| Scope | Interview | Asking | Reply | Remarks |
|---|---|---|---|---|
| **Ice Breaker for opening interview** | -What role does ICT play in your **everyday life**?<br>-What role does ICT play in **science education** today?<br>-What role does ICT play in **scientific investigation** today? | ☐ | ☐ | |
| The experience on conducting Remote-Controlled Laboratory (RCL) and traditional experiment | | | | |
| **RCL and Traditional experiment** | Based on your current experience in conducting the experiment using RCL system and compare with your previous experience in conducting the traditional experiment in school. Please list out the advantages and disadvantages for both experimental methods.<br>1. Let start with the advantages and disadvantages of **RCL**? First, please elaborate about the advantages. Then, please elaborate about the disadvantages.<br>2. How about the advantages and disadvantages of **traditional experiment**? First, please elaborate about the advantages. Then, please elaborate about the disadvantages. | ☐<br>☐ | ☐<br>☐ | |
| Several questions from student survey are selected for further explanation about student's reason(s) in selecting their response. (**Likert**) | | | | |
| **Inquiry Experiment through RCL system** | Do you think that the RCL system was easy to work with? Did you feel motivated to learn more from this system? Why? Why not? | ☐ | ☐ | |

| | | | | |
|---|---|---|---|---|
| | | | | |
| | Do you think you learned something important using the RCL or online laboratory? Why? Why not? | ☐ | ☐ | |
| | Would you like to use remote-controlled laboratory more often in your future course? Why? Why not? | ☐ | ☐ | |
| | Have you encountered any problems concerning the programme and the equipment used while doing the inquiry experiments? If so, briefly describe the problem(s).<br>(What were things that did not work so well?) | ☐ | ☐ | |
| | What technical issues need to be improved? If you were given another chance to do the experiments again, do you have any further suggestions for helping us to improve them? | ☐ | ☐ | |
| **Teaching Pedagogy** | Do you think this approach helped you to **improve** your future teaching? Why? Why not? | ☐ | ☐ | |
| | Do you think it has assisted you to increases **confidence** in your future teaching? Why? Why not? | ☐ | ☐ | |
| | Do you think the experience from RCL activity increases the **capabilities** of how to conduct your future scientific investigation in school? Why? Why not? | ☐ | ☐ | |
| **Self-efficacy: The Potential to run in Primary/ Secondary school** | If you have a chance to teach primary/ secondary students after graduation, are you confident enough to apply the RCL approach in primary/secondary schools?<br><br>Do you feel confident that the primary/secondary student can easily work with the RCL system? Why? Why not? | ☐ | ☐ | |

| | | | | |
|---|---|---|---|---|
| | | | | |
| | Do you feel confident that primary/secondary student will increase their motivation to learn science through the use of RCL system? Why? Why not? | ☐ | ☐ | |
| | Do you believe that the use of RCL activities is able to increase primary/secondary student capabilities and knowledge? Why? Why not? | ☐ | ☐ | |
| | Do you feel confident that the use of inquiry through RCL is able to encourage collaborative learning among primary/secondary students? Why? Why not? | ☐ | ☐ | |
| | Do you feel confident to guide primary/secondary students to engage in developing inquiry skills (e.g investigations, controlling variables, interpreting and drawing conclusions) through the use of RCL activity? Why? Why not? | ☐ | ☐ | |
| **Suggest related topic** | Please suggest science topic(s) or activity with a brief design that is possible to apply the inquiry experiments through use of RCL system. | ☐ | ☐ | |

**Appendix F: Eight Refined RCL Guided-Inquiry Worksheets with Teacher Guide**

**Student worksheet:**
**Center: Sound**

| **Name:** | **Date:** |
|---|---|
| 1. | **Group:** |
| 2. | |
| 3. | |
| 4. | |
| 5. | |

**Inquiry Question:** Have you ever seen the Beans Dance?
Human beings have five senses, namely, hear, see, smell, taste and touch. Sound is parts of our daily sensory experience and our ears are important for sound detection. Sound is generated by vibration of an object through a medium from one site to another. This vibration allows you to hear sound.

Noise is also parts of sound and it is known as undesirable sound. However, to categorize a sound as noise may depend on the listener such as Rock music can be pleasurable for somebody but it is annoying for others. If a person exposed to loud sound for a long period of time, it can be harmful to his or her hearing ability. Thus, personal hearing protection is important particularly for noise workplace like construction area.

You are asked to plan and carry out an investigation to test the following two hypotheses?

- If changing wave type, then the beans will jump highest because of the vibration.
- If the frequency adjusts to certain value, then the beans will jump highest because of the vibration.

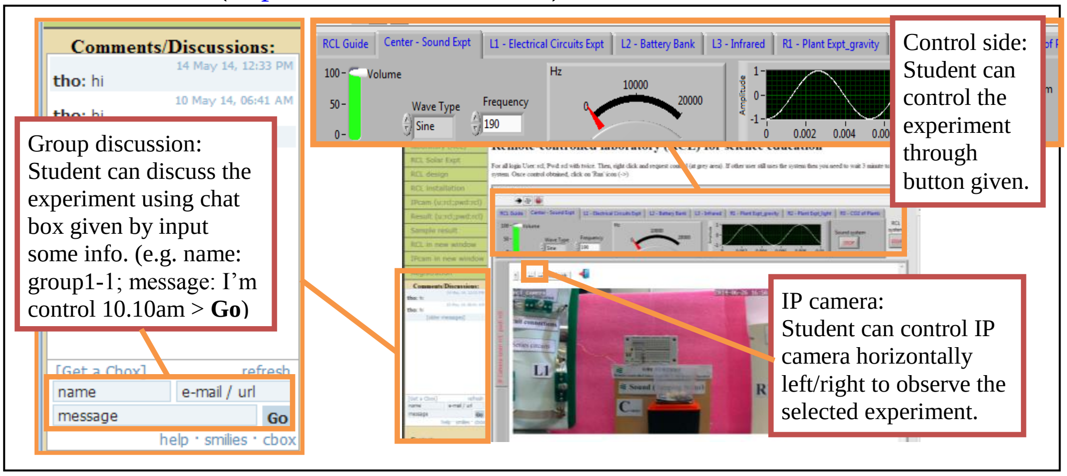
You are asked to answer the following question:

- How can you measure the sound vibration in different wave type?
- In result session, what patterns do you get from your findings?
- If you were given another chance to do the experiments again, what additional independent variable (variable to be changed) would you like to test?

**Material and Apparatus:**

1. Computer
2. Internet
3. RCL User Manual – Login Card and Guide
4. Center – Sound experiment

**Additional Note:** (http://rcl.ied.edu.hk:8000)




***How to measure high of the beans***

Go to video view and record the video "icon" and then play back the video by tracking the highest of jumping beans and measure its length. Record the length value (unit m) into the table.

**Variables:** Please underline or circle your variable(s)

| | |
|---|---|
| The variable to be changed (independent variable) is | Frequency /Height of beans /Volume / Wave type |
| The variable to be monitored (dependent variable) is | Frequency /Height of beans /Volume / Wave type |
| The variable(s) to be kept constant (controlled variable(s)) | Frequency /Height of beans /Volume / Wave type |

**List the experimental procedure and capture your setup with IP camera or print screen:**

The steps I follow are (The procedures are):

i. To remotely access the RCL system from laptop or desktop computer that has a web google chrome browser, go to browser and access the http://rcl.ied.edu.hk:8000/page_rcl.html

ii. Login the RCL with user: rcl, password: rcl.

iii. Right click & request for control (at grey colour area 在灰色區域) and then remember to click on Run ( ).

iv. Click on left/right button for observing & controlling the RCL experiments via IP camera ( Refresh ).

v Comment/Discussions (see Additonal Note): To tell your group / friend about your control and experiment time.

vi. Click on Tab for Center - sound experiment and then click on button for control.

vii.* ________

viii. ________

ix. ________

x. ________

(*Start from vii. list out your own experimental procedure)

**Figure(s) / picture(s):** (Window: Press the "Print Screen" key [Print Screen/PrtScr] on your keyboard and Paste the screenshot below. Mac: Press the Command + Shift + 3 key on your keyboard and then Open the screen capture on your desktop)

**Data:**

**Experiment 1:**

**Frequency:** ___________Hz (i.e. set to around180-200Hz)

| **Wave type** | **Height (line)** | **Your Observation** |
|---|---|---|
| Sine | | |
| Square | | |
| Saw tooth | | |
| Triangle | | |

**Experiment 2:**

**Wave type:** Sine/Square/Saw tooth/Triangle

| **Frequency** | **Height (line)** | **Your Observation** |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |

**Result:**

The patterns or relationships I found are (The data are organized on a chart or graph)
(Window: Press the "Print Screen" key [Print Screen/PrtScr] on your keyboard and Paste the screenshot below.
Mac: Press the Command + Shift + 3 key on your keyboard and then Open the screen capture on your desktop)

**Conclusion:**

The answer to my question (my conclusion) is

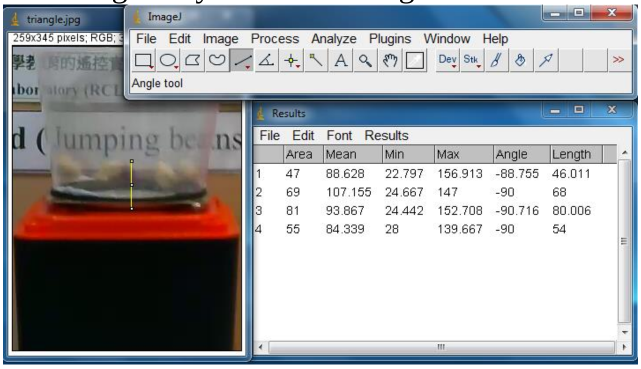
**Reflection:**

- What have you learnt in the sound experiment about (a) scientific methods, (b) scientific attitudes and (c) scientific knowledge?
- Have you encountered any difficulties? How do you solve these problems?
- If you were given another chance to do the experiments again, what additional independent variable (variable to be changed) would you like to test?

**Measuring the height: ImageJ Software**

**ImageJ: How to measure length of the jumping bean**

1. Measure the jumping bean by referring to a **SINGLE** selection bean using ImageJ (open source software able to measure angle changed).
2. First, download and install ImageJ (http://rsb.info.nih.gov/ij/) according to your operating system (OS) (i.e. Windows OS).
3. Open the selected image.
4. Measure the length of the single jumping bean using the angle tool  by drawing a vertical straight as yellow line in figure below.




5. Then, go to Analyse tab > Measure or you can use shortcut Ctrl+M to generate length result of your image. The values are expressed in physical size square units or in pixels if Pixel Units is checked.
6. Repeat step 4 and 5 by going to tab File > open next > your next result image. Then just move the yellow.

**Teacher Guide:**

**Objectives**

At the end of the lesson, all students should

- be able to identify the characteristic of sound
- be able to have practical experience on RCL for sound experiment

**Students' prior knowledge**

Primary 4:

- Hearing and Looking at Fantastic Things
    - Investigating sound
    - The wonderful world of sound
    - Special effects of sound

**Science Education Curriculum**

The underlying scientific concepts and principles closely match the science education curriculum of Hong Kong as recommended by the Education Bureau of the HKSAR.

- Energy
    - Different forms of energy: heat, light, sound, kinetic, potential,
- Sensing the Environment
    - How we hear: the production and transmission of sound; functions of main parts of the ear Living Things

**Background:**

***Sound***

Human beings have five senses, namely, hear, see, smell, taste and touch. Sound is parts of our daily sensory experience and our ears are important for sound detection. Sound is generated by vibration of an object through a medium from one site to another. This vibration allows you to hear sound.

Noise is also parts of sound and it is known as undesirable sound. However, to categorize a sound as noise may depend on the listener such as Rock music can be pleasurable for somebody but it is annoying for others. If a person exposed to loud sound for a long period of time, it can be harmful to his or her hearing ability. Thus, personal hearing protection is important particularly for noise workplace like construction area.

***Basic Facts and Supplemental Information:***

1. Sounds are produced by vibrations.
2. You can sense the vibration by putting your fingers on your throat and talk.
3. Human beings able hear the range frequency from 20 Hz up to 20,000 Hz
4. Hearing frequency may difference between individuals (range declines with age), especially at high frequencies, where a ongoing decline with age is reflected as normal.
5. Noise is unwanted sound.
6. Sound level and its duration may cause hearing loss or damage.
7. Thus, we must protect our hearing system

***What is the remote-controlled laboratory?***

Remote-controlled laboratory is a real-time experiment that can be controlled or monitored by user from their computer through the Internet browser. It is also known as Web-Based Laboratory.

The RCL system is commonly divided into two major parts, namely, hardware and software. The hardware part consists of the data acquisition system, digital input or output (DIO), camera, and various types of sensors. The software part executes data logging as well as controls and displays the real-time experiment on the computer screen via the Internet.

Thus, the RCL activity enables more flexible delivery (anytime), distance education (anyplace) and new visualization possibilities (interactivity).

**Sample result and procedure**

**Experiment 1:**

**Variables:** Please underline or circle your variable(s)

| | |
|---|---|
| The variable to be changed (independent variable) is | **Frequency** /Height of beans /Volume / Wave type |
| The variable to be monitored (dependent variable) is | Frequency /**Height of beans** /Volume / Wave type |
| The variable(s) to be kept constant (controlled variable(s)) | Frequency /Height of beans /**Volume / Wave type** |

**Experiment 2:**

**Variables:** Please underline or circle your variable(s)

| | |
|---|---|
| The variable to be changed (independent variable) is | Frequency /Height of beans /Volume / **Wave type** |
| The variable to be monitored (dependent variable) is | Frequency /**Height of beans** /Volume / Wave type |
| The variable(s) to be kept constant (controlled variable(s)) | **Frequency** /Height of beans /**Volume** / Wave type |

**Procedure:**

**Experiment 1*:**

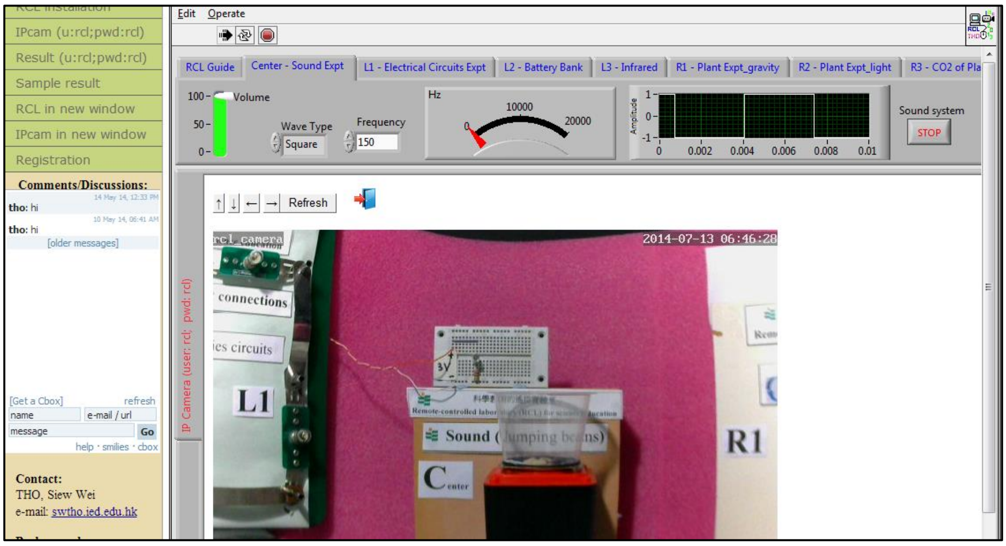
1. Record the experimental time.
2. Move the IP camera view to Center: Sound,
3. Increase the volume to maximum.
4. Change the frequency to certain value (i.e. 150Hz), snap the photo and record the height of the beans using ImageJ software.
5. Repeat the step 4 with different frequency – 160Hz, 170Hz 180Hz, 190Hz and 200Hz.

**Experiment 2*:**

6. Change the wave type (i.e. Sine wave), snap the photo and record the height of the beans using ImageJ software.
7. Repeat the step 4 with different frequency – square, triangle, sawtooth.

*** Based on their independent and controlled variable selection.**

**Figure:**



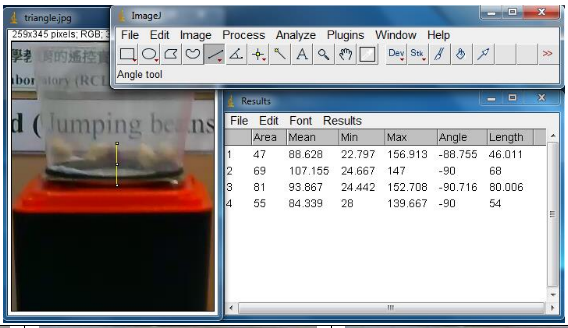

**Data:**

**Experiment 1:**

**Frequency:** 190 Hz

| **Wave type** | **Height (line unit pixels)** | **Your Observation** |
|---|---|---|
| Sine | 46 | |
| Square | 68 | |
| Saw tooth | 80 | |
| Triangle | 54 | |

**Figure:**



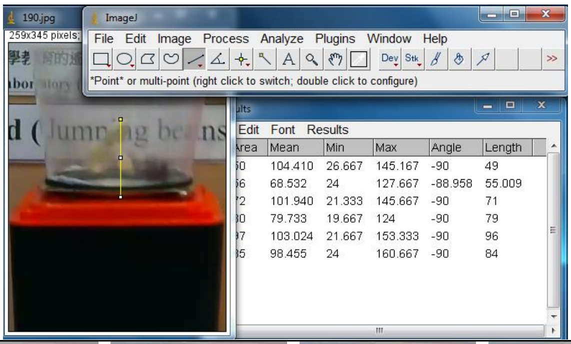

| | | | |
|---|---|---|---|
|  |  |  |  |
| Saw tooth | Sine | Square | Triangle |

**Experiment 2:**

**Wave type:** $\boxed{\text{Sine}}$/Square/Saw tooth/Triangle

| **Frequency** | **Height (line unit pixels)** | **Your Observation** |
|---|---|---|
| 150 | 49 | |
| 160 | 55 | |
| 170 | 71 | |
| 180 | 79 | |
| 190 | 96 | |
| 200 | 84 | |

**Figure:**




| 150Hz | 160Hz | 170Hz | 180Hz | 190Hz | 200Hz |
|---|---|---|---|---|---|

**Result:**

The results show that the frequency 190Hz and Square wave type set off the bean jump highest.

**Conclusion:**

The hypothesis is proven to be correct. The square wave type have longer peak amplitude duration, therefore it cause the bean jump to the highest. Wave type height: square > sine > triangle > saw tooth.

**References:**


Bell, R. L., Smetana, L., & Binns, I. (2005). Simplifying Inquiry Instruction. *Science Teacher, 72*(7), 30-33.

Cheung, D. (2006). *Inquiry-based laboratory work in chemistry: Teacher's guide*. Hong Kong: Department of Curriculum and Instruction, The Chinese University of Hong Kong.

ImageJ. (n.d.). *Image Processing and Analysis in Java*. Retrieved from [http://rsb.info.nih.gov/ij/](http://rsb.info.nih.gov/ij/)

Llewellyn, D. (2007). *Inquire within: implementing inquiry-based science standards in grades 3-8. (2nd ed.)*. California, US: Corwin Press.

Llewellyn, D. (2013). *Teaching high school science through inquiry and argumentation (2nd ed.)*. Thousand Oaks, California, US: Corwin Press.

Lorbeer, G. C. (2000). *Science activities for middle school students (2nd ed.)*. US: McGraw-Hill.

**Student worksheet:**
**L1: The closed, parallel and series electrical circuit connections**

| Name: | Date: |
|---|---|
| 1. | Group: |
| 2. | |
| 3. | |
| 4. | |
| 5. | |

**Inquiry Question:** What is the difference between a parallel (*並聯*) circuit and a series (*串聯*) circuit?

What is the example of a series circuit and a parallel circuit in your house? Electricity plays a vital role in our daily life, such as light, computer, mobile devices, refrigerator or even air-conditioner. Basically, it needs to complete an electric circuit for activating the electrical devices. The electric circuit is a path connected by wire for the flow of electrons. Therefore, an electric source is needed for the movement of electrons like a battery or other power source. These movements of the electron will make the device work. Normally, a switch is attached to the devices for turned 'ON' or 'OFF' process. In this activity, a battery, wire and a bulb are needed for the basic circuit connection to light up a bulb. To complete a circuit, you need to make a connection from positive terminal of battery to positive terminal of a bulb and from negative terminal of the bulb to negative terminal of the battery. With additional bulbs connected to a battery, you can get another two types of circuit connections called as series and parallel circuits' connection.

What is a real life example of a series circuit and a parallel circuit? Fuses and switches are the example of series circuit connection. Parallel circuit connection will be more common in our daily life for example any extension cord or socket and electrical appliances. In a parallel circuit connection (*並聯電路*), all the devices are connected in parallel (see Figure 1). If you put more bulbs into a parallel circuit, the bulbs will remain the same brightness (*燈泡將保持相同的亮度*). In a series circuit connection (串聯電路), all the devices are connected from one to the others (see Figure 2). If you put more bulbs into a series circuit, the bulbs will become dimmer (*燈泡會變得暗淡*).

**Task:** You are asked to plan and carry out a simple investigation to test series and parallel circuit connection experiment together with the following two questions (*測試串聯和並聯電路及以下問題*):

- In a parallel circuit, if the second bulb is removed from the circuit (*中斷第二燈泡*), do the remaining bulbs light up?
- In a series circuit, if the second bulb is removed from the circuit (*中斷第二燈泡*), do the remaining bulbs light up?

You are asked to answer the following question:

- In result session, what patterns do you get from your findings?
- If you were given another chance to do the experiments again, what additional independent variable (variable to be changed) would you like to test?

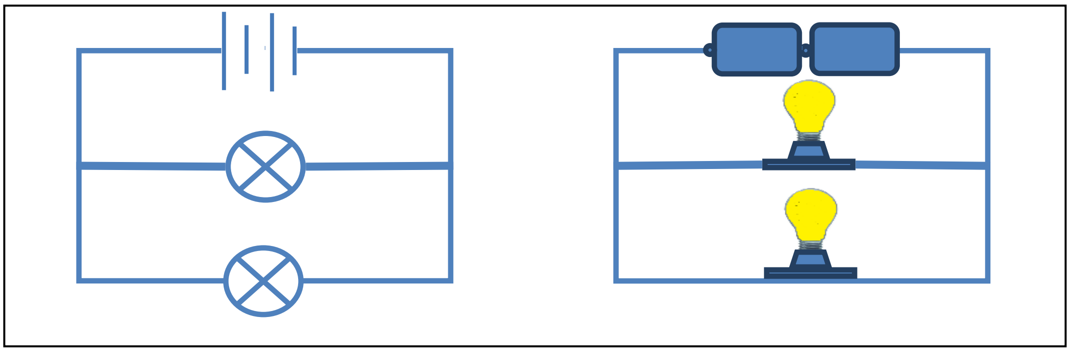


**Figure 1.** Parallel Circuit Connection (*並聯電路*)

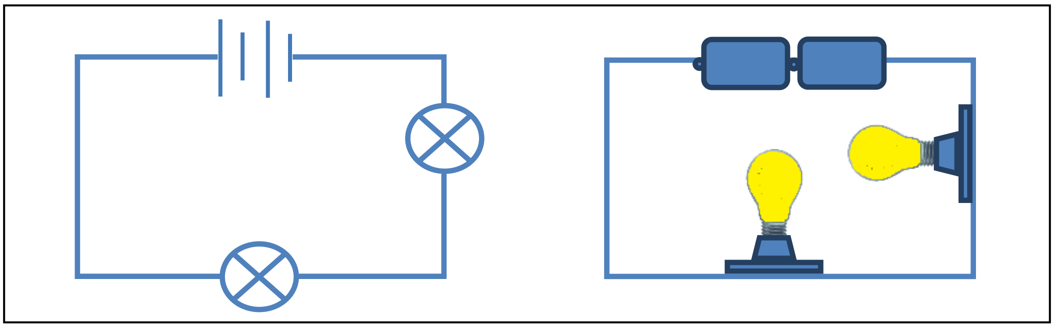
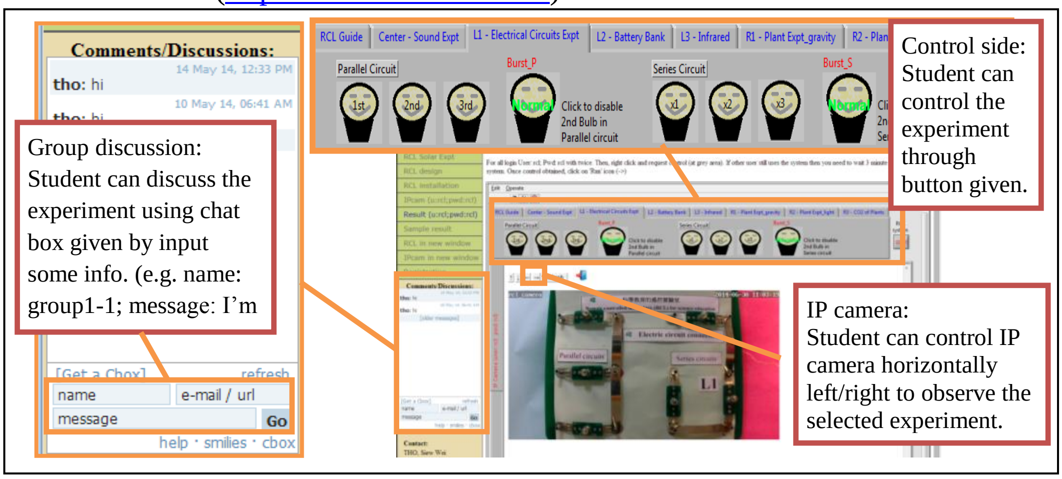


**Figure 2.** Series Circuit Connection (*串聯電路*)

**Material and Apparatus:**

1. Computer
2. Internet
3. RCL User Manual – Login Card and Guide
4. L1: Electrical circuit experiment

**Additional Note:** (http://rcl.ied.edu.hk:8000)




***How to disable the 2$^{nd}$ bulb in Parallel and Series circuits*** (*在串聯和並聯電路中斷第二燈泡*)

In the parallel circuit, click on the Burst_ P button  for disable the 2$^{nd}$ bulb in parallel circuit the button icon will change to , then try to conduct the parallel circuit experiment again.

In the series circuit, click on the Burst_ S button for disable the 2nd bulb in series circuit the button icon will change to , then try to conduct the series circuit experiment again.

**Variables (*變量/變數*):** Please underline or circle your variable(s)

| | |
|---|---|
| The variable to be changed (independent variable *獨立變數*) is | Brightness of bulb(s) /Number of bulbs /Power supply /Types of bulbs |
| The variable to be monitored (dependent variable *因變數*) is | Brightness of bulb(s) /Number of bulbs /Power supply /Types of bulbs |
| The variable(s) to be kept constant (controlled variable(s) *控制變數*) | Brightness of bulb(s) /Number of bulbs /Power supply /Types of bulbs |

**List the experimental procedure and capture your setup with IP camera or print screen:**
**(RCL procedures are provided)**

The steps I follow are (The procedures are):

i. To remotely access the RCL system from laptop or desktop computer that has a web google chrome browser, go to browser and input http://rcl.ied.edu.hk:8000/page_rcl.html (通過電腦的 Chrome 瀏覽器使用遙控實驗).

ii. Login the RCL with user 用戶: rcl, password 密碼: rcl.

iii. Right click & request for control (at grey colour area) and then remember to click on Run (). 在灰色區域右鍵單擊及要求的控制，然後記得點擊運行 ().

iv. Click on left/right button for observing & controlling the RCL experiments via IP camera 通過 IP 攝像頭，使用左/右按鈕來觀察實驗 (↑ ↓ ← → Refresh).

v Comment/Discussions (see Additonal Note): To tell your group / friend about your control and experiment time 在討論區告訴團隊/朋友對於你的控制和實驗時間.

vi. Click on Tab for L1-Electrical circuit experiment and then click on button for control 點擊選項於 L1 電路實驗，然後按鈕控制 (L1 - Electrical Circuits Expt).

vii.* ______

viii. ______

ix. ______

x. ______

(*Start from vii. list out your own experimental procedure 從七開始，列出你們的實驗步驟)

**Experimental setup (裝置) - Figure(s) / picture(s):**

Window: Press the "Print Screen (列印螢幕)" key [Print Screen/PrtScr] on your keyboard and Paste the screenshot below:

**Data:**

**In parallel circuit (*並聯電路*):**

| Number of Bulb *燈泡數量* | Brightness *亮度* | Your observation *觀察* |
|---|---|---|
| 1 | | |
| 2 | | |
| 3 | | |

If you remove 2nd bulb ( *中斷第二燈泡*) from the parallel circuit, do the remaining bulbs light up? **Yes / No**.

**In series circuit (*串聯電路*):**

| Number of Bulb *燈泡數量* | Brightness *亮度* | Your observation *觀察* |
|---|---|---|
| 1 | | |
| 2 | | |
| 3 | | |

If you remove 2nd bulb ( *中斷第二燈泡*) from the series circuit, do the remaining bulbs light up? **Yes / No**

**Result:**

The patterns or relationships I found are (The data are organized on a chart or graph)

Window: Press the "Print Screen (列印螢幕)" key [Print Screen/PrtScr] on your keyboard and Paste the screenshot below:


**Conclusion:**

The answer to my question (my conclusion) is

**Reflection:**

- What have you learnt in the electrical circuit experiment about (a) scientific methods (*方法*), (b) scientific attitudes (*態度*) and (c) scientific knowledge (*知識*)

- Have you encountered any difficulties (*困難*)? How do you solve these problems?

- If you were given another chance to do the experiments again, what additional independent variable (variable to be changed) would you like to test? *如果再做一次電路實驗，你想測試什麼額外的獨立變數？*

**Teacher Guide:**

**Objectives**

At the end of the lesson, all students should

- be able to identify the difference of a series circuit and a parallel circuit
- be able to have practical experience on RCL for electrical circuit experiment

**Students' prior knowledge**

Primary 5:

- Life in the City
    - Closed circuits
    - Investigating electricity (simple circuits)
    - Electricity and everyday life

**Science Education Curriculum**

The underlying scientific concepts and principles closely match the science education curriculum of Hong Kong as recommended by the Education Bureau of the HKSAR.

Secondary 2:

- Making Use of Electricity
    - Idea of a closed circuit
    - Circuit symbols: simple circuit diagrams
    - Series and parallel circuits

**Background:**

***Electrical circuit connection***

What is the example of a series circuit and a parallel circuit in your house? Electricity plays a vital role in our daily life, such as light, computer, mobile devices, refrigerator or even air-conditioner. Basically, it needs to complete an electric circuit for activate the electrical devices. The electric circuit is a path connected by wire for the flow of electrons. Therefore, an electric source is needed for the movement of electrons like a battery or other power source. These movements of the electron will make the device work. Normally, a switch is attached to the devices for turned 'ON' or 'OFF' process. In this activity, a battery, wire and a bulb are needed for the basic circuit connection to light up a bulb. To complete a circuit, you need to make a connection from positive terminal of battery to positive terminal of a bulb and from negative terminal of the bulb to negative terminal of the battery. With additional bulbs connected to a battery, you can get another two types of circuit connections called as series and parallel circuits' connection.

What is a real life example of a series circuit and a parallel circuit? Fuses and switches are the example of series circuit connection. Parallel circuit connection will be more common in our daily life for example any extension cord or socket (photo above) and electrical appliances. In a series circuit connection, all the devices are connected from one to the others (see Figure 1). If you put more bulbs into a series circuit, the bulbs will become dimmer. In a parallel circuit connection, all the devices are connected in parallel (see Figure 2). If you put more bulbs into a parallel circuit, the bulbs will remain the same brightness.

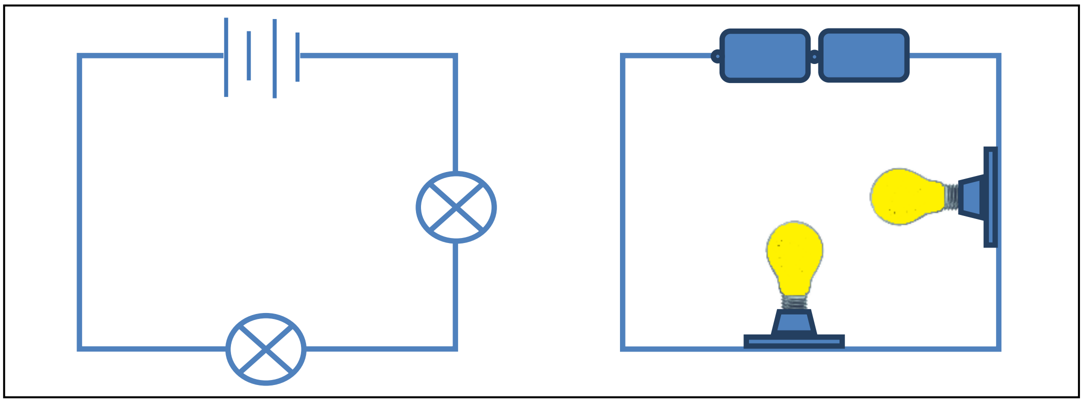


**Figure 1.** Series Circuit Connection

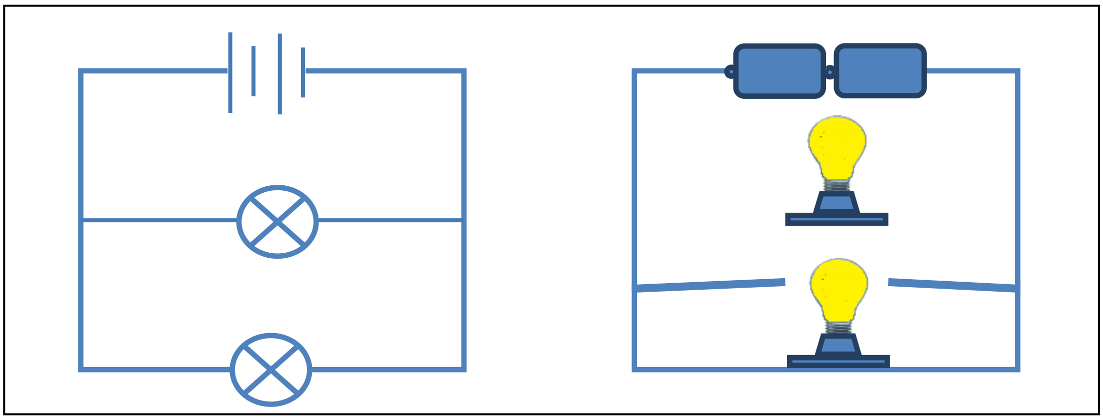


**Figure 2.** Parallel Circuit Connection

***Basic Facts and Supplemental Information:***

- Electricity is generated by the flow of electrons.
- There are two types of current: direct current (DC) and alternating current (AC).
- In DC, electrons move in a single direction
- In AC, the electrons change directions, switching between backwards and forwards.
- The electricity use at home is AC but DC comes from all forms of batteries.
- Two types of circuit connections called as series (Figure 1) and parallel (Figure 2) circuits' connection.
- In parallel circuits, the bulbs will keep same brightness.
- In series circuit, the bulbs will be dimmer with additional of bulbs.

***What is the remote-controlled laboratory?***

Remote-controlled laboratory is a real-time experiment that can be controlled or monitored by user from their computer through the Internet browser. It is also known as the Web-Based Laboratory.

The RCL system is commonly divided into two major parts, namely, hardware and software. The hardware part consists of the data acquisition system, digital input or output (DIO), camera, and various types of sensors. The software part executes data logging as well as controls and displays the real-time experiment on the computer screen via the Internet.

Thus, the RCL activity enables more flexible delivery (anytime), distance education (anyplace) and new visualization possibilities (interactivity).

**Sample result and procedure**

**Variables:** Please underline or circle your variable(s)

| | |
|---|---|
| The variable to be changed (independent variable) is | Brightness of bulb(s) /**Number of bulbs** /Power supply /Types of bulbs |
| The variable to be monitored (dependent variable) is | **Brightness of bulb(s)** /Number of bulbs /Power supply /Types of bulbs |
| The variable(s) to be kept constant (controlled variable(s)) | Brightness of bulb(s) /Number of bulbs /**Power supply /Types of bulbs** |

**Procedure:**

1. Move the IP camera view to L1: Electrical circuit experiment,

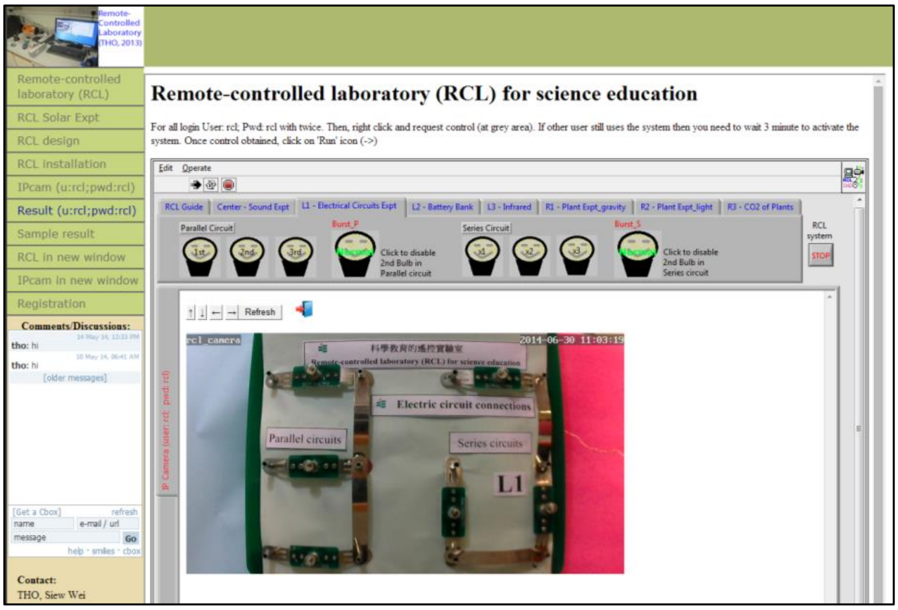
***In parallel circuit,***

2. Turn on the light of first bulb,
3. Turn on the light of second bulb, record the brightness of the bulbs.
4. Turn on the light of third bulb, record the brightness of the bulbs.
5. Disable the 2nd bulb by clicking on the Burst_P button
6. Repeat the step 2-3 and record your observation.

***In series circuit,***

7. Turn on the light of first bulb,
8. Turn on the light of second bulb, record the brightness of the bulbs.
9. Turn on the light of third bulb, record the brightness of the bulbs.
10. Disable the 2nd bulb by clicking on the Burst_S button
11. Repeat the step 7-9 and record your observation.

**Figure:**



**Data:**

**In parallel circuit:**

| Number of Bulb | Brightness | Your observation |
| --- | --- | --- |
| 1 | Bright, B1 | Bright. |
| 2 | Bright, B2 | B1=B2, Same brightness with first bulb. |
| 3 | Bright, B3 | B1=B2=B3, Same brightness with first and second bulbs. |

If you remove the 2nd bulb from the parallel circuit, do the remaining bulbs light up? **<u>Yes.</u>**

**In series circuit:**

| Number of Bulb | Brightness | Your observation |
| --- | --- | --- |
| 1 | Bright, B4 | B4, Same brightness with parallel circuit bulbs. |
| 2 | Dim, B5 | B4>B5, Lower brightness than first bulb |
| 3 | Very dim, B6 | B4>B5>B6, Lowest brightness |

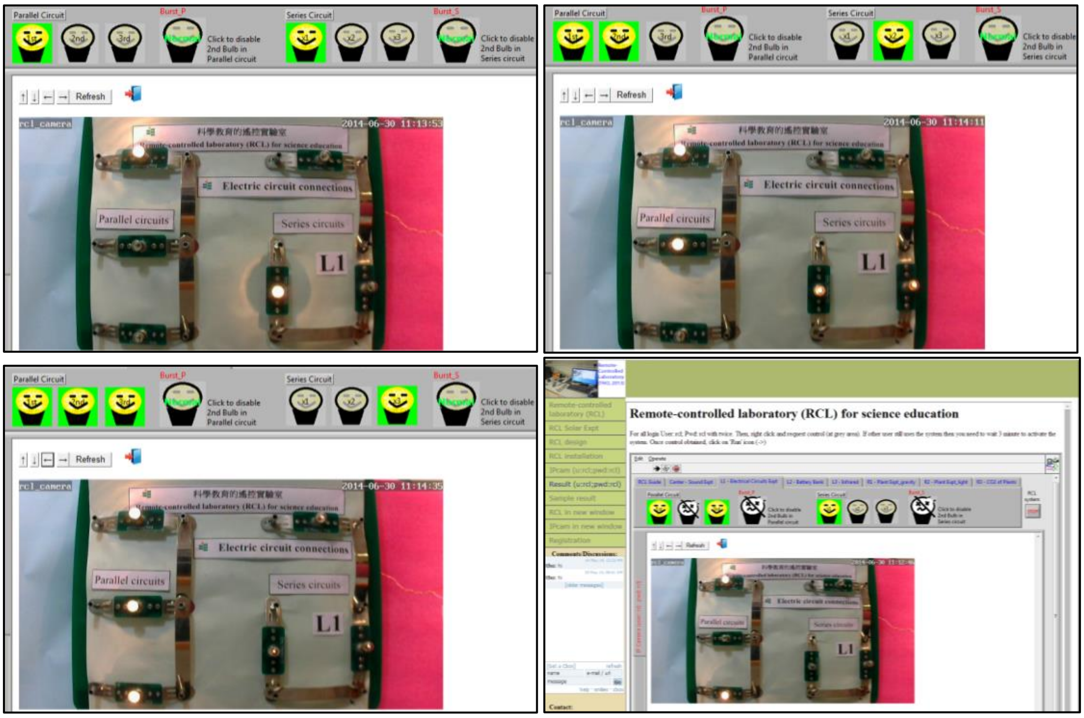
If you remove the 2nd bulb from the series circuit, do the remaining bulbs light up? **<u>No.</u>**

**Result:**

In a parallel circuit, brightness 1st bulb = brightness 2nd bulb = brightness 3rd bulb. If one bulb is removed, then the other bulb will light up.

In a series circuit, brightness One bulb > brightness two bulbs > brightness three bulbs. If one bulb is removed, then the other bulb will not light up.

**Figure:**



**Conclusion:**

In a parallel circuit, if one bulb is removed, then the electric current can still flow through the remaining point/circuit/path. In a series circuit, the electric current is same at all point in the series circuit. If one bulb is removed, then the electric current cannot flow the circuit.

**References:**


Bell, R. L., Smetana, L., & Binns, I. (2005). Simplifying Inquiry Instruction. *Science Teacher, 72*(7), 30-33.

Cheung, D. (2006). *Inquiry-based laboratory work in chemistry: Teacher's guide*. Hong Kong: Department of Curriculum and Instruction, The Chinese University of Hong Kong.

Llewellyn, D. (2007*). Inquire within: implementing inquiry-based science standards in grades 3-8. (2nd ed.)*. California, US: Corwin Press.

Llewellyn, D. (2013). *Teaching high school science through inquiry and argumentation (2nd ed.)*. Thousand Oaks, California, US: Corwin Press.

Lorbeer, G. C. (2000*). Science activities for middle school students (2nd ed.)*. US: McGraw-Hill.

Kong, S., Yeung, Y., & Wu, X. (2009). An Experience of Teaching for Learning by Observation: Remote-Controlled Experiments on Electrical Circuits. *Computers & Education, 52*(3), 702-717.

Tong, S. S., IP, H. W., Lam, W. L. & Wong, T. P. (2010). *Interactive Science 2A (2nd ed.)*. Hong Kong: Longman.

**Student worksheet:**
**L2: The Battery Bank**

| Name: | Date: |
|---|---|
| 1. | **Group:** |
| 2. | |
| 3. | |
| 4. | |
| 5. | |

**Inquiry Question:** Is the capacity of a battery bank or power bank always being true as stated *移動電池的容量是否真確*?

Recently, there are many fake (*假冒*) battery bank products (see Figure 1a retrieved from [http://hk.apple.nextmedia.com/realtime/news/20140415/52383124](http://hk.apple.nextmedia.com/realtime/news/20140415/52383124)) or low cost battery bank with unique name were presented. The questions you may ask like "is it safe to use such product?" and "Does the capacity of the battery products always be true as stated?" Battery bank plays a vital role in our daily life to charge up the Smartphone or tablet devices. Nowadays, the capacity of the battery bank is dramatically increased from below 2000mAh to more than 10000mAh. This experiment is to explore the efficiency of the battery bank (*探索移動電池的效率*).


**Figure 1a:** News of fake battery bank **Figure 1b:** three type of battery bank products

You are asked to plan and carry out an investigation to test the following two hypotheses?

- If the power of battery bank is consumed (*如果電池被消耗*), then the power output will be equal to the power stated because it is labelled at the product as the chemical energy of battery is converted into electrical energy (*電池中的化學能轉換成電能*).

You are asked to answer the following question:

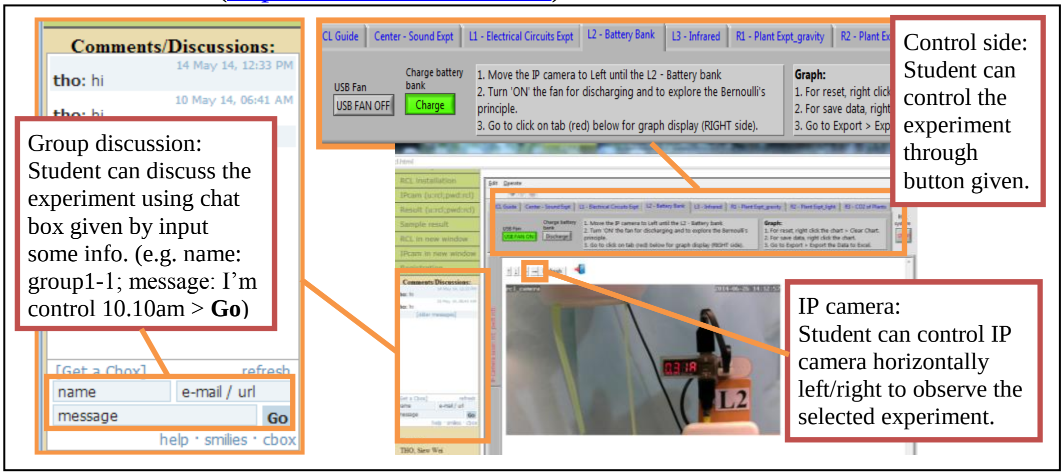
- What is energy efficiency of battery (*電池的能量效率*)? ( If low efficiency, please give your reasons)
- If you were given another chance to do the experiments again, what additional independent variable (variable to be changed) would you like to test?

**Material and Apparatus:**

1. Computer
2. Internet

3. RCL User Manual – Login Card and Guide
4. L2: Battery bank

**Additional Note:** (http://rcl.ied.edu.hk:8000)




***How to measure the power of fan*** (*如何測量風扇的電功率*)
Take an average of the data shown from the ammeter-voltmeter (red digit). Record the current (I) value with unit ampere and voltage (V) value unit volt into given blanks. Then, the electrical power (P) of fan with unit Watts (joules per second) is given by

$$P = I \times V$$

Where:

P is the instantaneous power *功率*, (watts or joules per second)
V is the potential difference *電壓* across the fan, (volts)
I is the current *電流* through the fan, (amperes)

The efficiency of the battery bank *電效率 is* given by

$$Efficiency = \frac{P_{out}}{P_{in}} \times 100\%$$

Where:

Pout is total output power (discharging the fan *風扇放電*)
Pin is total input power (Battery power based on the given information *根據提供電池功率*)

**Variables (*變量/變數*):** Please underline or circle your variable(s)

| | |
|---|---|
| The variable to be changed (independent variable *獨立變數*) is | Discharging battery bank /Fully charged /Temperature /Power of the battery bank |
| The variable to be monitored (dependent variable *因變數*) is | Discharging battery bank /Fully charged /Temperature /Power of the battery bank |
| The variable(s) to be kept constant (controlled variable(s) *控制變數*) | Discharging battery bank /Fully charged /Temperature /Power of the battery bank |

**List the experimental procedure and capture your setup with IP camera or print screen:**
**(RCL procedures are provided)**

The steps I follow are (The procedures are):

| | |
|---|---|
| i. | To remotely access the RCL system from laptop or desktop computer that has a web google chrome browser, go to browser and input http://rcl.ied.edu.hk:8000/page_rcl.html (通過電腦的 Chrome 瀏覽器使用遙控實驗). |
| ii. | Login the RCL with user 用戶: rcl, password 密碼: rcl. |
| iii. | Right click & request for control (at grey colour area) and then remember to click on Run ( ). 在灰色區域右鍵單擊及要求的控制，然後記得點擊運行 ( ). |
| iv. | Click on left/right button for observing & controlling the RCL experiments via IP camera 通過 IP 攝像頭，使用左/右按來鈕觀察實驗 (↑ ↓ ← → Refresh ). |
| v | Comment/Discussions (see Additonal Note): To tell your group / friend about your control and experiment time 在討論區告訴團隊/朋友對於你的控制和實驗時間. |
| vi. | Click on Tab for L2-battery bank experiment and then click on button for control 點擊選項於 L2-電池實驗，然後按鈕控制( L2 - Battery Bank ). |
| vii.* | |
| viii. | |
| ix. | |
| x. | |

(*Start from vii. list out your own experimental procedure 從七開始，列出你們的實驗步驟)

**Experimental setup (裝 置) - Figure(s) / picture(s):**

(Window: Press the "Print Screen (列印螢幕)" key [Print Screen/PrtScr] on your keyboard and Paste the screenshot below. Mac: Press the Command + Shift + 3 key on your keyboard and then Open the screen capture on your desktop)

**Data:**

**Given Information** *根據電池提供或標籤顯示的功率***:**

5 Volts Battery: 5200mAh (5.2A per hour)

Battery power (*電池標籤的功率*): 26W per hour = 93600W per second

**Task:** Fan voltage *電壓*: ±_______ V; Fan current *電流*: ± _______ A

Fan power 功率: ±_______ W (Fan voltage x Fan current)

| Time Start *開始時間* | Time End *結束時間* | *Duration time of Fan (Discharge) *放電時間*, s | Power consumed (*電池實驗的功率*)(Fan power x time) |
|---|---|---|---|
| | | | |
| | | | |

* convert all the time in second (Duration column) *將所有的時間轉為秒*

**Result:**

The patterns or relationships I found are (The data are organized on a movie or chart or graph)

[Images of the experiment are stored at 5-minute time interval & it can be downloaded from http://rcl.ied.edu.hk:8000/page_result.html with login by using user: rcl, password: rcl and then by clicking on date (e.g. 20140927) > time (e.g. images003) > images (JPEG format, e.g. P14082120214300.jpg). You can edit the images, rearrange them using video editing software, and create their own result movie ; 5分鐘間隔的實驗圖像將儲存在 http://rcl.ied.edu.hk:8000/page_result.html 用戶: rcl密碼: rcl然後點擊日期（如20140927）>時間（如images003）>圖像（JPEG格式，如P14082120214300.jpg），您可以使用視頻編輯軟件重新排列圖片，並編輯實驗結果影片]

**Conclusion:**

The answer to my question (my conclusion) is

**Reflection:**

- What have you learnt in the battery bank experiment about (a) scientific methods (*方法*), (b) scientific attitudes (*態度*) and (c) scientific knowledge (*知識*)?

- Have you encountered any difficulties (*困難*)? How do you solve these problems?

- If you were given another chance to do the battery bank experiment again, what additional independent variable (variable to be changed) would you like to test? *如果再做一次電池實驗，你想測試什麼額外的獨立變數？*

**Teacher Guide:**

**Objectives**

At the end of the lesson, all students should

- be able to explore the efficiency of the battery bank
- be able to have practical experience on RCL for battery bank experiment

**Students' prior knowledge**

Primary 5:

- Life in the City
  - Electricity and everyday life

Primary 6:

- Environment and Living
  - Energy and the environment

**Science Education Curriculum**

The underlying scientific concepts and principles closely match the science education curriculum of Hong Kong as recommended by the Education Bureau of the HKSAR.

Secondary 1:

- Energy
  - Different forms of energy: heat, light, sound, kinetic, potential, chemical and electrical energy
  - Simple energy changes: energy converters, controlled and uncontrolled energy conversion

Secondary 2:

- Making Use of Electricity
  - Current: measurement and its unit
  - Voltage: measurement and its unit
  - Power of an electrical appliance

**Background:**

***Battery Bank***

Recently, there are many fake battery bank products (see Figure 1a retrieved from http://hk.apple.nextmedia.com/realtime/news/20140415/52383124) or low cost battery bank with unique name were presented. The questions you may ask like "is it safe to use such product?" and "Does the capacity of the battery products always be true as stated?" Battery bank plays a vital role in our daily life to charge up the Smartphone or tablet devices. Nowadays, the capacity of the battery bank is dramatically increased from below 2000mAh to more than 10000mAh. This experiment is to explore the efficiency of the battery bank.

***Basic Facts and Supplemental Information:***

1. Electricity is generated by the flow of electrons.
2. There are two types of current: direct current (DC) and alternating current (AC).
3. In DC, electrons move in a single direction
4. In AC, the electrons change directions, switching between backwards and forwards.

5. The electricity use at home is AC but DC comes from all forms of batteries.

***What is the remote-controlled laboratory?***

Remote-controlled laboratory is a real-time experiment that can be controlled or monitored by user from their computer through the Internet browser. It is also known as the Web-Based Laboratory.

The RCL system is commonly divided into two major parts, namely, hardware and software. The hardware part consists of the data acquisition system, digital input or output (DIO), camera, and various types of sensors. The software part executes data logging as well as controls and displays the real-time experiment on the computer screen via the Internet.

Thus, the RCL activity enables more flexible delivery (anytime), distance education (anyplace) and new visualization possibilities (interactivity).

**Sample result and procedure**

**Variables:** Please underline or circle your variable(s)

| | |
|---|---|
| The variable to be changed (independent variable) is | **<u>Discharging battery bank</u>** /Fully charged /Temperature /Power of the battery bank |
| The variable to be monitored (dependent variable) is | Discharging battery bank /Fully charged /Temperature /**<u>Power of the battery bank</u>** |
| The variable(s) to be kept constant (controlled variable(s)) | Discharging battery bank /**<u>Fully charged /Temperature</u>** /Power of the battery bank |

**Procedure:**

1. Move the IP camera view to L2: Battery bank (see figure 1a),
2. Charge the battery bank until the 4 LED indicators light stop blinking (Fully charged sign as figure 1b and it may take several hours).
3. Record the experimental time.
4. Turn on the fan for discharging the battery bank, record the voltage and current of the fan as shown by red digit ammeter-voltmeter.
5. Observe the fan condition; it will turn off when all the chemical energy is converted into electrical energy by downloading the result from the server (http://rcl.ied.edu.hk:8000/page_result.html).
6. Calculate the efficiency of the battery bank.

**Extension:**

7. Student may try to charge the battery bank for 10minute and discharge by turn on the fan and repeat the step 5.
8. Then, repeat the step 6 for 20 and 30 minutes for plotting the power versus time graph.

*** Based on their independent variable selection (up to their decision, student may try three hour).**

**Figure:**

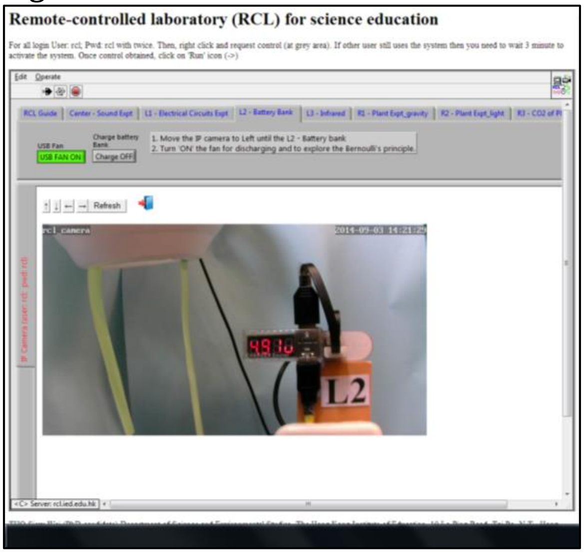




**Figure 1a:** Battery bank experimental setup **Figure 1b:** Fully charged sign

**Finding:**

**Data:**

**Given Information:**

5 Volts Battery: 5200mAh (5.2A per hour)

Battery power: 26W per hour = 93600W per second

Fan voltage: ±4.93 V

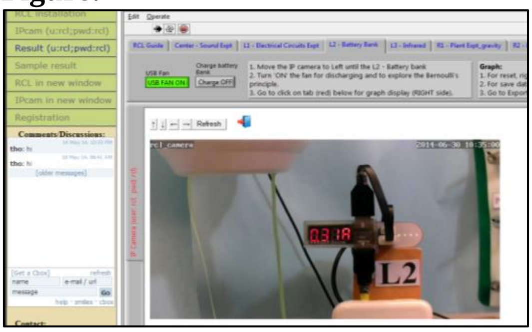
Fan current: ± 0.31 A

Fan power: ±1.5W (Fan voltage x Fan current)

| Time Start | Time End | *Duration time of Fan (Discharge), s | Power consumed (Fan power x time) |
|---|---|---|---|
| 1035 | 2107 | 8 hours and 32 minutes (30720s) | 46080 |
| | | | |

* convert all the time in second (Duration column)

**Figure:**



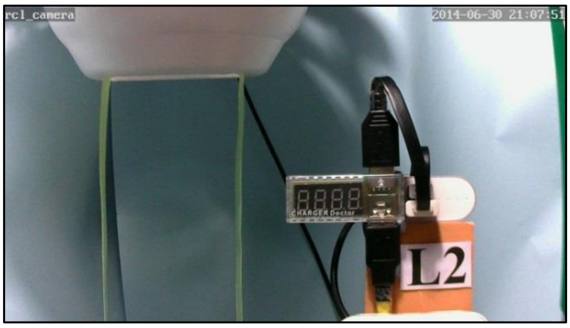




**Figure 2a:** Discharging by turn on the fan **Figure 2b:** the fan stop at 9.07pm

**Calculation:**

**Efficiency of battery bank**

Total input power (Battery power based on the given information) = 93600W per second

Total out power (Power consumed (Fan power x time)) =

The efficiency of the battery bank is given by

$$\text{Efficiency} = \frac{P_{out}}{P_{in}}\ x\ 100\%$$

$$\text{Efficiency} = \frac{46080}{93600}\ x\ 100\% = 49.2\%$$

Where:

$P_{out}$ is total output power (discharging the fan)

$P_{in}$ is total input power (Battery power based on the given information)

**Conclusion:**

The hypothesis is rejected. The power out of the battery is only 49.2%. However, this low efficiency may due to the noise (fractuation) of the current and voltage (as shown by the multimeter) as well as the energy is converted to other forms like heat.

**References:**


Bell, R. L., Smetana, L., & Binns, I. (2005). Simplifying Inquiry Instruction. *Science Teacher, 72*(7), 30-33.

Cheung, D. (2006). *Inquiry-based laboratory work in chemistry: Teacher's guide*. Hong Kong: Department of Curriculum and Instruction, The Chinese University of Hong Kong.

Llewellyn, D. (2007*). Inquire within: implementing inquiry-based science standards in grades 3-8. (2nd ed.)*. California, US: Corwin Press.

Llewellyn, D. (2013). *Teaching high school science through inquiry and argumentation (2nd ed.)*. Thousand Oaks, California, US: Corwin Press.

Lorbeer, G. C. (2000*). Science activities for middle school students (2nd ed.)*. US: McGraw-Hill.

**Student worksheet:**
**L3 – Infrared**

| Name: | Date: |
|---|---|
| 1. | Group: |
| 2. | |
| 3. | |
| 4. | |
| 5. | |

**Inquiry Question:** What are the colours of objects under the IR light of the IP camera?
What is the sequence of the brightness of the colours? IR is electromagnetic radiation with longer wavelengths than visible light which is beyond our human visible spectrum. There are a lot of applications of IR in our daily life comprising night vision, heating, tracking and remote control system. In this case, the remote experiment is to explore the application of IR for night vision and differentiate the different colours in darkness under IR light.

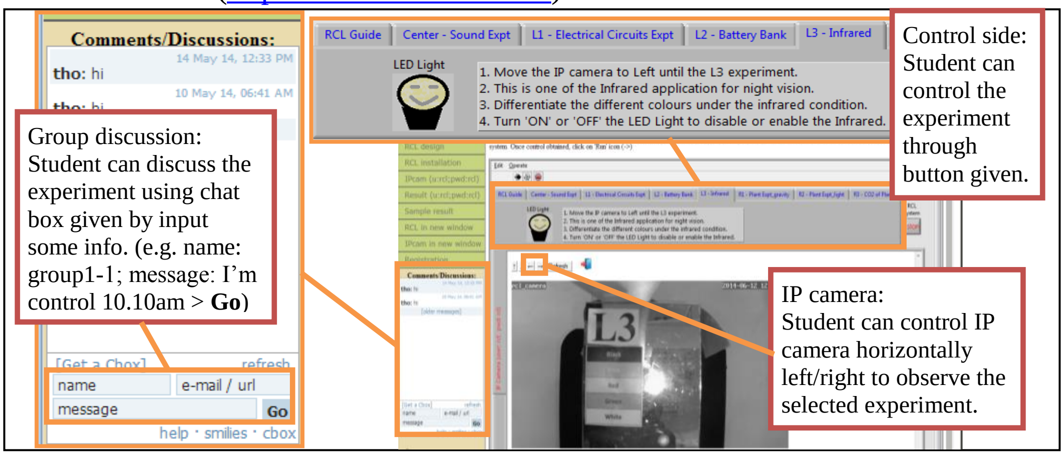

You are asked to plan and carry out an investigation to test the following hypothesis?

- If the light is turned off, then the colour will display with different brightness under infrared IP camera because the infrared radiation.

**Material and Apparatus:**

1. Computer
2. Internet
3. RCL User Manual – Login Card and Guide
4. L3: Infrared

**Additional Note:** (http://rcl.ied.edu.hk:8000)



**Variables:** Please underline or circle your variable(s)

| | |
|---|---|
| The variable to be changed (independent variable) is | Colour and brightness under white and IR light/ Enabling and disabling IR light / Intensity of IR radiation / Temperature |
| The variable to be monitored (dependent variable) is | Colour and brightness under white and IR light/ Enabling and disabling IR light / Intensity of IR radiation / Temperature |
| The variable(s) to be kept constant (controlled variable(s)) | Colour and brightness under white and IR light/ Enabling and disabling IR light / Intensity of IR radiation / Temperature |

**List the experimental procedure and capture your setup with IP camera or print screen:**

The steps I follow are (The procedures are):

i. To remotely access the RCL system from laptop or desktop computer that has a web google chrome browser, go to browser and access the http://rcl.ied.edu.hk:8000/page_rcl.html

ii. Login the RCL with user: rcl, password: rcl.

iii. Right click & request for control (at grey colour area 在灰色區域) and then remember to click on Run ( ).

iv. Click on left/right button for observing & controlling the RCL experiments via IP camera (↑ ↓ ← → Refresh).

v Comment/Discussions (see Additonal Note): To tell your group / friend about your control and experiment time.

vi. Click on Tab for L3-Infrared experiment and then click on button for control (L3 - Infrared).

vii.* __________

viii. __________

ix. __________

x. __________

(*Start from vii. list out your own experimental procedure)

**Figure(s) / picture(s):** (Window: Press the "Print Screen" key [Print Screen/PrtScr] on your keyboard and Paste the screenshot below. Mac: Press the Command + Shift + 3 key on your keyboard and then Open the screen capture on your desktop)

**Data:**

| No. | Colour under white light | Brightness under Infrared night vision | | | |
|---|---|---|---|---|---|
| 1 | | Dark | Light Grey | Grey | Dark Grey |
| 2 | | Dark | Light Grey | Grey | Dark Grey |
| 3 | | Dark | Light Grey | Grey | Dark Grey |
| 4 | | Dark | Light Grey | Grey | Dark Grey |
| 5 | | Dark | Light Grey | Grey | Dark Grey |

**Result:**

The patterns or relationships I found are (The data are organized on a chart or graph)
(Window: Press the "Print Screen" key [Print Screen/PrtScr] on your keyboard and Paste the screenshot below.
Mac: Press the Command + Shift + 3 key on your keyboard and then Open the screen capture on your desktop)

**Conclusion:**

The answer to my question (my conclusion) is

**Reflection:**

- What have you learnt in the IR experiment about (a) scientific knowledge, (b) scientific methods, and (c) scientific attitudes?
- Have you encountered any difficulties? How do you solve these problems?

**Teacher Guide:**

**Objectives**

At the end of the lesson, all students should

- be able to identify the characteristic of IR night vision through the observation of colours
- be able to have practical experience on RCL for night vision using IR camera

**Students' prior knowledge**

Primary 4:

- Hearing and Looking at Fantastic Things
    - Investigating light
    - The wonderful world of colours
    - Special effects of light

**Science Education Curriculum**

The underlying scientific concepts and principles closely match the science education curriculum of Hong Kong as recommended by the Education Bureau of the HKSAR.

Secondary 3

- Light, colours and beyond
- Beyond the visible spectrum
    - Infrared radiation and its applications

**Background**

***Infrared radiation and its applications***

What do different colours look in darkness under IR light? IR is electromagnetic radiation with longer wavelengths than visible light which is beyond our human visible spectrum. There are a lot of applications of IR in our daily life comprising night vision, heating, tracking and remote control system. In this case, the remote experiment is to explore the application of IR for night vision and differentiate the different colours in darkness under IR light.

***Basic Facts and Supplemental Information:***

1. IR radiation is commonly known as heat radiation.
2. IR radiation is lengthens than nominal red edge of the visible spectrum at 700 nanometers (nm) to 1 mm.
3. IR frequency range of around the region of 430 THz down to 300 GHz.
4. IR application: night vision, heating, tracking, remote control system and so on.

***What is the remote-controlled laboratory?***

Remote-controlled laboratory is a real-time experiment that can be controlled or monitored by user from their computer through the Internet browser. It is also known as the Web-Based Laboratory.

The RCL system is commonly divided into two major parts, namely, hardware and software. The hardware part consists of the data acquisition system, digital input or output (DIO), camera, and various types of sensors. The software part executes data logging as well as controls and displays the real-time experiment on the computer screen via the Internet.

Thus, the RCL activity enables more flexible delivery (anytime), distance education (anyplace) and new visualization possibilities (interactivity).

**Sample result and procedure**

**Variables:** Please underline or circle your variable(s)

| | |
|---|---|
| The variable to be changed (independent variable) is | Colour and brightness under white and IR light/ **Enabling and disabling IR light** / Intensity of IR radiation / Temperature |
| The variable to be monitored (dependent variable) is | **Colour and brightness under white and IR light**/ Enabling and disabling IR light / Intensity of IR radiation / Temperature |
| The variable(s) to be kept constant (controlled variable(s)) | Colour and brightness under white and IR light/ Enabling and disabling IR light / **Intensity of IR radiation / Temperature** |

**Procedure:**

1. Move the IP camera view to L3 – Infrared,
2. Turn on the light, record the colours in the table below.
3. Turn off the light, observe the paper with different colours under Infrared condition. Record your observations based on the brightness of the colours in the table below.


**Figure 1:** L3 – Infrared remote laboratory setup

**Findings:**

***Figure:***


**Figure 1a:** Under Infrared condition

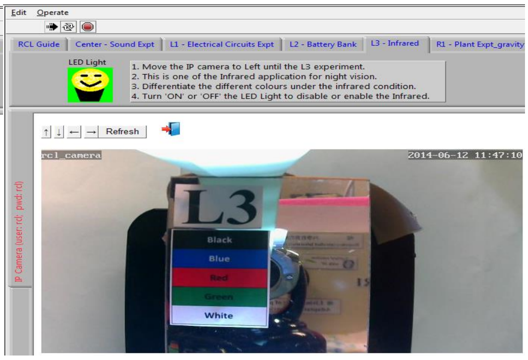



**Figure 1b:** Under white light condition

**Data:**

| No. | Colour under white light | Brightness under Infrared night vision | | | |
|---|---|---|---|---|---|
| 1 | Black | **Dark** | Light Grey | Grey | Dark Grey |
| 2 | Blue | Dark | Light Grey | **Grey** | Dark Grey |
| 3 | Red | Dark | **Light Grey** | Grey | Dark Grey |
| 4 | Green | Dark | Light Grey | Grey | **Dark Grey** |
| 5 | White | Dark | **Light Grey** | Grey | Dark Grey |

**Results:**

Night vision is an important of application of IR radiation. Based on the brightness, it is anticipated the original of the colours.

**Conclusion:**

The sequence of brightness from dark to light: Black > Green > Blue > Red > White.

**References:**

Bell, R. L., Smetana, L., & Binns, I. (2005). Simplifying Inquiry Instruction. *Science Teacher, 72*(7), 30-33.

Cheung, D. (2006). *Inquiry-based laboratory work in chemistry: Teacher's guide*. Hong Kong: Department of Curriculum and Instruction, the Chinese University of Hong Kong.

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Llewellyn, D. (2007*). Inquire within: implementing inquiry-based science standards in grades 3-8. (2nd ed.)*. California, US: Corwin Press.

Llewellyn, D. (2013). *Teaching high school science through inquiry and argumentation (2nd ed.)*. Thousand Oaks, California, US: Corwin Press.

Lorbeer, G. C. (2000*). Science activities for middle school students (2nd ed.)*. US: McGraw-Hill.

Tong, S. S., Ip, H. W., Lam, W. L. & Wong, T. P. (2012) *Interactive Science 3C (2nd ed.)*. Hong Kong: Pearson.

**Student worksheet:**

**R1 – Plant - Gravity**

| Name: | Date: |
|---|---|
| 1. | **Group:** |
| 2. | |
| 3. | |
| 4. | |
| 5. | |

**Inquiry Question:** Do the shoots always grow upward *植物芽是否一直向上生長*?
Do you ever observe the plants around you like figure below? How do the plants move? Why do the plants move? Tropism (*向性*) is the ordinary growth response of a plant to external stimuli. The stimuli can be light (*phototropism 向光性*), touch (*thigmotropism 向觸性*), chemical (*chemotropism 向化性*) or gravity (*gravitropism* or *geotropism 向地性*). The positive response (*正向性*) is directed by growth toward a stimulus and the negative response (*負向性*) is indicated by growth away from the stimulus.

You are asked to plan and carry out an investigation to test the following two hypotheses?

- In day time, if the upward position plants are rotated by $90^o$ to a horizontal direction (*90 度轉動到水準方向*), then the plants will grow upward because the force of gravity (*重力*).
- In night time, if the upward position plants are rotated by $90^o$ to a horizontal direction (*90 度轉動到水準方向*), then the plants will grow upward because the force of gravity (*重力*).

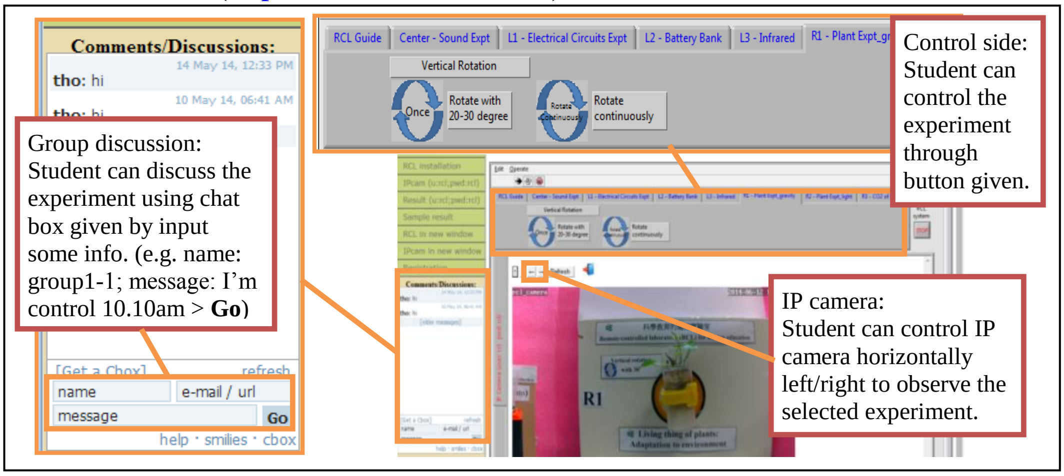
You are asked to answer the following question:

- How can you measure the rate of plants growth in daytime [8am-6pm] and night time [after 6pm] (*日間[8am-6pm]和夜間[>6pm]*)?
- In result session, what patterns do you get from your findings?
- If you were given another chance to do the experiments again, what additional independent variable (variable to be changed) would you like to test?

**Material and Apparatus:**

1. Computer
2. Internet
3. RCL User Manual – Login Card and Guide
4. R1: Plants experiment – gravity

**Additional Note:** (http://rcl.ied.edu.hk:8000)




**Variables (*變量/變數*):** Please underline or circle your variable(s)

| | |
|---|---|
| The variable to be changed (independent variable *獨立變數*) is | Daytime / Night-time / Position of the pot / Rate of the plant growth response / Temperature / Types of plants |
| The variable to be monitored (dependent variable *因變數*) is | Daytime / Night-time / Position of the pot / Rate of the plant growth response / Temperature / Types of plants |
| The variable(s) to be kept constant (controlled variable(s) *控制變數*) | Daytime / Night-time / Position of the pot / Rate of the plant growth response / Temperature / Types of plants |

**List the experimental procedure and capture your setup with IP camera or print screen:**

**(RCL procedures are provided)**

The steps I follow are (The procedures are):

i. To remotely access the RCL system from laptop or desktop computer that has a web google chrome browser, go to browser and input http://rcl.ied.edu.hk:8000/page_rcl.html (通過電腦的 Chrome 流覽器使用遙控實驗).

ii. Login the RCL with user 用戶: rcl, password 密碼: rcl.

iii. Right click & request for control (at grey colour area) and then remember to click on Run ( ). 在灰色區域按右鍵及要求的控制，然後記得點擊運行 ( ).

iv. Click on left/right button for observing & controlling the RCL experiments via IP camera 通過 IP 攝像頭，使用左/右按鈕來觀察實驗 ( Refresh ).

v Comment/Discussions (see Additonal Note): To tell your group / friend about your control and experiment time 在討論區告訴團隊/朋友對於你的控制和實驗時間.

vi. Click on Tab for R1- plant experiment respond to gravity & click on button for control 點擊選項於 R1 植物重力實驗，然後按鈕控制 ( R1 - Plant Expt_gravity ).

vii.* ______

viii. ______

ix. ___

x. ___

(*Start from vii. list out your own experimental procedure 從七開始，列出你們的實驗步驟)

**Experimental setup (裝置) - Figure(s) / picture(s):**

(Window: Press the "Print Screen (列印螢幕)" key [Print Screen/PrtScr] on your keyboard and Paste the screenshot below. Mac: Press the Command + Shift + 3 key on your keyboard and then Open the screen capture on your desktop)

**Data:**

Time Start *開始時間*: ___

Time End *結束時間*: ___

Orientation of plants position (in degree) *植物的位置定位(度)*: ___

| Time (hh:mm) *時間* | Angle *角度*(photo attached *附圖片*) | Your Observation *觀察* |
|---|---|---|
| | | |
| | | |
| | | |
| | | |

**Result:**

The patterns or relationships I found are (The data are organized on a chart or graph)

[Images of the experiment are stored at 5-minute time interval & it can be downloaded from http://rcl.ied.edu.hk:8000/page_result.html with login by using user: rcl, password: rcl and then by clicking on date (e.g. 20140927) > time (e.g. images003) > images (JPEG format, e.g. P14082120214300.jpg). You can edit the images, rearrange them using video editing software, and create their own result movie; 5分鐘間隔的實驗圖像將儲存在 http://rcl.ied.edu.hk:8000/page_result.html 用戶: rcl密碼: rcl然後點擊日期（如20140927）>時間（如images003）>圖像（JPEG格式，如P14082120214300.jpg），您可以使用視頻編輯軟體重新排列圖片，並編輯實驗結果影片]

**Conclusion:**

| |
|---|
| The answer to my question (my conclusion) is |

**Reflection:**

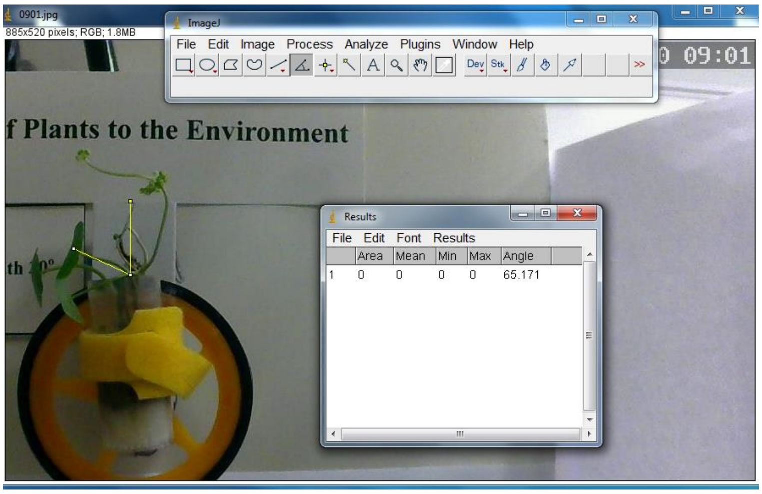
- What have you learnt in the plants respond to gravity experiment about (a) scientific methods (*方法*), (b) scientific attitudes (*態度*) and (c) scientific knowledge (*知識*)?

- Have you encountered any difficulties (*困難*)? How do you solve these problems?

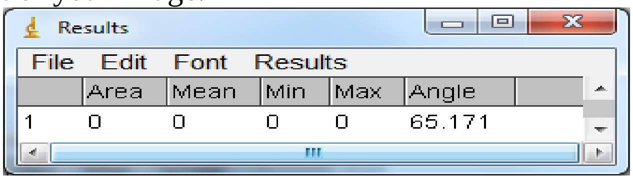
- If you were given another chance to do the experiments again, what additional independent variable (variable to be changed) would you like to test? *如果再做一次植物重力實驗，你想測試什麼額外的獨立變數？*

**Extra Note: length or angle measuring skills (特注：長度或角度測量技巧)**
**ImageJ Software: How to measure Plants' angle (Image J 軟體：**如何測量植物生長角度**)**

1. Measure the move of plant by referring to the change of angle based on **SINGLE** selection shoot using ImageJ (open source software able to measure angle changed).
2. First, download and install ImageJ (http://rsb.info.nih.gov/ij/) according to your operating system (OS) (i.e. Windows OS).
3. Open the selected image.
4. Measure the angles of the single shoot using the angle tool  by drawing a vertical reference straight line then go to the selected shoot as yellow line in figure below.

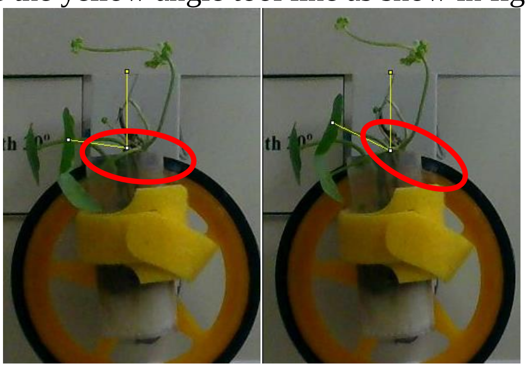



5. Then, go to Analyse tab > Measure or you can use shortcut Ctrl+M to generate angle result of your image.




| | Area | Mean | Min | Max | Angle |
|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 65.171 |

6. Repeat step 4 and 5 by go to tab File > open next > your next result image. Then just move the yellow angle tool line as show in figure below.



**Teacher Guide:**

**Objectives**

At the end of the lesson, all students should

- be able to investigate plant growth response through the external (gravity) stimuli **(An extension part of syllabus**)
- be able to have practical experience on RCL for plant's experiment

**Students' prior knowledge**

Primary 6:

- Environment and Living
    - o Adaptation of living things to the environment
    - o Adaptation of Living Things

**Science Education Curriculum**

The underlying scientific concepts and principles closely match the science education curriculum of Hong Kong as recommended by the Education Bureau of the HKSAR.

Secondary 1:

- Looking at Living Things
    - o Living things: characteristics of living things
    - o Living Things

**Background:**

***Plant growth response***

Do the shoots always grow upward? Tropism is the ordinary growth response of a plant to external stimuli. The stimuli can be light (*phototropism*), touch (*thigmotropism*), chemical (*chemotropism*) or gravity (*gravitropism* or geotropism). The positive response is directed by growth toward a stimulus and the negative response is indicated by growth away from the stimulus. In this case, *gravitropism* is the directional growth of a plant in response to gravity, and the response is negative.

***Basic Facts and Supplemental Information:***

- This attribute of shoots always seeking to grow upward is called negative "gravitropism".
- Roots have the opposite tendency. They always seek to grow downward. This attribute is called "geotropism" or "gravitropism".
- This means that roots tend to grow toward the centre of the Earth, and shoots tend to grow away from the centre, toward the Sun position.

***What is the remote-controlled laboratory?***

Remote-controlled laboratory is a real-time experiment that can be controlled or monitored by user from their computer through the Internet browser. It is also known as the Web-Based Laboratory.

The RCL system is commonly divided into two major parts, namely, hardware and software. The hardware part consists of the data acquisition system, digital input or output (DIO), camera, and various types of sensors. The software part executes data logging as well as controls and displays the real-time experiment on the computer screen via the Internet.

Thus, the RCL activity enables more flexible delivery (anytime), distance education (anyplace) and new visualization possibilities (interactivity).

**Sample result and procedure**
**Variables:** Please underline or circle your variable(s)

| | |
|---|---|
| The variable to be changed (independent variable) is | **Position of the pot** / Rate of the plant growth response /Temperature / Types of plants |
| The variable to be monitored (dependent variable) is | Position of the pot / **Rate of the plant growth response** /Temperature / Types of plants |
| The variable(s) to be kept constant (controlled variable(s)) | Position of the pot / Rate of the plant growth response /**Temperature / Types of plants** |

**Procedure:**
***Night time experiment:**

1. Record the experimental time.
2. Move the IP camera view to R1 – plant experiment of gravity,
3. At night time, the upward position plants are rotated by 90$^{o}$ to a horizontal direction, record the time, angle and pattern of the plant growth response and your observation for several hours (4-10 hours) in the table below by downloading the result from the server (http://rcl.ied.edu.hk:8000/page_result.html).

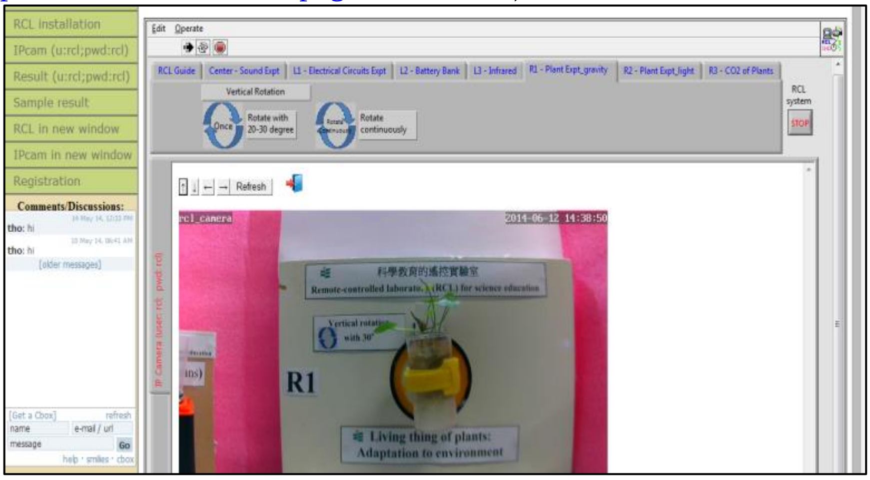
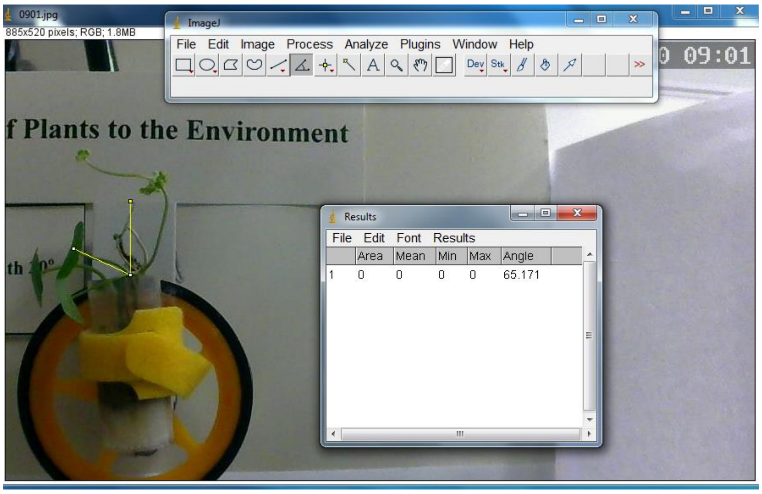
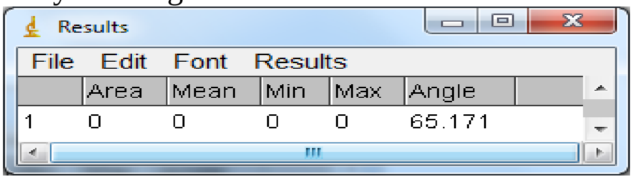



**Figure 1:** The setup of L3 – Plants experiment – gravity

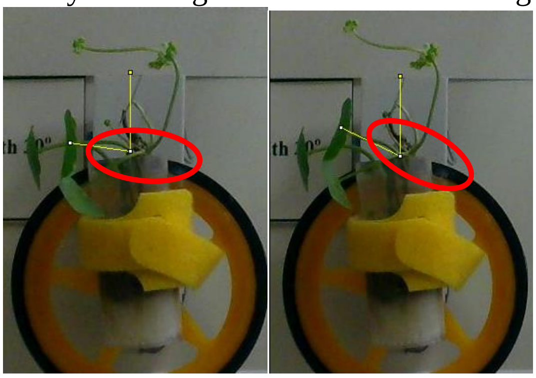
4. Measure the move of plant by referring to the change of angle based on single selection shoot using ImageJ software.
5. Open the selected image.
6. Measure the angles of the single shoot using the angle tool  by drawing a vertical reference straight line then go to the selected shoot as yellow line in figure below.




7. Then, go to Analyse tab > Measure or you can use shortcut Ctrl+M to generate angle result of your image.




8. Repeat step 4 and 5 by go to tab File > open next > your next result image. Then just move the yellow angle tool line as show in figure below.



9. Or you may print and measure the movement of plant by referring to the change of angle based on single selection shoot using protractor.

***Day time experiment:**

10. At day time, repeat the step 3 and 4 with vertically rotate the pot by 270$^{o}$ back to original position.
11. Fill in the time and angle response based on the result photo selection.
12. Plot the graph using excel by inserting the scatter chart function (Angle difference versus Time graph)

*** Based on their independent variable selection.**

**Findings**

***Figure:***

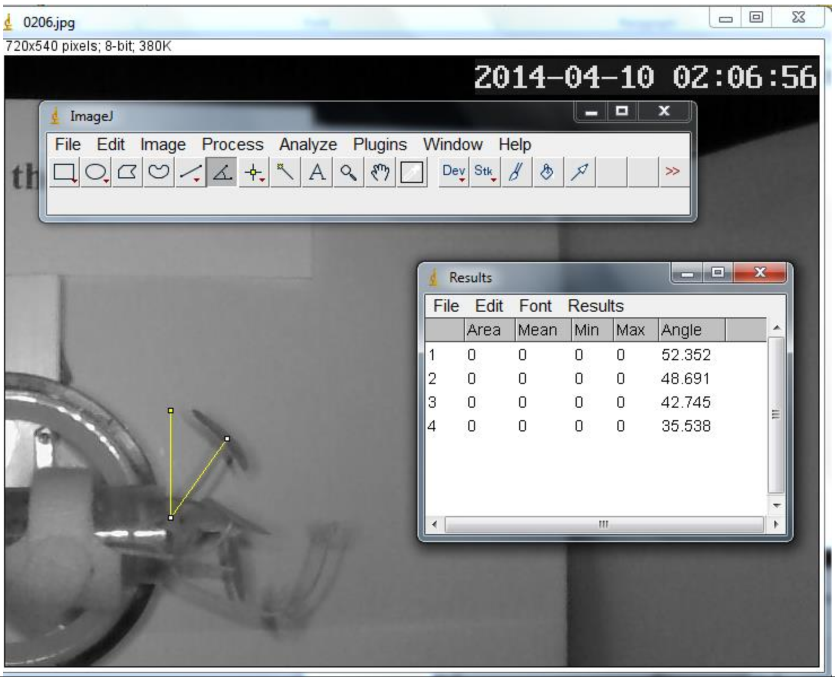
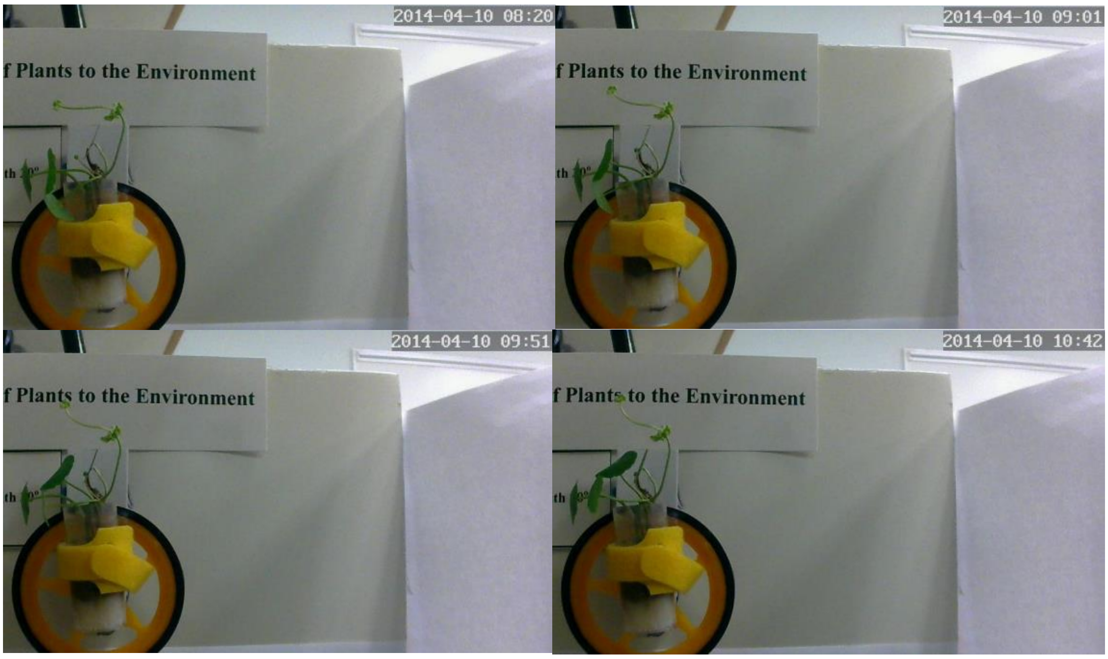




**Figure 2:** result photo for night time - ten hours

**Data: Night time**
Time Start: 8.03pm
Time End: 6.09am
Plant's pot position (in degree): 90

| Time | Duration (mins.) | Angle (degree) | Angle difference | Movement (Angle) | Your Observation |
|---|---|---|---|---|---|
| 2003 | 0 | 52.35 | 0 | 0 | Move upward slowly |
| 2204 | 41 | 48.69 | 3.66 | 3.66 | Move upward |
| 0005 | 80 | 42.75 | 5.95 | 9.61 | Move upward |
| 0206 | 122 | 35.54 | 7.21 | 16.82 | Move upward |
| 0408 | 162 | 27.20 | 8.34 | 25.16 | Move upward (high) |
| 0609 | 203 | 18.91 | 8.29 | 33.45 | Movement start decreasing and almost stable |



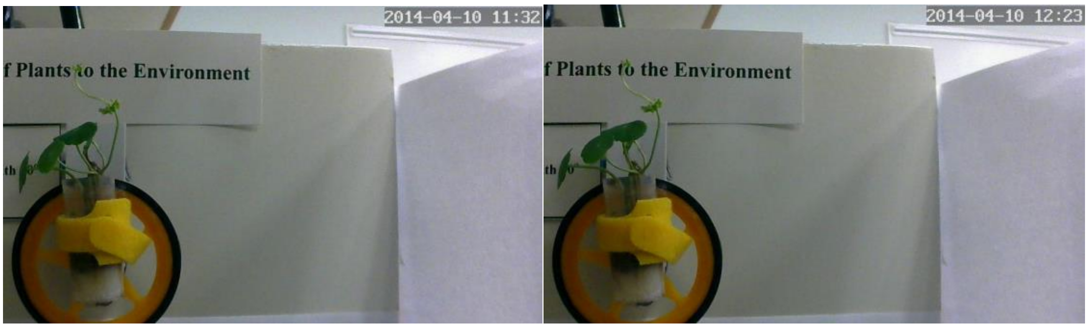
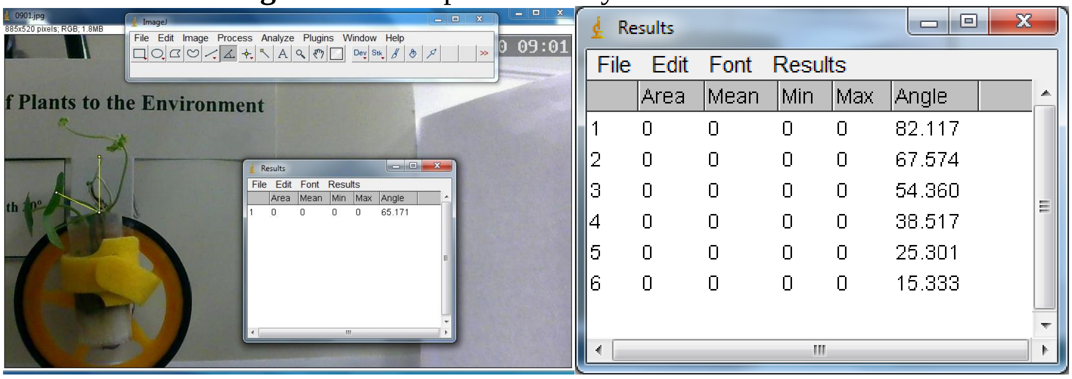



**Figure 3:** result photo for day time - four hours




| | Area | Mean | Min | Max | Angle |
|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 82.117 |
| 2 | 0 | 0 | 0 | 0 | 67.574 |
| 3 | 0 | 0 | 0 | 0 | 54.360 |
| 4 | 0 | 0 | 0 | 0 | 38.517 |
| 5 | 0 | 0 | 0 | 0 | 25.301 |
| 6 | 0 | 0 | 0 | 0 | 15.333 |

**Figure 4:** result of measure angle using ImageJ software

**Data: Day time**

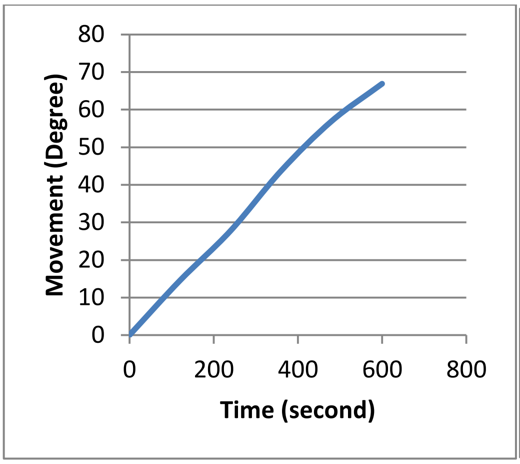
Time Start: 8.20am

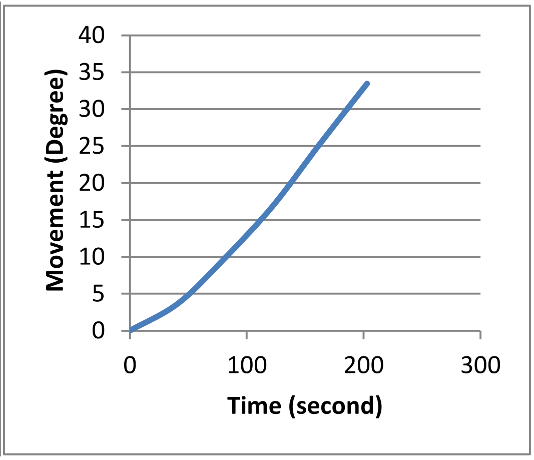
Time End: 12.23pm

Plant's pot position (in degree): 0 (back to original)

| Time | Duration (mins.) | Angle (degree) | Angle difference | Movement (Angle) | Your Observation |
|---|---|---|---|---|---|
| 0820 | 0 | 82.12 | 0 | 0 | - |
| 0901 | 41 | 67.57 | 14.54 | 14.54 | Move upward |
| 0951 | 80 | 54.36 | 13.21 | 27.75 | Move upward |
| 1042 | 122 | 38.52 | 15.84 | 43.69 | Highest moving rate |
| 1132 | 162 | 25.30 | 13.22 | 56.91 | Moving rate start decreasing |
| 1223 | 203 | 15.33 | 9.97 | 66.88 | Moving rate start decreasing and lowest |

**Result:**




**Graph:** Night and day time for plants experiment - gravity

The results show that the growth response of day time is faster than night time due to additional external light stimuli for day time.

**Conclusion:**
The hypothesis is proven to be correct. The growth response of the shoot is always upward for day and night time.

**References:**

Bell, R. L., Smetana, L., & Binns, I. (2005). Simplifying Inquiry Instruction. *Science Teacher, 72*(7), 30-33.

Cheung, D. (2006). *Inquiry-based laboratory work in chemistry: Teacher's guide*. Hong Kong: Department of Curriculum and Instruction, The Chinese University of Hong Kong.

ImageJ. (n.d.). *Image Processing and Analysis in Java*. Retrieved from http://rsb.info.nih.gov/ij/

Llewellyn, D. (2007*). Inquire within: implementing inquiry-based science standards in grades 3-8. (2nd ed.)*. California, US: Corwin Press.

Llewellyn, D. (2013). *Teaching high school science through inquiry and argumentation (2nd ed.)*. Thousand Oaks, California, US: Corwin Press.

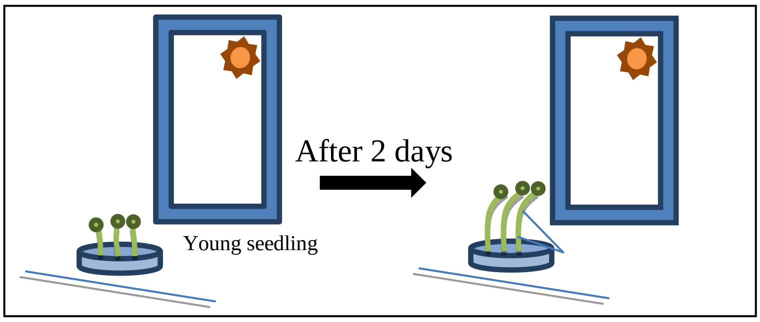
Lorbeer, G. C. (2000*). Science activities for middle school students (2nd ed.)*. US: McGraw-Hill.

**Student worksheet:**
**R2 – Plant - Light**

| Name: | Date: |
|---|---|
| 1. | Group: |
| 2. | |
| 3. | |
| 4. | |
| 5. | |

**Inquiry Question:** How does the position and colour of light (green and white) affect the rate of plants grow toward the light *如何座向位置或光的顏色（綠和白光）影響植物向光生長?*

How you ever observe the plants around you like figure 1? How do the plants move? Why do the plants move? Tropism (*向性*) is the ordinary growth response of a plant to external stimuli. The stimuli can be light (*phototropism 向光性*), touch (*thigmotropism 向觸性*), chemical (*chemotropism 向化性*) or gravity (*gravitropism* or *geotropism* 向地性). The positive response (*正向性*) is directed by growth toward a stimulus and the negative response (*負向性*) is indicated by growth away from the stimulus.




You are asked to plan and carry out an investigation to test the following three hypotheses?

- If the white light (Left) is turned on (*點擊白光按鈕*), then the upward position plants will grow toward the white light because of the characteristics of living things.
- If the plants growing to light are rotated 180$^{o}$ to a vertical direction (*180 度轉動到垂直方向*), then the plants will grow toward light again because the light stimuli.

You are asked to answer the following question:

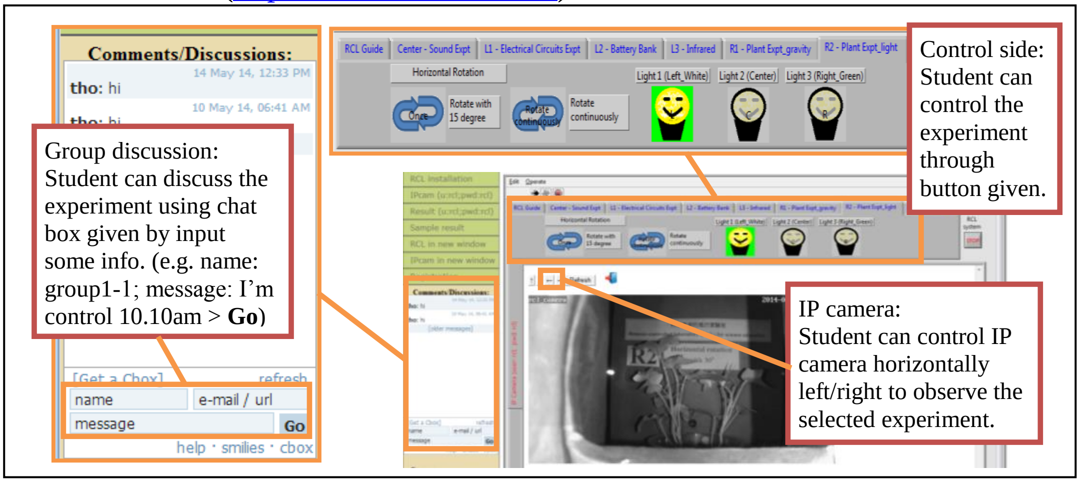
- How can you measure the rate of plants growth in different position or colour of light (*不同座向位置或光的顏色*)?
- In the result session, what patterns do you get from your findings?
- If you were given another chance to do the experiments again, what additional independent variable (variable to be changed) would you like to test?

**Material and Apparatus:**

1. Computer
2. Internet

3. RCL User Manual – Login Card and Guide
4. R2: Plants experiment – light

**Additional Note:** (http://rcl.ied.edu.hk:8000)




**Variables (*變量/變數*):** Please underline or circle your variable(s)

| | |
|---|---|
| The variable to be changed (independent variable *獨立變數*) is | Colour of light /Position of the pot /Rate of the plant growth response /Temperature /Types of plants |
| The variable to be monitored (dependent variable *因變數*) is | Colour of light /Position of the pot / Rate of the plant growth response /Temperature / Types of plants |
| The variable(s) to be kept constant (controlled variable(s) *控制變數*) | Colour of light /Position of the pot / Rate of the plant growth response /Temperature / Types of plants |

**List the experimental procedure and capture your setup with IP camera or print screen:**
**(RCL procedures are provided)**

The steps I follow are (The procedures are):

i. To remotely access the RCL system from laptop or desktop computer that has a web google chrome browser, go to browser and input http://rcl.ied.edu.hk:8000/page_rcl.html (通過電腦的 Chrome 瀏覽器使用遙控實驗).

ii. Login the RCL with user 用戶: rcl, password 密碼: rcl.

iii. Right click & request for control (at grey colour area) and then remember to click on Run ( ). 在灰色區域右鍵單擊及要求的控制，然後記得點擊運行 ( ).

iv. Click on left/right button for observing & controlling the RCL experiments via IP camera 通過 IP 攝像頭，使用左/右按鈕來觀察實驗 ( ↑ ↓ ← → Refresh ).

v Comment/Discussions (see Additonal Note): To tell your group / friend about your control and experiment time 在討論區告訴團隊/朋友對於你的控制和實驗時間.

vi. Click on Tab for R2- plant experiment respond to light and then click on button for control 點擊選項於 R2 植物向光實驗，然後按鈕控制 ( R2 - Plant Expt_light ).

vii.* ______________________________

viii. ______________________________

ix. ______________________________

x. ______________________________

(*Start from vii. list out your own experimental procedure 從七開始，列出你們的實驗步驟)

**Experimental setup (裝置) - Figure(s) / picture(s):**

(Window: Press the "Print Screen (列印螢幕)" key [Print Screen/PrtScr] on your keyboard and Paste the screenshot below. Mac: Press the Command + Shift + 3 key on your keyboard and then Open the screen capture on your desktop)

**Data:**

Time Start *開始時間*: ______________________

Time End *結束時間*: ______________________

Selected independent variable (*已選獨立變數*): ______________________

| Time (hh:mm) *時間* | Angle *角度*(photo attached *附圖片*) | Your Observation *觀察* |
|---|---|---|
| | | |
| | | |
| | | |
| | | |

**Result:**

The patterns or relationships I found are (The data are organized on a chart or graph)

[Images of the experiment are stored at 5-minute time interval & it can be downloaded from http://rcl.ied.edu.hk:8000/page_result.html with login by using user: rcl, password: rcl and then by clicking on date (e.g. 20140927) > time (e.g. images003) > images (JPEG format, e.g. P14082120214300.jpg). You can edit the images, rearrange them using video editing software, and create their own result movie; 5分鐘間隔的實驗圖像將儲存在 http://rcl.ied.edu.hk:8000/page_result.html 用戶: rcl密碼: rcl然後點擊日期（如20140927）>時間（如images003）>圖像（JPEG格式，如P14082120214300.jpg），您可以使用視頻編輯軟件重新排列圖片，並編輯實驗結果影片]

**Conclusion:**

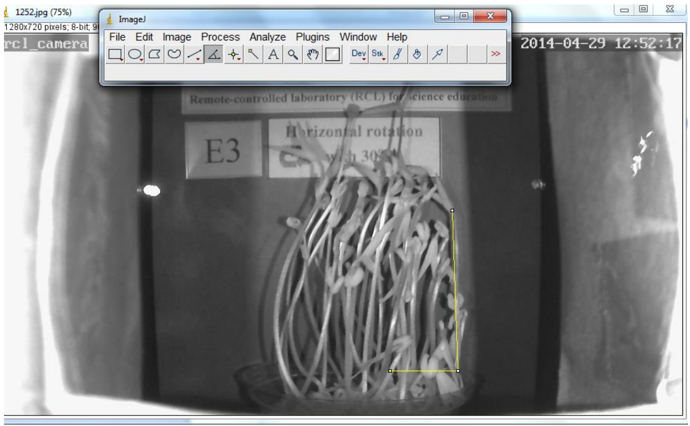
The answer to my question (my conclusion) is

**Reflection:**

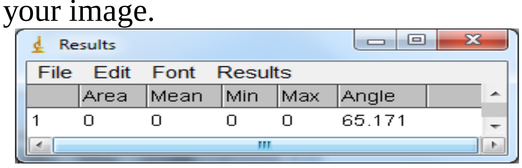
- What have you learnt in the plants respond to the light experiment about (a) scientific methods (*方法*), (b) scientific attitudes (*態度*) and (c) scientific knowledge (*知識*)?
- Have you encountered any difficulties (*困難*)? How do you solve these problems?
- If you were given another chance to do the experiments again, what additional independent variable (variable to be changed) would you like to test? *如果再做一次植物向光實驗，你想測試什麼額外的獨立變數？*

**Extra Note: length or angle measuring skills (特注：長度或角度測量技巧)**
**ImageJ Software: How to measure Plants' angle (Image J 軟件：**如何測量植物生長角度**)**

1. Measure the move of plant by referring to the change of angle based on **SINGLE** selection shoot using ImageJ (open source software able to measure angle changed).
2. First, download and install ImageJ (http://rsb.info.nih.gov/ij/) according to your operating system (OS) (i.e. Windows OS).
3. Open the selected image.
4. Measure the angles of the single shoot using the angle tool by drawing a horizontal reference straight line then go to the selected shoot as yellow line in figure below.



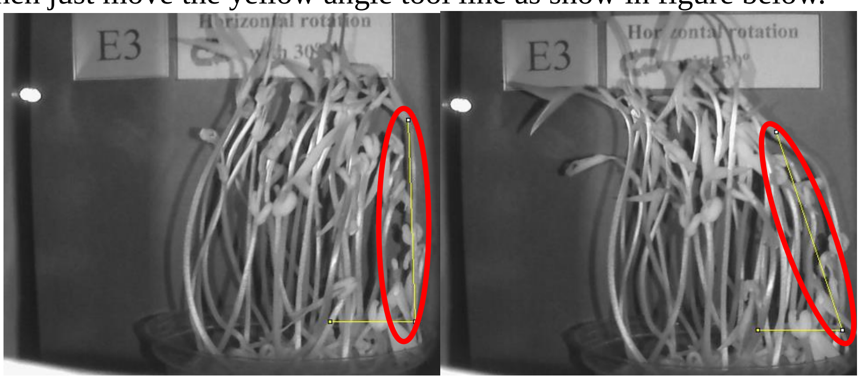

5. Then, go to Analyse tab > Measure or you can use shortcut Ctrl+M to generate angle result of your image.


Results

File Edit Font Results

| | Area | Mean | Min | Max | Angle |
|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 65.171 |

6. Repeat step 4 and 5 by go to tab File > open next > your next result image. Then just move the yellow angle tool line as show in figure below.



**Teacher Guide:**

**Objectives**

At the end of the lesson, all students should

- be able to identify the characteristic of plant growth response through the external (light) stimuli **(An extension part of syllabus**)
- be able to have practical experience on RCL for plant's experiment

**Students' prior knowledge**

Primary 6:

- Environment and Living
    - o Adaptation of living things to the environment
    - o Adaptation of Living Things

**Science Education Curriculum**

The underlying scientific concepts and principles closely match the science education curriculum of Hong Kong as recommended by the Education Bureau of the HKSAR.

Secondary 1 and 2

- Living things: characteristics of living things
- Living Things
- How do the green plants obtain energy: photosynthesis

**Background:**

***Plant growth response***

Tropism is a growth response between a plant and an external stimulus. The stimulus could be weather, touch, time, gravity or light. A positive response is indicated by growth toward a stimulus and a negative response is indicated by growth away from the stimulus.

Light is a stimulus that plants respond to. This is called *phototropism* (photo= light). Plants usually display a positive phototropic response to light, which means they grow toward a light source. Plant hormones called auxins play a part in *phototropism*. Auxin is a plant growth hormone. When light is shined on one side of a plant the auxins move to the dark side of the plant. The hormones stimulate the cells on the dark side of the plant to elongate, while the cells on the light side of the plant remain the same. This elongation on one side and staying the same on the other causes the plant to bend in the direction of the light. This bending allows more light to reach more cells on the plant that are responsible for conducting photosynthesis.

***Basic Facts and Supplemental Information:***

- When school plants are placed near windows they should be turned occasionally to prevent one-sided growth.
- The tendency of plants to grow towards light is called "phototropism".
- When moths are attracted to light, this too, is called "phototropism".
- Light is essential to plants.
- Plants use light in the process of photosynthesis.
- The word "photosynthesis means putting together by light.
- Plants take carbon dioxide and water in the presence of sunlight make glucose a simple sugar.

- Plants also give off oxygen in the process of photosynthesis.
- The chemical equation for photosynthesis is;
- $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

***What is the remote-controlled laboratory?***

Remote-controlled laboratory is a real-time experiment that can be controlled or monitored by user from their computer through the Internet browser. It is also known as Web-Based Laboratory.

The RCL system is commonly divided into two major parts, namely, hardware and software. The hardware part consists of the data acquisition system, digital input or output (DIO), camera, and various types of sensors. The software part executes data logging as well as controls and displays the real-time experiment on the computer screen via the Internet.

Thus, the RCL activity enables more flexible delivery (anytime), distance education (anyplace) and new visualization possibilities (interactivity).

**Sample result and procedure**

**Experiment 1:**

**Variables:** Please underline or circle your variable(s)

| | |
|---|---|
| The variable to be changed (independent variable) is | Colour of light /**<u>Position of the pot</u>** /Rate of the plant growth response /Temperature /Types of plants |
| The variable to be monitored (dependent variable) is | Colour of light /Position of the pot **/ <u>Rate of the plant growth response</u>** /Temperature / Types of plants |
| The variable(s) to be kept constant (controlled variable(s)) | **Colour of light** /Position of the pot / Rate of the plant growth response /**<u>Temperature / Types of plants</u>** |

**Experiment 2:**

**Variables:** Please underline or circle your variable(s)

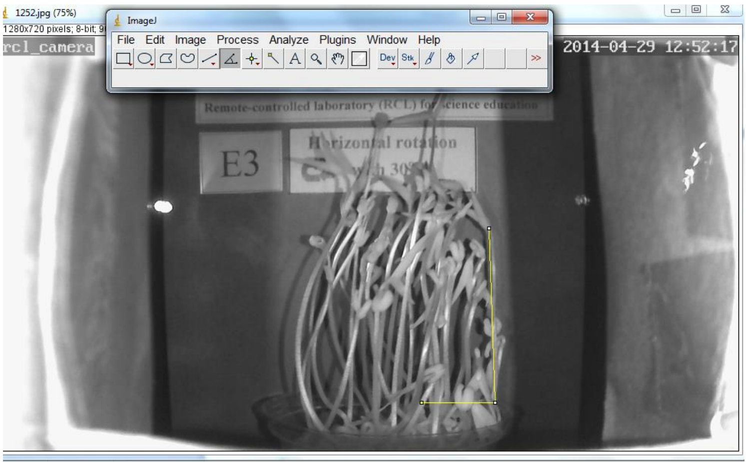
| | |
|---|---|
| The variable to be changed (independent variable) is | **<u>Colour of light</u>** /Position of the pot /Rate of the plant growth response /Temperature /Types of plants |
| The variable to be monitored (dependent variable) is | Colour of light /Position of the pot / **<u>Rate of the plant growth response</u>** /Temperature / Types of plants |
| The variable(s) to be kept constant (controlled variable(s)) | Colour of light /**<u>Position of the pot</u>** / Rate of the plant growth response /**<u>Temperature / Types of plants</u>** |

**Procedure:**

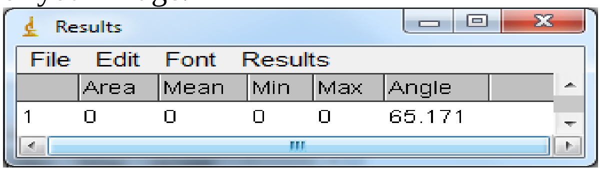
**Experiment 1*:**

1. Record the experimental time.

2. Move the IP camera view to R2 – plant experiment of light,
3. Turn on the white light (left), record the time, angle and pattern of the plant growth response and your observation for several hours (3-4 hours) in the table below by downloading the result from the server (http://rcl.ied.edu.hk:8000/page_result.html).
4. Measure the move of plant by referring to the change of angle based on single selection shoot using ImageJ software.
5. Open the selected image.
6. Measure the angles of the single shoot using the angle tool  by drawing a horizontal reference straight line then go to the selected shoot as yellow line in figure below.

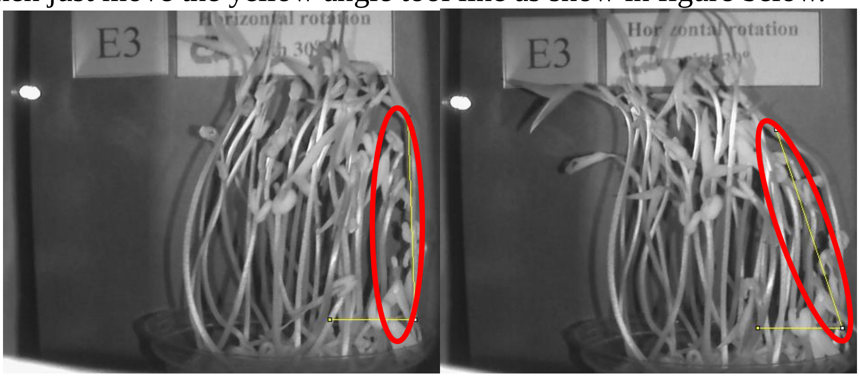



7. Then, go to Analyse tab > Measure or you can use shortcut Ctrl+M to generate angle result of your image.


Results
File Edit Font Results

| | Area | Mean | Min | Max | Angle |
|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 65.171 |

8. Repeat step 4 and 5 by going to tab File > open next > your next result image. Then just move the yellow angle tool line as show in figure below.




9. Measure the movement of plant by referring to the change of angle based on single selection shoot using protractor.
10. Turn off the white light (left) and turn on the centre light, observe the plants growth back to the original position.
11. Repeat the step 3 and 10 by rotating the pot horizontally to 180°.

**Experiment 2*:**

12. Repeat the step 3 and 10 with turn the green light (right) instead of white light.
13. Fill in the time and angle response based on the result photo selection.
14. Plot the graph using excel by inserting the scatter chart function (Angle difference versus Time graph)

*** Based on their independent variable selection.**

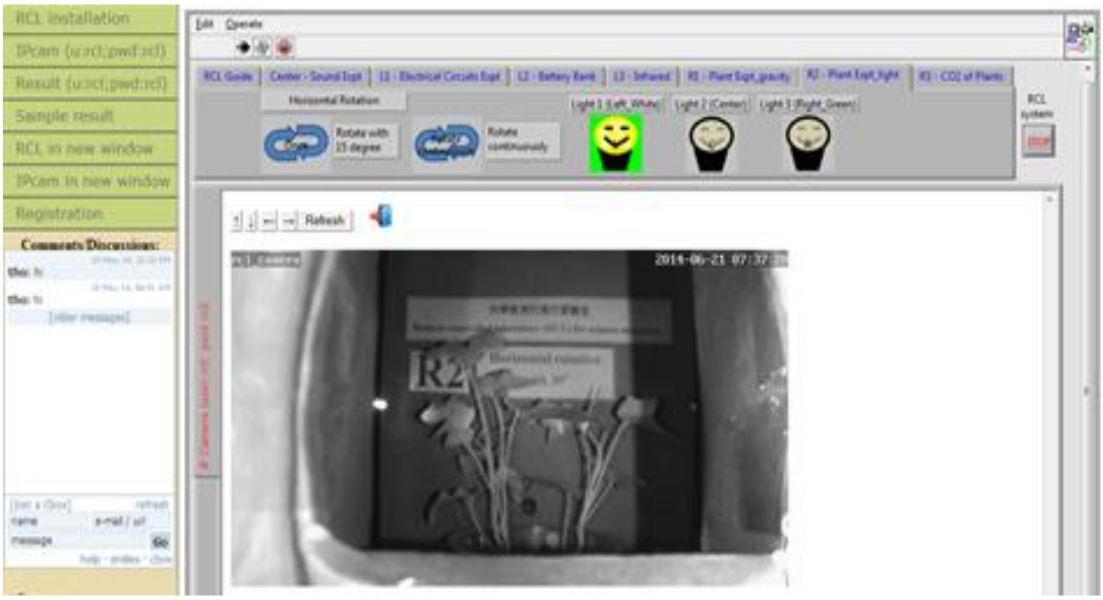
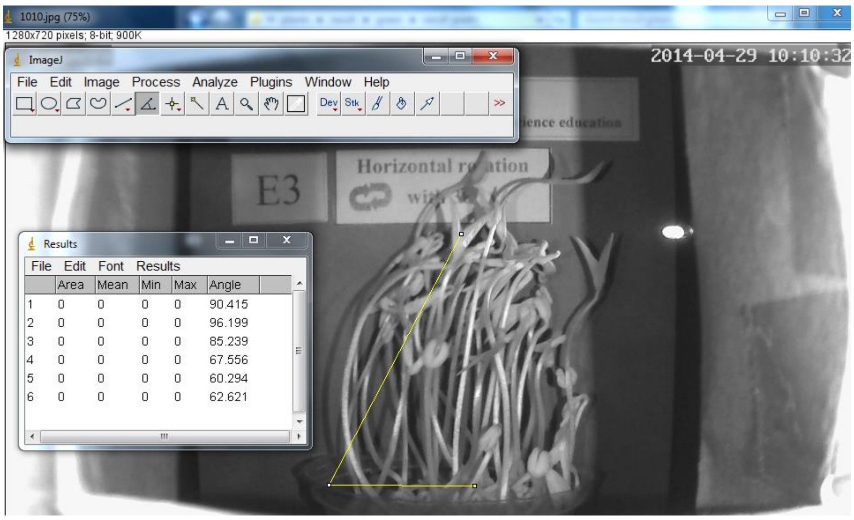



**Figure 1:** R2 – Plant experiment_light setup

**Findings:**

***Figure:***



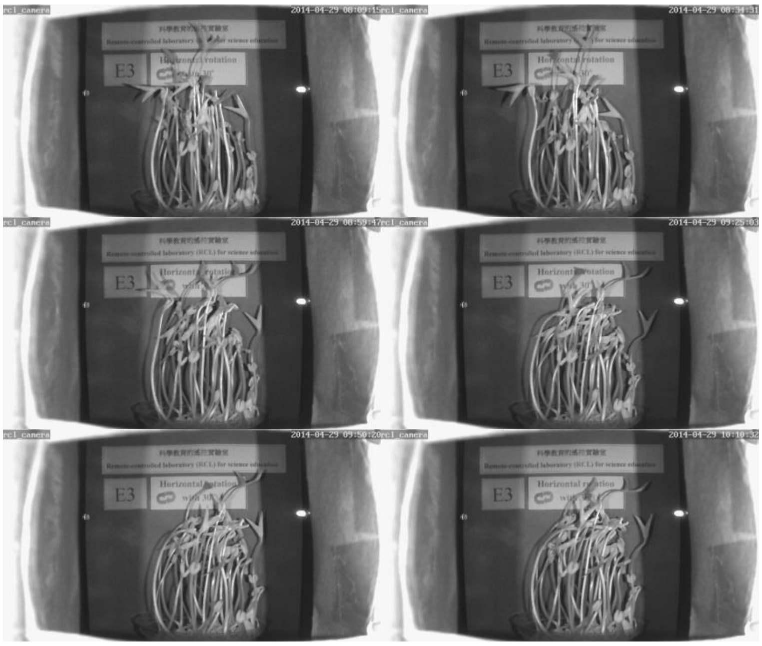
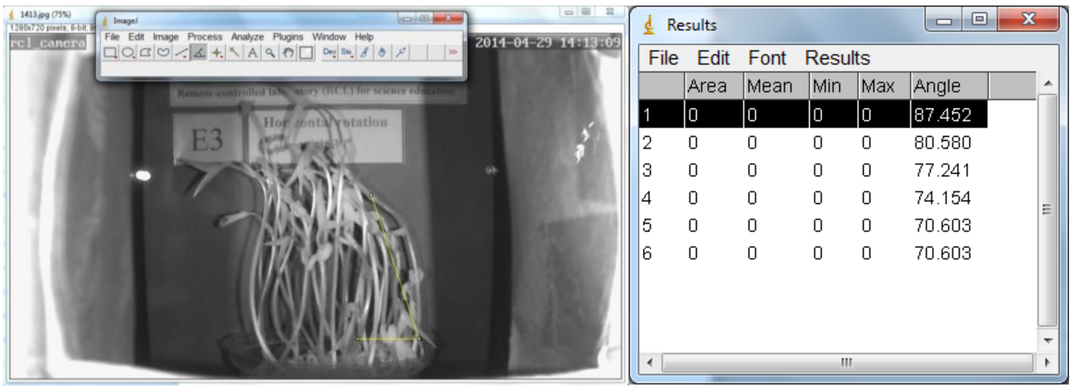


**Figure 2:** result photo for green light - two hours

**Data:**
Time Start: 8.09am and Time End: 10.10am
Selected independent variable: green light

| Time | Duration (mins.) | Angle (degree) | Angle difference | Movement (Angle) | Your Observation |
|---|---|---|---|---|---|
| 0809 | 0 | 90.422 | 0 | 0 | Move to left |
| 0834 | 25 | 96.20 | -5.78 | -5.78 | Move to left (negative sign) |
| 0859 | 50 | 85.24 | 10.96 | 5.18 | Keep |
| 0925 | 76 | 67.56 | 17.68 | 22.86 | Begin move to right |
| 0950 | 101 | 60.29 | 7.26 | 30.12 | Move to right (high) |
| 1010 | 121 | 62.62 | -2.33 | 27.79 | Stable but try to obtain maximum light |



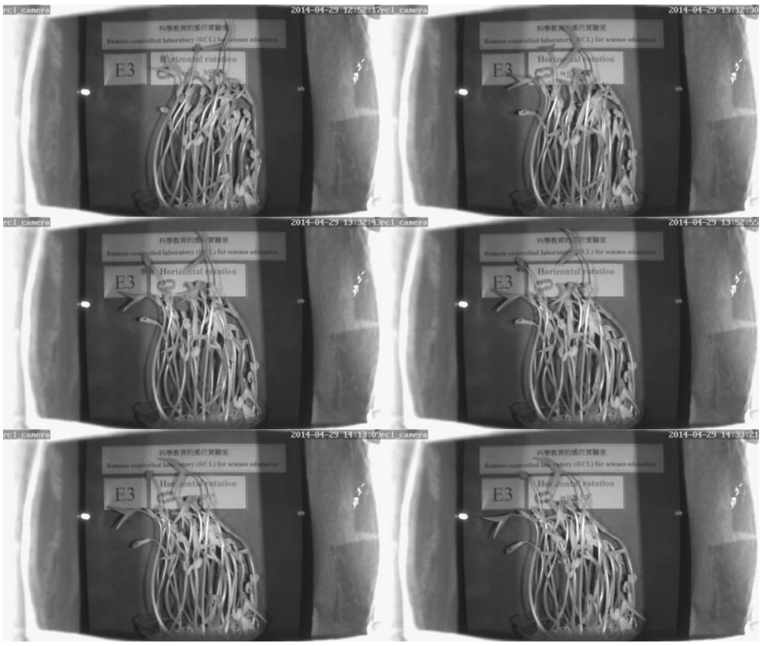
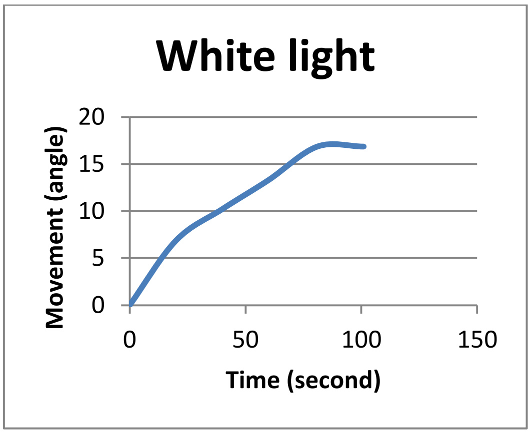


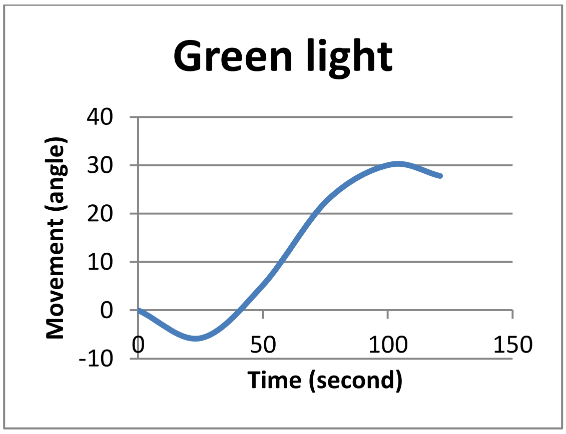
**Figure 3:** result photo for white light - two hours

**Data:**
Time Start: 12.52pm
Time End: 14.33pm
Selected independent variable: white light

| Time | Duration (mins.) | Angle (degree) | Angle difference | Movement (Angle) | Your Observation |
|---|---|---|---|---|---|
| 1252 | 0 | 87.45 | 0 | 0 | Move to left |
| 1312 | 20 | 80.58 | 6.872 | 6.87 | Move to left |
| 1332 | 40 | 77.24 | 3.339 | 10.21 | Move to left |
| 1352 | 60 | 74.15 | 3.087 | 13.30 | Move to left |
| 1413 | 81 | 70.60 | 3.551 | 16.85 | Move to left |
| 1433 | 101 | 70.60 | 0 | 16.85 | Stable |

**Result:**




For green light, the plant began to move to the left (suppose move to right), then it move to the right constantly. For white light, the plant began to move to the left constantly. The results show that the growth response of white light is faster than green light.

**Conclusion:**
The hypothesis is proven to be correct. The plants grow toward the light source. The results also showed that the growth response of white light is faster than green light.

**References:**

Bell, R. L., Smetana, L., & Binns, I. (2005). Simplifying Inquiry Instruction. *Science Teacher, 72*(7), 30-33.

Cheung, D. (2006). *Inquiry-based laboratory work in chemistry: Teacher's guide*. Hong Kong: Department of Curriculum and Instruction, The Chinese University of Hong Kong.

ImageJ. (n.d.). *Image Processing and Analysis in Java*. Retrieved from http://rsb.info.nih.gov/ij/

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Llewellyn, D. (2013). *Teaching high school science through inquiry and argumentation (2nd ed.)*. Thousand Oaks, California, US: Corwin Press.

Lorbeer, G. C. (2000*). Science activities for middle school students (2nd ed.)*. US: McGraw-Hill.

**Student worksheet:**

**R3: The plants emit gas carbon dioxide ($CO_2$) in the darkness**

| Name: | Date: |
|---|---|
| 1. | Group: |
| 2. | |
| 3. | |
| 4. | |
| 5. | |

**Inquiry Question:** Do plants emit CO2 gas in the dark? *在黑暗中植物是否會排放出二氧化碳*?

Do the plants emit $CO_2$ in darkness? Actually the plants give off oxygen and $CO_2$ during the day and only $CO_2$ when placed in darkness (*在日間植物排放出氧和二氧化碳，在夜間植物只是排放出二氧化碳*). These processes are called respiration (*植物呼吸作用*). This process is necessary for the plants to use food they have produced.

The simplified formula is:

Sugar (food) + Oxygen = Carbon dioxide (to the air) + water + energy.

**Figure 1:** Day: Photosynthesis, Night: Respiration

You are asked to plan and carry out an investigation to test the following two hypotheses?

- In day time *日間*, if the lights turn on, then the plants will release gas oxygen because the plants consume more gas $CO_2$.
- In night time *夜間*, if the lights turn on, then the plants will release gas $CO_2$ because the plants consume more gas oxygen.

You are asked to answer the following question:

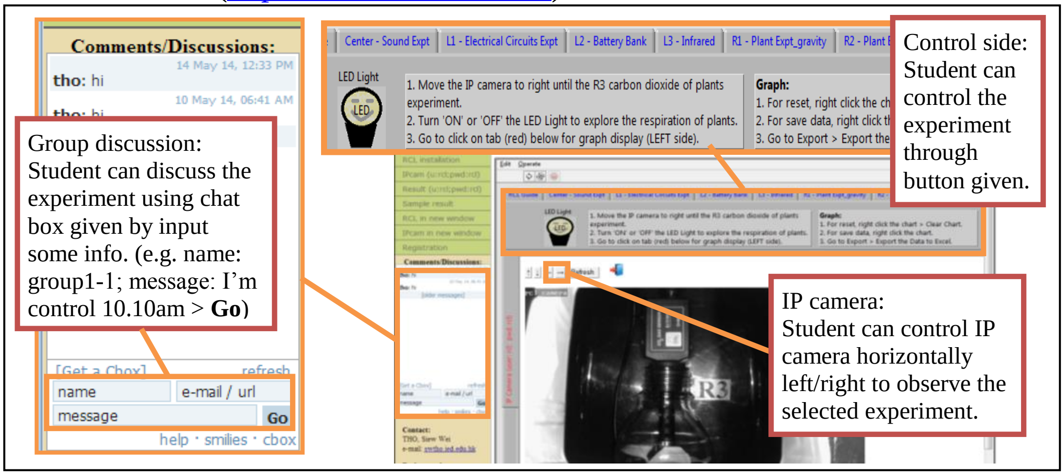
- How can you measure the gas $CO_2$ of plants in daytime and night time (*日間和夜間*)?
- In the session of result, what patterns do you get from your findings?
- If you were given another chance to do the experiments again, what additional independent variable (variable to be changed) would you like to test?

**Material and Apparatus:**

1. Computer
2. Internet

3. RCL User Manual – Login Card and Guide
4. R3: Plants experiment - Respiration

**Additional Note:** (http://rcl.ied.edu.hk:8000)




***How to measure $CO_2$ (如何測量二氧化碳)***

Noise is unavoidable in the $CO_2$ sensor measurement in this system. Therefore, save data by exporting the data into excel file. Based on the data, take the highest $CO_2$ value (unit ppm) at the interval and record into the table given. *在該系統中二氧化碳傳感器的雜訊產生是不可避免的。因此，通過將數據導出到Excel 檔中保存的數據。然後以讀取最高二氧化碳值為準確(單位：ppm)。*

**Variables (變量/變數):** Please underline or circle your variable(s)

| | |
|---|---|
| The variable to be changed (independent variable *獨立變數*) is | Rate of the gas $CO_2$/ Presence of light/ Water supply/ Temperature / Types of plants |
| The variable to be monitored (dependent variable *因變數*) is | Rate of the gas $CO_2$/ Presence of light/ Water supply/ Temperature / Types of plants |
| The variable(s) to be kept constant (controlled variable(s) *控制變數*) | Rate of the gas $CO_2$/ Presence of light/ Water supply/ Temperature / Types of plants |

**List the experimental procedure and capture your setup with IP camera: (RCL procedures are provided)**

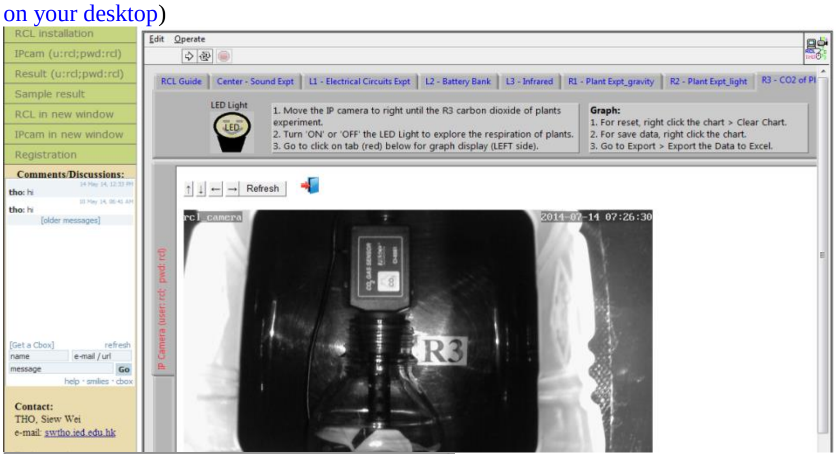
The steps I follow are (The procedures are):

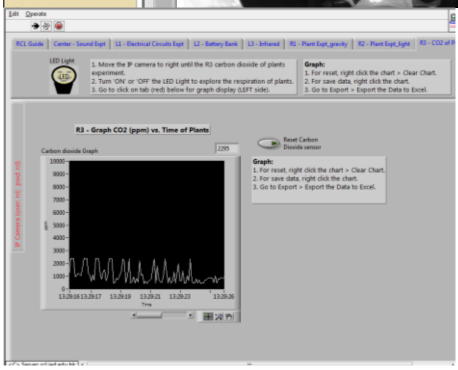
| | |
|---|---|
| i. | To remotely access the RCL system from laptop or desktop computer that has a web google chrome browser, go to browser and input http://rcl.ied.edu.hk:8000/page_rcl.html (通過電腦的 Chrome 瀏覽器使用遙控實驗). |
| ii. | Login the RCL with user 用戶: rcl, password 密碼: rcl. |
| iii. | Right click & request for control (at grey colour area) and then remember to click on Run ( ). 在灰色區域右鍵單擊及要求的控制，然後記得點擊運行 ( ). |
| iv. | Click on left/right button for observing & controlling the RCL experiments via IP camera 通過 IP 攝像頭，使用左/右按鈕來觀察實驗 (↑ ↓ ← → Refresh ). |
| v | Comment/Discussions (see Additonal Note): To tell your group / friend about your control and experiment time 在討論區告訴團隊/朋友對於你的控制和實驗時間. |
| vi. | Click on Tab for L3- $CO_2$ of plant experiment and then click on button for control 點擊選項於 R3 植物呼吸作用實驗，然後按鈕控制 (R3 - CO2 of Plants). |
| vii.* | |
| viii. | |
| ix. | |
| x. | |

(*Start from vii. list out your own experimental procedure 從七開始，列出你們的實驗步驟)

**Experimental setup (裝置) - Figure(s) / picture(s):**

(Window: Press the "Print Screen (列印螢幕)" key [Print Screen/PrtScr] on your keyboard and Paste the screenshot below. Mac: Press the Command + Shift + 3 key on your keyboard and then Open the screen capture on your desktop)



**Data:**

Time Start*開始時間*: 10.00am 27/10/2014

Time End *結束時間*: 3.xx_pm 28/10/2014

| Time (hh:mm) *時間* | Gas $CO_2$ (ppm) *二氧化碳* | Your Observation *觀察* |
|---|---|---|
| | | |
| | | |
| | | |
| | | |

**Result:**

| |
|---|
| The patterns or relationships I found are (The data are organized on a chart or graph)<br>[Noise is unavoidable in the CO2 sensor measurement in this system. Therefore, save data by exporting the data into excel file. Based on the data, take the highest CO2 value (unit ppm) at the interval and record into the table given.*在該系統中的雜訊產生是不可避免的。因此，通過將數據導出到Excel檔中保存的數據。然後以讀取最高二氧化碳值為準確(單位：ppm)]* |

**Conclusion:**

| |
|---|
| The answer to my question (my conclusion) is |

**Reflection:**

- What have you learnt in the plant respiration experiment about (a) scientific methods (*方法*), (b) scientific attitudes (*態度*) and (c) scientific knowledge (*知識*)?

- Have you encountered any difficulties (*困難*)? How do you solve these problems?

- If you were given another chance to do the experiments again, what additional independent variable (variable to be changed) would you like to test? *如果再做一次植物呼吸作用實驗，你想測試什麼額外的獨立變數？*

**Teacher Guide:**

**Objectives**

At the end of the lesson, all students should

- be able to investigate the plant respiration
- be able to have practical experience on RCL for plant's experiment

**Students' prior knowledge**

Primary 3:

- Living in Hong Kong
    - Basic needs of living things

**Science Education Curriculum**

The underlying scientific concepts and principles closely match the science education curriculum of Hong Kong as recommended by the Education Bureau of the HKSAR.

Secondary 1:

- Living things: characteristics of living things
- Living Things

Secondary 2:

- How do green plants obtain energy: photosynthesis
- Gaseous exchange in plants: respiration and the release of chemical energy from food

**Background:**

***Plant respiration***

Do the plants emit $CO_2$ in darkness? Actually the plants give off oxygen and $CO_2$ during the day and only $CO_2$ when placed in darkness. These processes are called respiration. This process is necessary for the plants to use food they have produced. (p. 149)

The simplified formula is:

Sugar (food) + Oxygen = Carbon dioxide (to the air) + water + energy.

***Basic Facts and Supplemental Information:***

- All animal and plants requires oxygen for survival.
- The plants give off oxygen and $CO_2$ during the day.
- The plants emit only $CO_2$ when placed in darkness.
- These processes are called respiration.
- This process is necessary for the plants to use food they have produced.
- The simplified formula is:

  Sugar (food) + Oxygen = Carbon dioxide (to the air) + water + energy.

***What is the remote-controlled laboratory?***

Remote-controlled laboratory is a real-time experiment that can be controlled or monitored by user from their computer through the Internet browser. It is also known as the Web-Based Laboratory.

The RCL system is commonly divided into two major parts, namely, hardware and software. The hardware part consists of the data acquisition system, digital input or output (DIO), camera, and various types of sensors. The software part executes data logging as well as controls and displays the real-time experiment on the computer screen via the Internet.

Thus, the RCL activity enables more flexible delivery (anytime), distance education (anyplace) and new visualization possibilities (interactivity).

**Sample result and procedure**

**Variables:** Please underline or circle your variable(s)

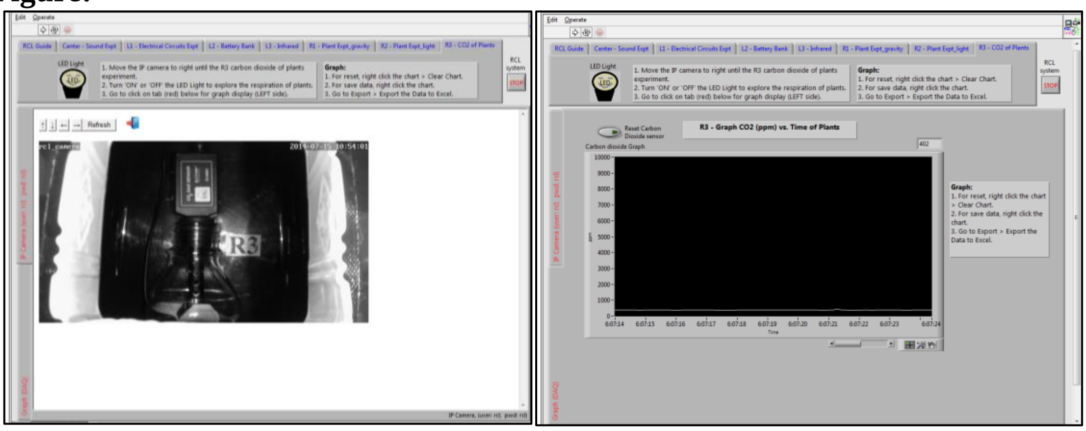
| | |
|---|---|
| The variable to be changed (independent variable) is | Rate of the gas $CO_2$/ **<u>Presence of light</u>**/ Water supply/ Temperature / Types of plants |
| The variable to be monitored (dependent variable) is | **<u>Rate of the gas $CO_2$</u>**/ Presence of light/ Water supply/ Temperature / Types of plants |
| The variable(s) to be kept constant (controlled variable(s)) | Rate of the gas $CO_2$/ Presence of light/ **<u>Water supply/ Temperature / Types of plants</u>** |

**Procedure:**

1. Record the experimental time.
2. Move the IP camera view to R3: Plants experiment - Respiration,
3. Turn on the LED light, record the initial gas $CO_2$ by exporting the graph into excel file and then hourly record the gas $CO_2$ again by log-on the RCL system & exporting the graph into excel file in the table below for four times (4-hour).
4. Turn off the LED light, repeat the step 3 for another four times (4-hour).
5. Noise is unavoidable in the $CO_2$ sensor measurement in this system. Therefore, save data by exporting the data into excel file and take the highest $CO_2$ value (unit ppm) at the interval into the table.

*** Based on their independent variable selection (up to their decision, student may try three hour).**

**Figure:**



**Result:**

**Data:**

Time Start: 6.44am 13/07/14

Time End: 6.26am 14/07/14

| Time | Gas $CO_2$ (ppm) | Your Observation |
|---|---|---|
| 6.44am | 443 | Normal rate of $CO_2$ |
| 6.26am | 1342 | Increase of $CO_2$ in darkness area |
| | | |

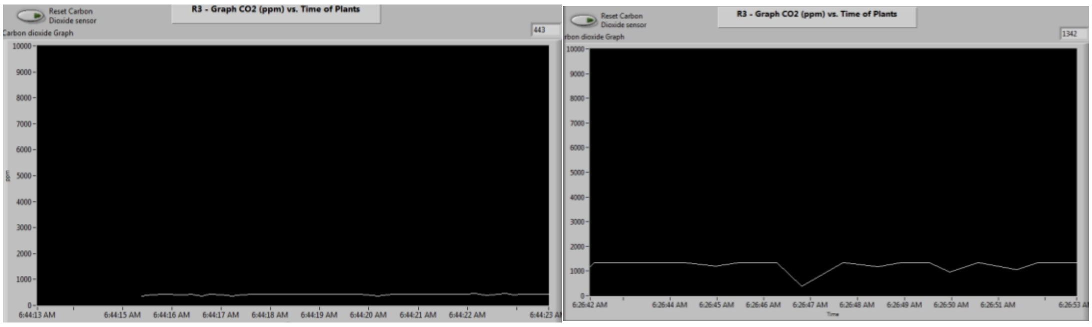



**Figure:** CO2 graph at 13/07/14 6.44am (Left) and Next day 14/07/14 6.26am (Right)

The gas produced during respiration is gas $CO_2$

**Conclusion:**

The hypothesis is proven to be correct. The gas $CO_2$ generated by the plants will be at its highest when the LED light turned off for 24 hours. While the LED light turned on, the gas $CO_2$ deceases constantly. Thus, the plants give off gas $CO_2$ during at darkness through the respiration process.

**References:**


Bell, R. L., Smetana, L., & Binns, I. (2005). Simplifying Inquiry Instruction. *Science Teacher, 72*(7), 30-33.

Cheung, D. (2006). *Inquiry-based laboratory work in chemistry: Teacher's guide*. Hong Kong: Department of Curriculum and Instruction, The Chinese University of Hong Kong.

Llewellyn, D. (2007*). Inquire within: implementing inquiry-based science standards in grades 3-8. (2nd ed.)*. California, US: Corwin Press.

Llewellyn, D. (2013). *Teaching high school science through inquiry and argumentation (2nd ed.)*. Thousand Oaks, California, US: Corwin Press.

Lorbeer, G. C. (2000*). Science activities for middle school students (2nd ed.)*. US: McGraw-Hill.

**Student worksheet:**
**Remote-controlled laboratory: Solar Experiment**

| Name: | Date: |
|---|---|
| 1. | Group: |
| 2. | |
| 3. | |
| 4. | |
| 5. | |

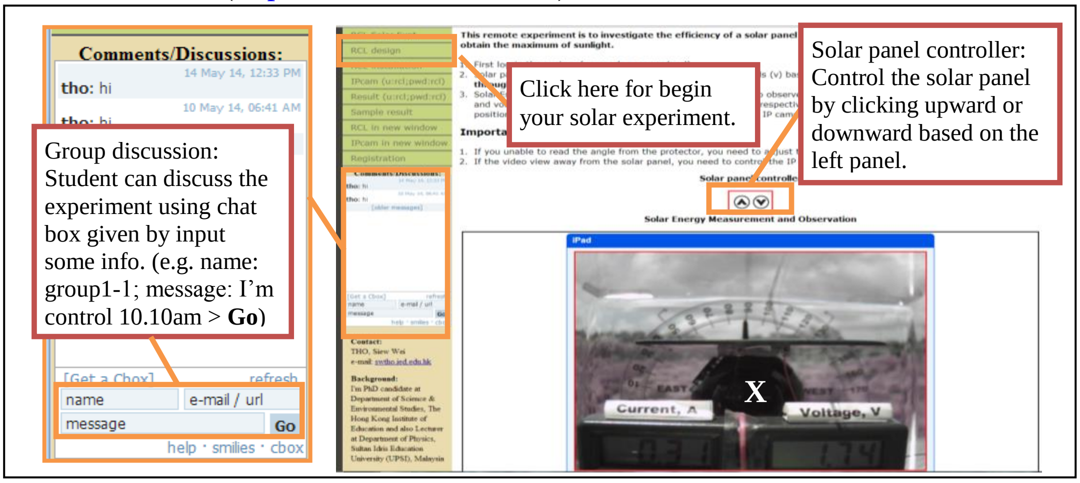
**Inquiry Question:** How does the position of the sun affect the power of the solar panel? *太陽位置如何影響太陽能板的功率？*
Many form of energy we can obtain from the sun like electrical and thermal energy. Especially, solar panel is the most important part to convert energy from the sunlight into electrical energy *太陽能轉化為電能*. In normal practice, this energy can be easily transformed into other form of energy like mechanical energy or consumed for operating the direct current (DC) electrical devices as well as stored it for night use. As the solar panel is quite expensive, for that reason we need to optimize the performance by allowing the panel to obtain sunlight for its maximum. Thus, the solar tracking system *太陽追蹤系統* (Solar tracker *太陽追蹤器*) had been used for improving the efficiency of a solar panel. In this case, the remote experiment is to investigate the efficiency of a solar panel by remotely changing angle of solar panel to obtain sunlight for its maximum.

You are asked to plan and carry out an investigation to test the following hypothesis?
- If the solar panel is adjusted perpendicular toward the sun *垂直調整朝向太陽*, then the power will increase because the sunlight intensity.

You are asked to answer the following question:
- How can you measure the power of solar cell in different angle/time/weather *如何測量太陽能板的功率在不同角度/時間/天氣?*
- In result session, what patterns do you get from your findings?
- If you were given another chance to do the experiments again, what additional independent variable (variable to be changed) would you like to test?

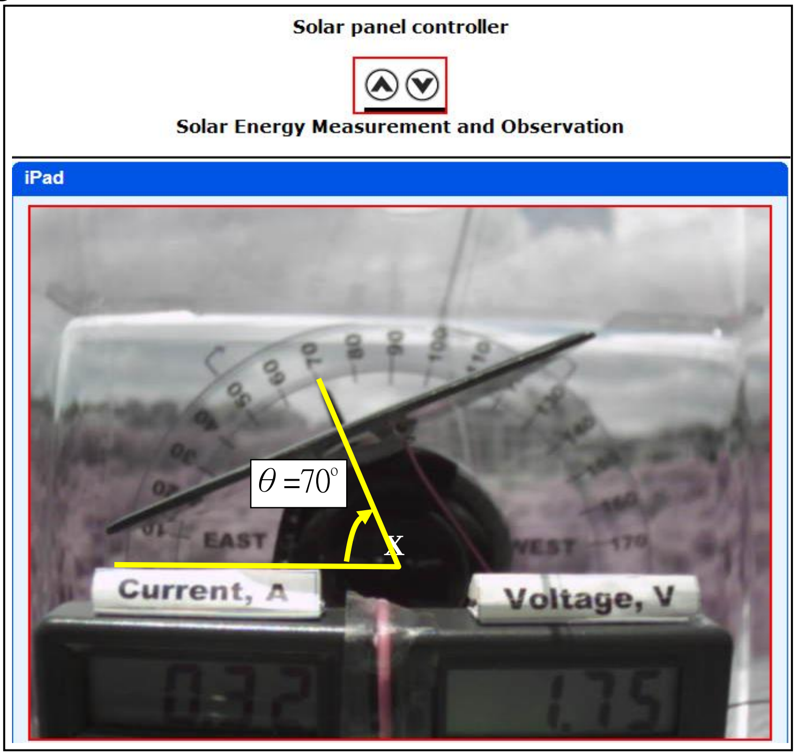
**Material and Apparatus:**
1. Computer
2. Internet
3. RCL User Manual – Login Card and Guide
4. Remote-controlled laboratory: Solar Experiment

**Additional Note:** (http://rcl.ied.edu.hk:8000)




***The setting of the protector and solar panel***

In this case, the IP camera is the moving object therefore the centre point is located at the medium of the IP camera which is marked as "X". The angle of solar panel presented figure below is EAST 70$^o$.




***Limitation:***

1. Doing this experiment within 5-10 minutes *5-10 分鐘內完成這實驗*.
2. Browser: This RCL experiment only works with **Firefox/Google Chrome browser** (Internet Explorer do NOT support this feature - *瀏覽器限制：IE 瀏覽器不支援此功能*).

3. Place and time: Doing this solar energy experiment before 4pm. (Due to the season change, the angle of the sunlight will also be changed, called the solar declination. During summer, do these experiments before 1pm.) *地方限制：下午 4 點前做太陽能實驗.，由於季節變化，太陽的角度也會發生變化，稱為太陽赤緯。夏季時要在下午 1 點前做太陽能實驗*
4. Angle: changing the angle from $50^0$ to $130^0$. *角度限制：改變角度從 50 度到 130 度.*

**Variables (*變量/變數*):** Please underline or circle your variable(s)

| | |
|---|---|
| The variable to be changed (independent variable *獨立變數*) is | Angle of solar panel /Time /Temperature /Weather /Power of solar panel |
| The variable to be monitored (dependent variable *因變數*) is | Angle of solar panel /Time /Temperature /Weather /Power of solar panel |
| The variable(s) to be kept constant (controlled variable(s) *控制變數*) | Angle of solar panel /Time /Temperature /Weather /Power of solar panel |

**List the experimental procedure and capture your setup with IP camera or print screen:**

**(RCL procedures are provided)**

The steps I follow are (The procedures are):

i. To remotely access the RCL system from laptop/desktop computer that has a web google chrome browser, go to browser and access the http://rcl.ied.edu.hk:8000/page_solar.html (通過電腦的 Chrome 瀏覽器使用遙控實驗).

ii. Login the RCL solar experiment with user 用戶: rcl, password 密碼: rcl.

iii. Comment/Discussions (see Additonal Note): To tell your group / friend about your control and experiment time. 在討論區告訴團隊/朋友對於你的控制和實驗時間.

iv. Click on up/down button at solar panel controller for controlling the angle of the panel 點擊向上/向下按鈕來控制太陽能板的角度 ().

v.* ______

vi. ______

vii. ______

viii. ______

(*Start from v. list out your own experimental procedure 從五開始，列出你們的實驗步驟)

**Experimental setup (裝置) - Figure(s) / picture(s):**

(Window: Press the "Print Screen (列印螢幕)" key [Print Screen/PrtScr] on your keyboard and Paste the screenshot below. Mac: Press the Command + Shift + 3 key on your keyboard and then Open the screen capture on your desktop)

**Data:**

Weather condition*天氣情況*: sunny/cloudy/windy/rainy/stormy/foggy (please **Circle**)

Angle/time* of Experiment*實驗角度/時間*: ____________

| Angle/time*角度/時間** | Current*電流*, I (A) | Voltage*電壓*, V (V) | Power*功率*= I x V, (W) |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

*Please delete where inappropriate*請刪去不適用.*

**Result:** (Enter the data I and V into Solar Graph excel file [folder], then copy the graph & paste here)

| The patterns or relationships I found are (The data are organized on a chart or graph)<br>(Window: Press the "Print Screen (列印螢幕)" key [Print Screen/PrtScr] on your keyboard and Paste the screenshot below. Mac: Press the Command + Shift + 3 key on your keyboard and then Open the screen capture on your desktop) |
|---|

**Conclusion:**

| The answer to my question (my conclusion) is |
|---|

**Reflection:**

- What have you learnt in the solar energy experiment about (a) scientific methods (*方法*), (b) scientific attitudes (*態度*) and (c) scientific knowledge (*知識*)?

- Have you encountered any difficulties (*困難*)? How do you solve these problems?

- If you were given another chance to do the experiments again, what additional independent variable (variable to be changed) would you like to test? *如果再做一次太陽能實驗，你想測試什麼額外的獨立變數？*

**Teacher Guide:**

**Objectives**

At the end of the lesson, all students should

- be able to learn the position sunlight affect the efficiency of the solar panel
- be able to have practical experience on RCL for solar experiment

**Students' prior knowledge**

Primary 3:

- The Weather of Hong Kong
    - Daily changes of the Sun relative positions
    - Simple features of a day's weather

Primary 5:

- Life in the City
    - Electricity and everyday life

Primary 6:

- Environment and Living
    - Energy and the environment

**Science Education Curriculum**

The underlying scientific concepts and principles closely match the science education curriculum of Hong Kong as recommended by the Education Bureau of the HKSAR.

Secondary 1:

- Energy
    - Different forms of energy: heat, light, sound, kinetic, potential, chemical and electrical energy
    - Simple energy changes: energy converters, controlled and uncontrolled energy conversion

Secondary 2:

- Making Use of Electricity
    - Current: measurement and its unit
    - Voltage: measurement and its unit
    - Power of an electrical appliance

**Background**

***Solar panel***

Many form of energy can obtained from the sun like electrical and thermal energy. Especially, solar panel is the most important part to convert energy from the sunlight into electrical energy. In normal practice, this energy can be easily transformed into other form of energy like mechanical energy or consumed for operating the direct current (DC) electrical devices as well as stored it for night use. As the solar panel is quite expensive, for that reason we need to optimize the performance by allowing the panel to obtain maximum of sunlight. Thus, the solar tracking system (Solar tracker) had been used for improving the efficiency of a solar panel. In this case, the remote experiment is to investigate the efficiency of a solar panel by remotely changing angle of solar panel to obtain the maximum of sunlight.

***Basic Facts and Supplemental Information:***

1. Electricity is generated by the flow of electrons.
2. There are two types of current: direct current (DC) and alternating current (AC).
3. In DC, electrons move in a single direction
4. In AC, the electrons change directions, switching between backwards and forwards.
5. The electricity use at home is AC but DC comes from all forms of batteries.

***What is the remote-controlled laboratory?***

Remote-controlled laboratory is a real-time experiment that can be controlled or monitored by user from their computer through the Internet browser. It is also known as Web-Based Laboratory.

The RCL system is commonly divided into two major parts, namely, hardware and software. The hardware part consists of the data acquisition system, digital input or output (DIO), camera, and various types of sensors. The software part executes data logging as well as controls and displays the real-time experiment on the computer screen via the Internet.

Thus, the RCL activity enables more flexible delivery (anytime), distance education (anyplace) and new visualization possibilities (interactivity).

**Sample result and procedure**

**Variables:** Please underline or circle your variable(s)

| | |
|---|---|
| The variable to be changed (independent variable) is | **<u>Angle of solar panel</u>** /Time /Temperature /weather /Power of solar panel |
| The variable to be monitored (dependent variable) is | Angle of solar panel /Time /Temperature /Weather /**<u>Power of solar panel</u>** |
| The variable(s) to be kept constant (controlled variable(s)) | Angle of solar panel /**<u>Time /Temperature /Weathe</u>**r /Power of solar panel |

**Procedure:**

1. Record the experimental time.
2. Move the right-hand-side IP camera to right to record the current temperature.
3. Then, move the IP camera back to the original position.
4. Move vertically upwards or downwards of the left-hand side IP camera is to change the angel of the solar panel.
5. Record the angle, current and voltage through the right-hand side IP camera into the table.
6. Repeat step 4 and 5 with different angle of the solar panel.
7. Calculate the power of the solar panel by using the formula below:
    a. Power = Current x Voltage (unit: Watt)

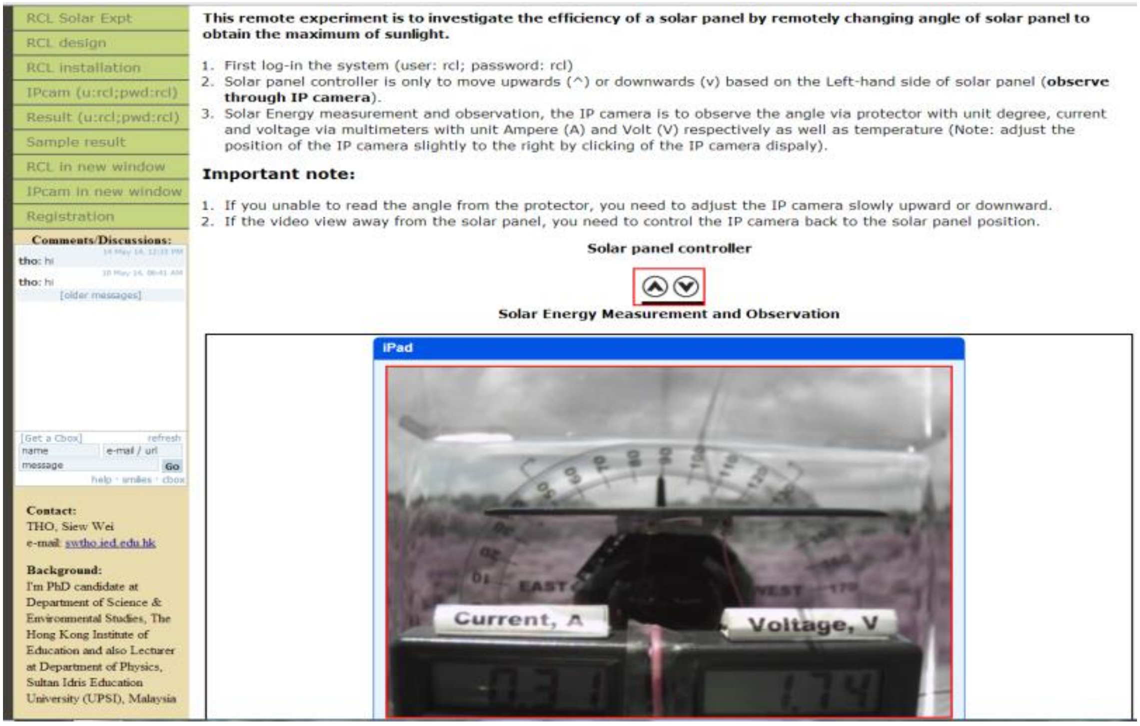



**Figure 1:** L3 – Solar experiment of remote laboratory setup

**Findings:**

***Data:***

Weather condition: sunny/cloudy/windy/rainy/stormy/foggy (please **Circle**)

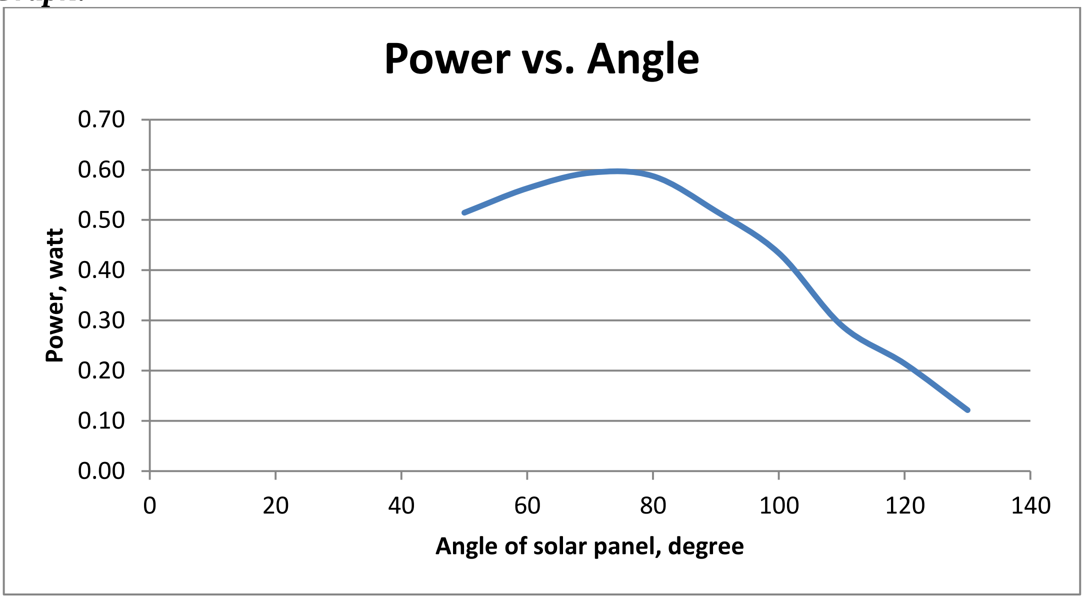
Temperature in solar container: 44 degree Celsius

Time of Experiment: 10.40.am

| Angle, θ($^o$) | Current, I (A) | Voltage, V (V) | Power = I x V, (W) |
|---|---|---|---|
| 50 | 0.31 | 1.66 | 0.51 |
| 60 | 0.32 | 1.76 | 0.56 |
| 70 | 0.33 | 1.80 | 0.59 |
| 80 | 0.33 | 1.78 | 0.59 |
| 90 | 0.31 | 1.67 | 0.52 |
| 100 | 0.28 | 1.55 | 0.43 |
| 110 | 0.23 | 1.26 | 0.29 |
| 120 | 0.20 | 1.07 | 0.21 |
| 130 | 0.15 | 0.81 | 0.12 |

**Figures:**


***Graph:***




For sunny day, the results showed that the highest power of solar panel when it surface is 70$^{o}$ at 10.40am and this power constantly decrease as the surface of solar panel away from the sunlight. Thus, this data may be varied due to the weather condition.

**Conclusion:**

The hypothesis is proven to be correct. The power generated by solar panel will be at its highest when the solar panel is adjusted perpendicularly to the sun.

**References:**


Bell, R. L., Smetana, L., & Binns, I. (2005). Simplifying Inquiry Instruction. *Science Teacher, 72*(7), 30-33.

Cheung, D. (2006). *Inquiry-based laboratory work in chemistry: Teacher's guide*. Hong Kong: Department of Curriculum and Instruction, The Chinese University of Hong Kong.

Llewellyn, D. (2007*). Inquire within: implementing inquiry-based science standards in grades 3-8. (2nd ed.)*. California, US: Corwin Press.

Llewellyn, D. (2013). *Teaching high school science through inquiry and argumentation (2nd ed.)*. Thousand Oaks, California, US: Corwin Press.

Lorbeer, G. C. (2000*). Science activities for middle school students (2nd ed.)*. US: McGraw-Hill.

Science Fair Project (2013). How different angles of incidence of solar rays impact the performance of a solar cell http://www.all-science-fair-projects.com/print_project_1091_96?print=1

## Appendix G: The Refined RCL User Guide

### Remote-Controlled Laboratory (RCL) Guideline

RCL is a real-time experiment that can be controlled or monitored by user from their computer through the Internet browser. It is also known as Web-Based Laboratory. Moreover, the RCL activity enables more flexible delivery (anytime), distance education (anyplace) and new visualization possibilities (interactivity).

### Student's Login Card

**(Example) Group 1:**

You assigned date and time:

- **Date: <u>03/05/2014 – 06/05/2014 (Saturday - Tuesday)</u>**
- **Time: <u>1000-0959</u>**

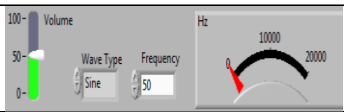
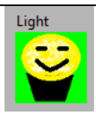
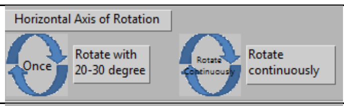
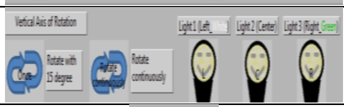
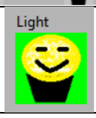
RCL Website information:

- **RCL website:** http://rcl.ied.edu.hk:8000
- **RCL interface:** http://rcl.ied.edu.hk:8000/tho.html
- **IP camera:** http://rcl1.ied.edu.hk:81/web/firstpage.htm
- **Result:** http://rcl1.ied.edu.hk:81/sd

Please enter a username and password below:

- Username: **<u>rcl</u>** & Password: **<u>rcl</u>**

**Table 1**: The design and content of remote-controlled experiments

| **RCL Experiment** | **Learning Objective** | **Changing Parameter** | **Control Button** |
|---|---|---|---|
| Center: Sound as vibration (jumping beans) | Understand the sound as vibration. | Wave type, sound frequency and volume. |  |
| L1: Electrical circuit (Series & parallel) | Understand the series and parallel circuit connections. | Number of bulbs in series and parallel. |  |
| L2: Battery bank | Explore the efficiency of the battery bank. | Charging-discharging battery & turn on devices. |  |
| L3: Infrared (IR) radiation | Explore the IR light application. | Turn on & off the light for observing different colours. |  |
| R1: Plants experiment – *Gravitropism* | Long-time observation of plant due to gravity. | Plants vertical position at $30^{o}$ or continuously. |  |
| R2: Plants experiment – *Phototropism* | Long-time observation of plant due to light source. | Three position of bulbs and plants horizontal position. |  |
| R3: Plants emit carbon dioxide ($CO_2$) | Understand the respiration of plants. | Turn on & off the light for observing plant respiration. |  |
| Solar energy experiment | Investigate the efficiency of a solar panel. | Changing angle of solar panel. | **Solar panel controller**  |

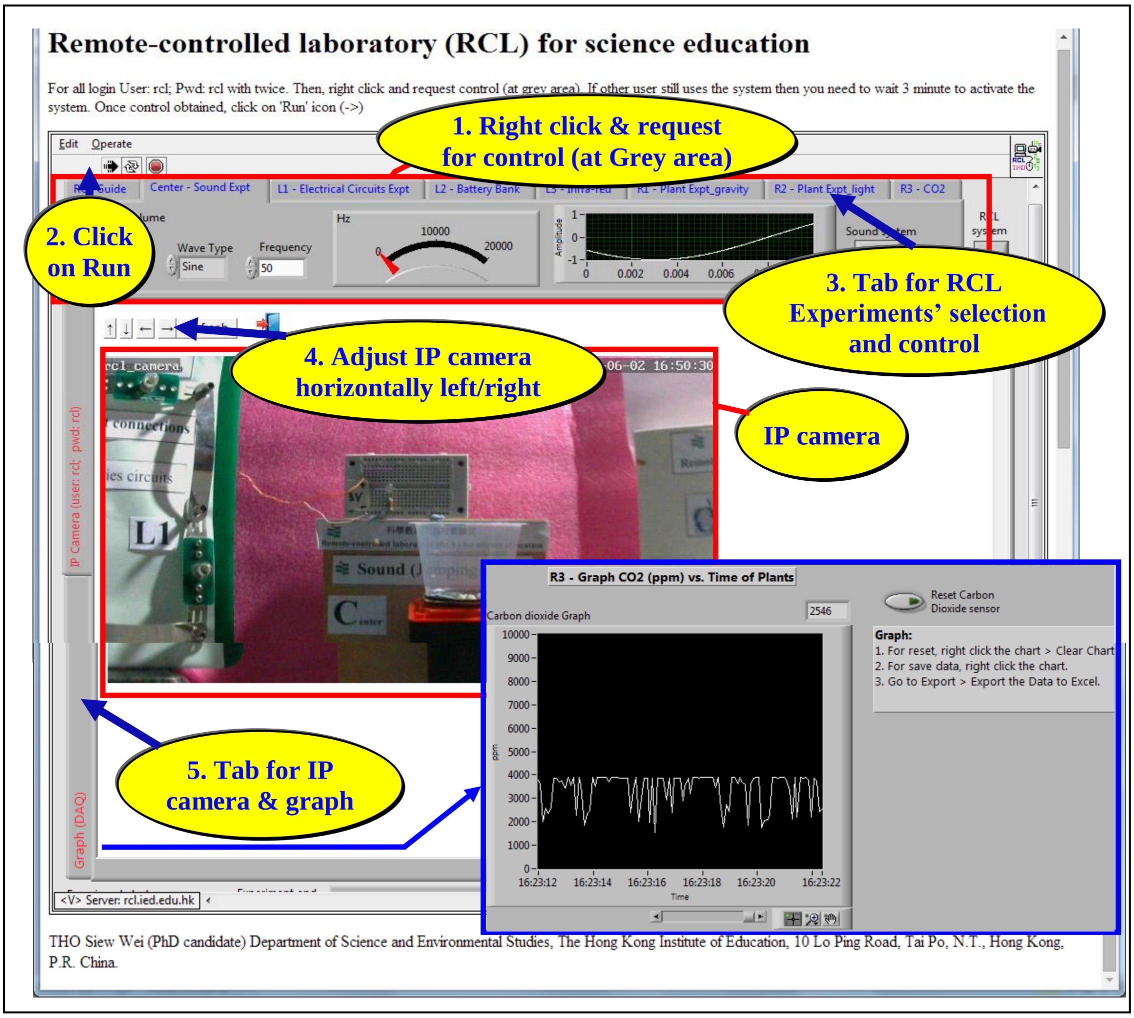
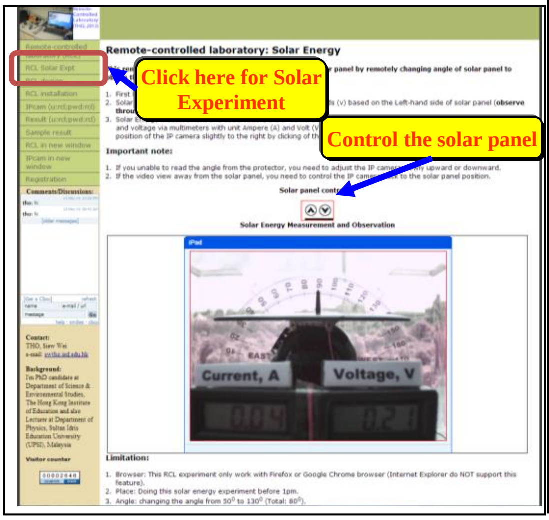



**Figure 1:** RCL software guide.



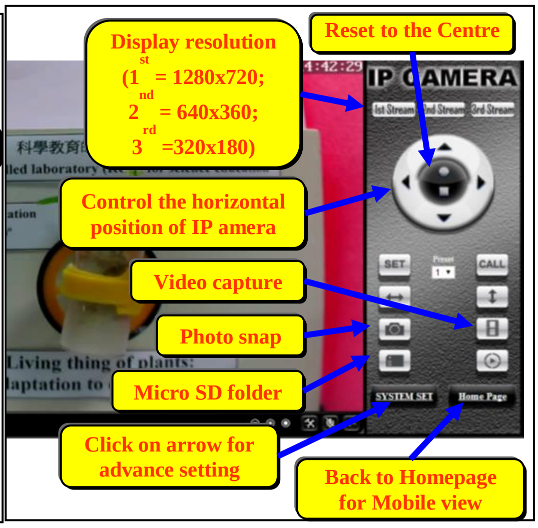




**Figure 2:** RCL: Solar Energy Experiment. **Figure 3:** Additional Functions of IP Camera.

## Appendix H: Secondary Student's Conceptual Understanding Test

**ANSWER SHEET:** The data and information obtained will be kept confidential and used only for the purposes of academic research. Your identity will not be disclosed to any party.

| | |
|---|---|
| **Student No.** | |
| **Gender** | ☐ Male ☐ Female (Please tick, √) |
| **Birth of Year-Month** | ☐ ☐ - ☐ ☐ ☐ ☐ (mm-yyyy) |
| **Date** | ☐ ☐ - ☐ ☐ - ☐ ☐ (dd-mm-yyyy) |

Your participation is voluntary, but strongly encouraged. You should plan to finish the following 24 multiple choice questions in 24-30 minutes WITHOUT discussion. **CIRCLE** only one answer per item and **TICK (√)** your confident level indicator to reflect your idea and confident level. Please do not skip any question.

| **No.** | **Answer** | | | | **Confident level indicator (信心指數)** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | A | B | C | D | □Very Sure | □Sure | □Unsure | □Very Unsure | □Best Guess |
| 2 | A | B | C | D | □Very Sure | □Sure | □Unsure | □Very Unsure | □Best Guess |
| 3 | A | B | C | D | □Very Sure | □Sure | □Unsure | □Very Unsure | □Best Guess |
| 4 | A | B | C | D | □Very Sure | □Sure | □Unsure | □Very Unsure | □Best Guess |
| 5 | A | B | C | D | □Very Sure | □Sure | □Unsure | □Very Unsure | □Best Guess |
| 6 | A | B | C | D | □Very Sure | □Sure | □Unsure | □Very Unsure | □Best Guess |
| 7 | A | B | C | D | □Very Sure | □Sure | □Unsure | □Very Unsure | □Best Guess |
| 8 | A | B | C | D | □Very Sure | □Sure | □Unsure | □Very Unsure | □Best Guess |
| 9 | A | B | C | D | □Very Sure | □Sure | □Unsure | □Very Unsure | □Best Guess |
| 10 | A | B | C | D | □Very Sure | □Sure | □Unsure | □Very Unsure | □Best Guess |
| 11 | A | B | C | D | □Very Sure | □Sure | □Unsure | □Very Unsure | □Best Guess |
| 12 | A | B | C | D | □Very Sure | □Sure | □Unsure | □Very Unsure | □Best Guess |
| 13 | A | B | C | D | □Very Sure | □Sure | □Unsure | □Very Unsure | □Best Guess |
| 14 | A | B | C | D | □Very Sure | □Sure | □Unsure | □Very Unsure | □Best Guess |
| 15 | A | B | C | D | □Very Sure | □Sure | □Unsure | □Very Unsure | □Best Guess |
| 16 | A | B | C | D | □Very Sure | □Sure | □Unsure | □Very Unsure | □Best Guess |
| 17 | A | B | C | D | □Very Sure | □Sure | □Unsure | □Very Unsure | □Best Guess |
| 18 | A | B | C | D | □Very Sure | □Sure | □Unsure | □Very Unsure | □Best Guess |
| 19 | A | B | C | D | □Very Sure | □Sure | □Unsure | □Very Unsure | □Best Guess |
| 20 | A | B | C | D | □Very Sure | □Sure | □Unsure | □Very Unsure | □Best Guess |
| 21 | A | B | C | D | □Very Sure | □Sure | □Unsure | □Very Unsure | □Best Guess |
| 22 | A | B | C | D | □Very Sure | □Sure | □Unsure | □Very Unsure | □Best Guess |
| 23 | A | B | C | D | □Very Sure | □Sure | □Unsure | □Very Unsure | □Best Guess |
| 24 | A | B | C | D | □Very Sure | □Sure | □Unsure | □Very Unsure | □Best Guess |

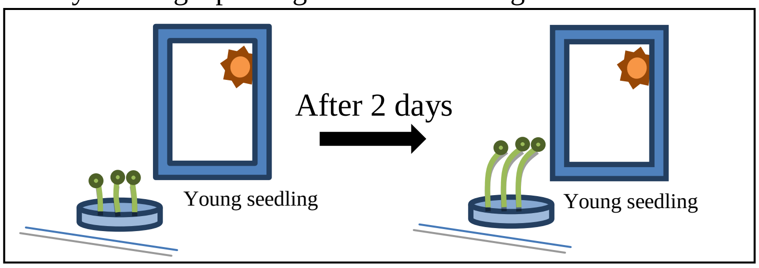
**Plants Questions** - Please answer all the question into **ANSWER SHEET** provided.

1. Which of the following statement about the plants are **TRUE**?
   - I. Plants are unable to move around in their environment.
   - II. Plants and animals have the same common characteristics (共同特徵).
   - III. Plants respond to sunlight and grow towards it.
     - A. I, II only.
     - B. I, III only.
     - C. II, III only.
     - D. I, II, III

2. Ki Yuen planted a pot of green bean seedlings and observed their growth. After a week, she found the seedlings bend toward window side. Which of the following is the best answer?
   - A. The stems (莖) bend toward light, because seedlings require larger space for growth.
   - B. The stems bend toward light, because seedlings need much more sunlight for photosynthesis.
   - C. The auxin (plant growth substances - 生長素) moves into the cells less exposed to light and makes them elongate faster than the cells on the illuminated side. (照亮的一面) The difference in their growth rates brings about the bending toward light.
   - D. The nutrient (營養) moves into the cells less exposed to light and makes them elongate faster than the cells on the illuminated side. The difference in their growth rates brings about the bending toward light.

3. Positive phototropism (向光性) can cause plant leaves to change growing patterns and ________.
   - A. Grow towards a touch stimulus.
   - B. Stop making new cells.
   - C. Become day-neutral plants.
   - D. Grow towards a light source.

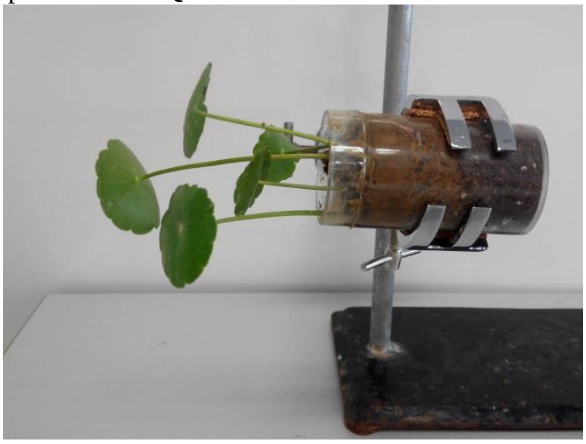
4. An experiment by locating a pot of green bean seedling near to window as figure below:




   What characteristics (特徵) do the plants show?
   - I. Growth
   - II. Movement
   - III. Respond to stimuli
     - A. I, II only.
     - B. I, III only.
     - C. II, III only.
     - D. I, II, III

5. If we place a pea seedling on its side on the soil, then the pea's root will grow down into the soil. The reason for such growth is a response to gravity. Which of the following is a best answer?
    A. The pea's root grows downward to gain water from soil.
    B. The pea's root grows downward to gain nutrients from soil.
    C. Gravity causes the auxin (plant growth substances) to move into the cells on the lower side of the root, those cells will not elongate as much as cells on the upper side, and the root will turn downward.
    D. Gravity causes the nutrient to move into the cells on the lower side of the root, those cells will elongate much longer than cells on the upper side, and the root will turn downward.

The following figure is presented for **Question 6 and 8**



6. Which of the following about the plants growth response of the shoot (萌芽) is/are **CORRECT** for figure above?
    A. The shoot of the plants will bend and grow upward.
    B. The shoot of the plants will bend and grow downward.
    C. The shoot of the plants will stop growing and remain unchanged.
    D. The shoot of the plants will grow in same direction as shown in the figure.

7. What happens when plants are grown (figure above) in **ZERO** gravity on the space shuttle (零重力太空船)?
    A. The shoot of the plants will bend and grow upward.
    B. The shoot of the plants will bend and grow downward.
    C. The shoot of the plants will stop growing and remain unchanged.
    D. The shoot of the plants will grow in the same direction as shown in the figure.

8. If the plants are placed in a chamber **WITHOUT** any light (沒有光線的室內) for two days,
    A. The shoot of the plants will bend and grow upward.
    B. The shoot of the plants will bend and grow downward.
    C. The shoot of the plants will stop growing and remain unchanged.
    D. The shoot of the plants will grow in the same direction as shown in the figure.

9. Which gas is taken by green plants in large amounts when there is no light energy at all?
    A. Argon gas.
    B. Oxygen gas.
    C. Nitrogen gas.
    D. Carbon dioxide gas.

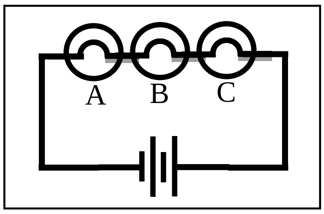
10. Which of the following is a true reason for your answer in **QUESTION 9**?
    A. This gas is used in photosynthesis which occurs in green plants all the time.
    B. This gas is used in respiration which takes place continuously in green plants.
    C. This gas is used in photosynthesis which occurs in green plants when there is no light energy at all.
    D. This gas is used in respiration which only occurs in green plants when there is no light energy to photosynthesise.

11. Respiration in plants takes place in:
    A. Every plant cell.
    B. The cells of the roots only.
    C. The cells of the leaves only.
    D. The cells of the fruits only.

12. Which of the following is a true reason for your answer in **QUESTION 11**?
    A. All living cells need energy to maintain (維持) life.
    B. Only roots need energy to absorb (吸收) water.
    C. Only fruits have small pores (stomata-氣孔) for gas exchange.
    D. Only leaves have small pores (stomata-氣孔) for gas exchange.

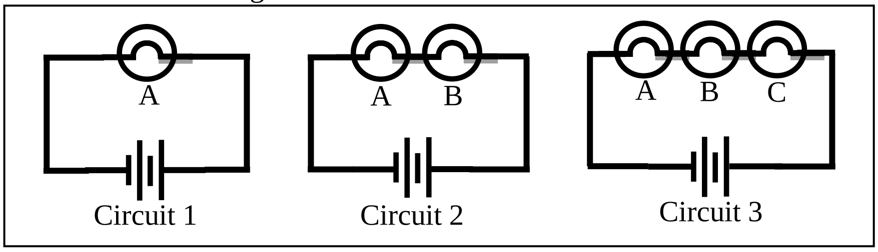
**Electricity Questions** – Please answer the entire question into **ANSWER SHEET** provided.

13. What happens to the brightness (亮度) of the bulbs A and C in the circuit below, if the bulb B has **BURNT OUT**?



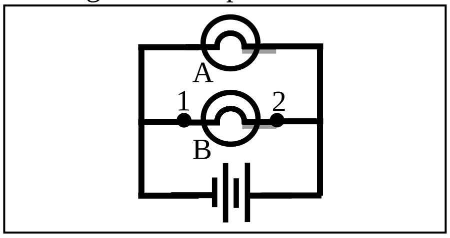

    A. Stay the same.
    B. Their brightness increase.
    C. Their brightness decrease.
    D. None of the bulbs will light up.

14. Compare the brightness of the bulb A in circuit 1 with bulb A in circuit 2 and bulb A in circuit 3. Which bulb is brighter?



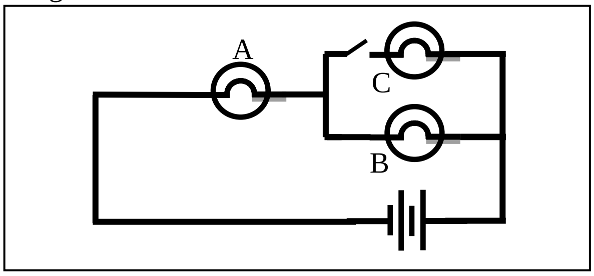

    A. Bulb A in circuit 1.
    B. Bulb A in circuit 2.
    C. Bulb A in circuit 3.
    D. Neither, they are the same.

15. What happens to the total voltage between points 1 and 2 if bulb A is **REMOVED**?




A. Zero.
B. Increases.
C. Decreases.
D. Stay the same.

16. What happens to the brightness of bulbs A and B when the switch is **CLOSED**?




A. A and B increase.
B. A and B decrease.
C. A becomes brighter, B dims.
D. A stays the same, B dims.

17. A battery can make electric current (電流) flow because it
    A. Makes electrons (電子).
    B. Creates electric charge (電荷).
    C. Adds charge to electrons.
    D. Adds energy to existing charges.

18. Is a battery:
    A. A store of electrons?
    B. A store of electricity?
    C. A store of chemical energy?
    D. A store of chemical electricity?

19. The power (P-功率) of a battery is related to the current (I-電流) and voltage (V-電壓) in the following ways
    I. P is directly proportional to I.
    II. P is inversely proportional to I.
    III. P is directly proportional to V.
    IV. P is inversely proportional to V.
        A. I, III only.
        B. I, IV only.
        C. II, III only.
        D. II, IV only

20. Why does a battery go flat (耗盡)?
    A. The electrical device runs out of the battery electricity.
    B. The electrical devices used up the chemical of the battery.
    C. All of the chemical potential energy has been converted to electrical energy.
    D. All of the chemical energy of the battery has been used up to electrical energy.

21. In what form can solar energy be converted?
    A. Thermal energy.
    B. Electrical energy.
    C. Mechanical Energy.
    D. All of above

22. Solar photovoltaic cell or solar panel (太陽能板) converts solar energy directly into
    A. Electricity.
    B. Heat energy.
    C. Transportation.
    D. Mechanical energy.

23. Which of the following is **NOT** a renewable source of energy?
    A. Solar.
    B. Wind.
    C. Natural gas.
    D. Geothermal.

24. Solar tracker (太陽能追蹤器) is device used for
    A. Cooling (製冷) down the solar panel.
    B. Storing (存儲) maximum of electricity.
    C. Generating (生產) maximum of electricity.
    D. Orienting (定向) the solar panel toward the sun.

## Appendix I: Secondary Student's Pre-Survey

**The Effectiveness of Remote-Controlled Laboratory System for Science Education**
**Student's Pre-Survey**

The data and information obtained from this survey will be kept confidential and it will be used only for the purposes of evaluation and related research. Answer all items to the best of your perception. Do not skip any item, avoid guessing and finish the survey in 10-15 minutes. Your responses should reflect what you actually and honestly think and there are no correct or incorrect answers. Please write down your information, put a tick '✓' symbol in appropriate boxes ☐ and circle the most appropriate number.

### A. Personal particulars:

| | |
|---|---|
| **Student No.:** ☐ | **Gender:** ☐ Male ☐ Female |
| **Group:** ☐ | |
| Birth of **Year** & **Month:** ☐ ☐ ☐ ☐ - ☐ ☐ (yyyy-mm) | |
| Please rate how you presently view your own science knowledge level?<br>☐ High ☐ Medium ☐ Low | |
| How do you rate your personal ability in conducting scientific experiment?<br>☐ High ☐ Medium ☐ Low | |
| **Last year Science Grade or Marks**: ☐ | |

B. Survey items: Please circle **only one** answer per item to show your level of agreement with the following statements.

| **Strongly Disagree** | **Disagree** | **Agree** | **Strongly Agree** |
|---|---|---|---|
| ☹☹ | ☹ | ☺ | ☺☺ |
| 1 | 2 | 3 | 4 |

| **No.** | **Statement** | ☹☹ | ☹ | ☺ | ☺☺ |
|---|---|---|---|---|---|
| | ***Personal interest*** | | | | |
| 1 | I like science more than any other subjects. | 1 | 2 | 3 | 4 |
| 2 | I like trying to solve new problems in science. | 1 | 2 | 3 | 4 |
| 3 | I study science to learn knowledge that will be useful in my life outside school. | 1 | 2 | 3 | 4 |
| | ***Experiment*** | | | | |
| 4 | I enjoy conducting experiments and investigations on science. | 1 | 2 | 3 | 4 |
| 5 | When I am working in the science laboratory, I feel I am doing something important. | 1 | 2 | 3 | 4 |
| 6 | I seek to connect what I learn from science experiments with what happens in the science lesson. | 1 | 2 | 3 | 4 |

| No. | Statement | ☹☹ | ☹ | ☺ | ☺☺ |
|---|---|---|---|---|---|
| | ***ICT learning*** | | | | |
| 7 | I like teacher demonstrate (示範) science on a computer. | 1 | 2 | 3 | 4 |
| 8 | Studying science using Information and Communication Technology (ICT) will increase my learning motivation (動機). | 1 | 2 | 3 | 4 |
| 9 | I enjoy using data-logging tools (數據記錄儀 e.g PASCO scientific) in conducting science experiments. | 1 | 2 | 3 | 4 |
| | ***Science practices*** | | | | |
| 10 | I can ask a question for scientific investigation. | 1 | 2 | 3 | 4 |
| 11 | I can propose workable hypotheses (假設). | 1 | 2 | 3 | 4 |
| 12 | I can use models to design practical work. | 1 | 2 | 3 | 4 |
| 13 | I can plan meaningful practical work. | 1 | 2 | 3 | 4 |
| 14 | I can predict (預測) results reasonably of practical work. | 1 | 2 | 3 | 4 |
| 15 | I can conduct practical work correctly. | 1 | 2 | 3 | 4 |
| 16 | I can distinguish (區分) correctly between independent, dependent and control variables. | 1 | 2 | 3 | 4 |
| 17 | I can design experimental procedures properly. | 1 | 2 | 3 | 4 |
| 18 | I can handle equipment and apparatus properly and safely. | 1 | 2 | 3 | 4 |
| 19 | I can observe the results of practical work closely and carefully. | 1 | 2 | 3 | 4 |
| 20 | I can classify (分類) correctly. | 1 | 2 | 3 | 4 |
| 21 | I can measure experimental data accurately. | 1 | 2 | 3 | 4 |
| 22 | I can interpret the data of practical work correctly. (i.e. plot graph and calculate related equations) | 1 | 2 | 3 | 4 |
| 23 | I can communicate effectively (有效的溝通) the results of practical work to others. | 1 | 2 | 3 | 4 |
| 24 | I can infer (推斷) from the observation and experimental data for a new situation. | 1 | 2 | 3 | 4 |

## Appendix J: Secondary Student's Post-Survey

**The Effectiveness of Remote-Controlled Laboratory System for Science Education**
**Student Post-Survey**

The data & information obtained from this survey will be kept confidential & it will be used only for the purposes of evaluation and related research. Do not skip any item, avoid guessing and finish the survey in 20-25 minutes. Your responses should reflect what you actually and honestly think/perception and there are no correct or incorrect answers. Please write down your information, put a tick '✓' symbol in appropriate boxes ☐ and circle the most appropriate number.

**A. Personal particulars:**

| |
|---|
| **Student No.:** ☐ **Gender:** ☐ Male ☐ Female **Group:** ☐ |
| Birth of **Year** & **Month:** ☐ ☐ ☐ ☐ - ☐ ☐ (yyyy-mm) |
| During the assigned time, how many times you log-in and used the RCL (遙控實驗) system?<br>☐ Less than 5 times ☐ 6-10 times ☐ Over 10 times |
| Please indicate the total amount of time you spend on the RCL system.<br>☐ Less than 1 hour ☐ 1-2 hours ☐ Over 3 hours |
| If you had more free time, would you use (RCL system) more? ☐YES ☐NO |

B. Survey items: Please circle **only one** answer per item to show your level of agreement with statements about the RCL experience.

| **Strongly Disagree** | **Disagree** | **Agree** | **Strongly Agree** |
|---|---|---|---|
| ☹☹ | ☹ | ☺ | ☺☺ |
| 1 | 2 | 3 | 4 |

| **No.** | **Statement** | | | | |
|---|---|---|---|---|---|
| | ***Personal interest*** | ☹☹ | ☹ | ☺ | ☺☺ |
| 1 | I like science more than any other subjects. | 1 | 2 | 3 | 4 |
| 2 | I like trying to solve more new problems in science. | 1 | 2 | 3 | 4 |
| 3 | I study science to learn knowledge that will be more useful in my life outside school. | 1 | 2 | 3 | 4 |
| | ***Experiment*** | ☹☹ | ☹ | ☺ | ☺☺ |
| 4 | I enjoy more in conducting experiments and investigations on science. | 1 | 2 | 3 | 4 |
| 5 | When I am working in the Remote-controlled Laboratory (RCL-遙控實驗), I feel I am doing something very important. | 1 | 2 | 3 | 4 |
| 6 | I seek more to connect what I learn from science experiments with what happens in the science lesson. | 1 | 2 | 3 | 4 |
| | ***Operation of RCL system*** | ☹☹ | ☹ | ☺ | ☺☺ |
| 7 | The RCL software interface and features are easy to work with. | 1 | 2 | 3 | 4 |
| 8 | The advantages of conducting the RCL system will be greater than any technical challenges. | 1 | 2 | 3 | 4 |
| 9 | Browsing and controlling real experiment on the online laboratory are easy to work with. | 1 | 2 | 3 | 4 |
| | ***Motivation (動機)*** | ☹☹ | ☹ | ☺ | ☺☺ |
| 10 | The contents meet my expectation (期望). | 1 | 2 | 3 | 4 |
| 11 | The science topics in the RCL are interesting. | 1 | 2 | 3 | 4 |
| 12 | My experience in RCL increases my motivation to learn science. | 1 | 2 | 3 | 4 |

| | | | | | |
|---|---|---|---|---|---|
| 13 | The advantages of the RCL system worth the extra time and effort to learn it. | 1 | 2 | 3 | 4 |
| | ***Teamwork*** | | | | |
| 14 | The learning through RCL system can promote collaboration in learning (合作學習). | 1 | 2 | 3 | 4 |
| 15 | The use of RCL system for science learning assists me to interact more with other students. | 1 | 2 | 3 | 4 |
| 16 | RCL assists me to actively participate in the group discussions. | 1 | 2 | 3 | 4 |
| | ***Importance of RCL system*** | ☹☹ | ☹ | ☺ | ☺☺ |
| 17 | RCL allows long-time observation of experiment | 1 | 2 | 3 | 4 |
| 18 | RCL can replace conventional (傳統) practical work. | 1 | 2 | 3 | 4 |
| 19 | I feel more motivated to try things with the remote experiments than conventional practical work. | 1 | 2 | 3 | 4 |
| 20 | The RCL can be used as a supplement (補充) to school practical work. | 1 | 2 | 3 | 4 |
| 21 | RCL can equally (相等的) develop my scientific investigation skills as compare with conventional practical work. | 1 | 2 | 3 | 4 |
| | ***Science practices*** | ☹☹ | ☹ | ☺ | ☺☺ |
| 22 | I can ask better scientific investigation questions. | 1 | 2 | 3 | 4 |
| 23 | I can plan meaningful practical work more effectively (更有效). | 1 | 2 | 3 | 4 |
| 24 | I can predict (預測) results more reasonably of practical work. | 1 | 2 | 3 | 4 |
| 25 | I can conduct practical work more confidently (更有信心). | 1 | 2 | 3 | 4 |
| 26 | I can distinguish (區分) between independent, dependent & control variables more confidently. | 1 | 2 | 3 | 4 |
| 27 | I can design experimental procedures more properly. | 1 | 2 | 3 | 4 |
| 28 | I can handle equipment and apparatus more confidently. | 1 | 2 | 3 | 4 |
| 29 | I can observe the results of practical work more closely and carefully. | 1 | 2 | 3 | 4 |
| 30 | I can measure experimental data accurately and confidently. | 1 | 2 | 3 | 4 |
| 31 | I can interpret the data of practical work correctly and confidently. (i.e. plot graph and calculate related equations) | 1 | 2 | 3 | 4 |
| 32 | I can communicate more effectively the results of practical work to others. | 1 | 2 | 3 | 4 |
| 33 | I can infer (推斷) better from the observation and experimental data for a new situation. | 1 | 2 | 3 | 4 |

C. Survey items: Please circle **only one** answer per item to compare the RCL experience to school science practical work in general.

| **No.** | **Statement** | **School practical work is much better** | **School practical work is somewhat better** | **Equally good** | **RCL is somewhat better** | **RCL is much better** |
|---|---|---|---|---|---|---|
| 34 | Reliability (可靠性) of observations | 1 | 2 | 3 | 4 | 5 |
| 35 | Ease of gathering (採集) data | 1 | 2 | 3 | 4 | 5 |
| 36 | Personal involvement (個人參與) | 1 | 2 | 3 | 4 | 5 |
| 37 | Personal Motivation (個人動機) | 1 | 2 | 3 | 4 | 5 |
| 38 | Ease of learning new things | 1 | 2 | 3 | 4 | 5 |
| 39 | Teamwork/collaboration in learning | 1 | 2 | 3 | 4 | 5 |

**Open-ended question:** Write down your opinion(s) in either **English or Chinese (中文)**.

40. What have you learned from the RCL guided inquiry experiments (knowledge, attitude and skills)?

41. Have you encountered any problems concerning the RCL programme and the equipment while doing the remote experiments? If so, briefly describe the problem(s).

42. If you were given another chance to do the RCL again, please suggest some ways for improvement?

**Appendix K: Secondary Teacher's and Student's Interview Questions**

**The Effectiveness of Remote-Controlled Laboratory System for Science Education**

**Teacher's Pre-Interview about the School Science Experiments**

Name______________________ Gender: Male / Female,

Date: __________ Venue: ________________ Time-Start: ____________

All data are **confidential.** Your identity will not be disclosed to any party.

| Scope | Interview | Asking | Reply | Remarks |
|---|---|---|---|---|
| Science experiments | Today, our interview is about the science experiments.<br>I want to know about your views on science experiments and your school science experiments' methods<br><br>Do you think it is important to let student to conduct science experiments? Why? | ☐ | ☐ | |
| | Do you allow your students to conduct science experiments frequently? Why? | ☐ | ☐ | |
| Experimental techniques or methods | Please list out the experimental techniques or methods of your school science experiments (such as conventional experiment / scientific inquiry / simulation experiment / other science experimental methods) and its ratio. (Have you used any ICT tools to assist student learning when conducting school practical work? Is it common for student to use ICT when learning?) | ☐ | ☐ | |
| Disadvantages | Please list out (conventional experiment / scientific inquiry / simulation experiment / other science experimental methods) the disadvantages of science experiments. | ☐ | ☐ | |
| Advantages | Please list out (conventional experiment / scientific inquiry / simulation experiment / other | ☐ | ☐ | |

| | | | | |
|---|---|---|---|---|
| | science experimental methods) the advantages of science experiments. | | | |
| Problem Encountered | Throughout the experiments, do students have encountered any difficulties? How did they solve it? | ☐ | ☐ | |
| Gender differences | What are the differences, if any, between male and female students' participation in science experiments? Why? Whether there is also a participation difference in the classroom? | ☐ | ☐ | |
| Other | Is there anything you would like to add? | ☐ | ☐ | |

1. Remarks: *Please specify any problem occurred, noisy environment or interviewee's special expression*

| |
|---|
| |

Researcher: ______________________ Recorded File: ______________________

**The Effectiveness of Remote-Controlled Laboratory System for Science Education**

**Teacher's Interview**

Name:______________________ Gender: Male / Female,

Date: ___________ Venue: ____________________ Time-Start: _________

All data are **confidential.** Your identity will not be disclosed to any party.

| Scope | Interview | Asking | Reply | Remarks |
|---|---|---|---|---|
| **RCL and school practical work** | Have you used any ICT tool to assist student's learning while conducting school practical work? Can you give me some examples? Is it common for student to use ICT while learning? | ☐ | ☐ | |
| | Based on your observation, what are the differences between RCL approach and school practical work? (i.e. contexts and topic) | ☐ | ☐ | |
| | Do you think the RCL could be used as a supplement or integrated to school practical work? Why? Why not? | ☐ | ☐ | |
| **Related to RCL** | The lesson can be divided into three major parts; RCL briefing session with guided-inquiry, performing the RCL in classroom/ home and students' presentation.<br>What is your opinion and suggestion of the RCL Briefing Session? | ☐ | ☐ | |
| | What is your opinion and suggestion for performing RCL via guided-inquiry in classroom/home? | ☐ | ☐ | |
| | What is your opinion and suggestion of the students' presentation? | ☐ | ☐ | |
| | What are the strengths and weakness of the RCL system? Would recommend it to other teachers or schools? | ☐ | ☐ | |
| | Do you think there is any help or benefit for secondary student to explore the RCL system? Why? Why not? | ☐ | ☐ | |
| | What is your view of using the Internet environment to do the science practical work and learn science? | ☐ | ☐ | |
| **Self-efficacy: The RCL run in** | With sufficient guide, are you confident enough to implement and apply the RCL approach in your classroom or secondary schools? Why? Why not? | ☐ | ☐ | |

| | | | | |
|---|---|---|---|---|
| **secondary school** | | | | |
| | Do you feel confident that the secondary student can easily work with the RCL system? Why? Why not? | ☐ | ☐ | |
| | Do you feel confident that secondary student will increase their motivation to learn science through the use of RCL system? Why? Why not? | ☐ | ☐ | |
| | Based on your observation, do you think the use of RCL activities is able to increase secondary student capabilities in learning and knowledge? Why? Why not? | ☐ | ☐ | |
| | Do you feel confident that the use of inquiry through RCL is able to encourage collaboration in learning among secondary students? Why? Why not? | ☐ | ☐ | |
| **Related to Student** | What is your view of the students' sense of involvement throughout the lesson? | ☐ | ☐ | |
| | Throughout the lesson, do students have encountered any difficulties? How did they solve it? | ☐ | ☐ | |
| | Is there any difference between the school practical work and RCL approach related to student participation throughout the lesson (including the teamwork)? Why? | ☐ | ☐ | |
| | What are the differences, if any, between male and female students' participation in RCL approach? | ☐ | ☐ | |
| **Other** | Is there anything you would like to add? | ☐ | ☐ | |

Remarks: *Please specify any problem occurred, noisy environment or interviewee's special expression*

| |
|---|
| |

Researcher: ______________________ Recorded File: _________________

**The Effectiveness of Remote-Controlled Laboratory System for Science Education**

**Secondary Student's Interview**

Name: ___________ Gender: Male / Female, Group: __________, Code: ____
Date: __________ Venue: ___________________ Time-Start: ____________

Several questions from student survey are selected for further explanation about student's reason(s) in selecting their response.

| Scope | Interview | Asking | Reply | Remarks |
|---|---|---|---|---|
| **School practical work** | Based on your experience in conducting the school practical work, please describe using Likert scale (1=strongly disagree, 2=disagree, 3=agree and 4=strongly agree) of several questions for further explanation about your reason(s) in selecting the response. (Likert)<br><br>Do you think that the Science practical work was easy to work with? Why? Why not? | ☐ | ☐ | |
| | Did you feel motivated to learn more from science experiment? Why? Why not? | ☐ | ☐ | |
| | Please describe any help or benefit you have observed when school practical work is used for science learning. | ☐ | ☐ | |
| | Have you encountered any problem concerning the school practical work and the equipment used while doing the experiments? If so, please briefly describe the problem(s).<br>(What were things that did not work so well?) | ☐ | ☐ | |
| **RCL** | Based on your experience in conducting the RCL, please describe using Likert scale (1=strongly disagree, 2=disagree, 3=agree and 4=strongly agree) of several questions for further explanation about your reason(s) in selecting the response. (Likert)<br><br>Do you think that the RCL system was easy to work with? Why? Why not? | ☐ | ☐ | |
| | Did you feel motivated to learn more from this RCL system? Why? Why not? | ☐ | ☐ | |

| | | | | |
|---|---|---|---|---|
| | Please describe any help or benefit you have observed when RCL is used for science learning. | ☐ | ☐ | |
| | What have you learned from the RCL guided inquiry experiments (knowledge (is it interesting topic), attitude and skills, teamwork)? | ☐ | ☐ | |
| | Have you encountered any problem concerning the programme and the equipment used while doing the inquiry experiments? If so, please briefly describe the problem(s). (What were things that did not work so well?) | ☐ | ☐ | |
| | What technical issues are needed to be improved? If you were given another chance to repeat the experiments, do you have any further suggestions for help us to improve them? | ☐ | ☐ | |
| **RCL & school practical work** | Based on your opinion, which one is better RCL & school practical work? Or it is just equally good? Or it can be used as a supplement to school practical work? Why? | ☐ | ☐ | |
| **Other** | Is there anything you would like to add?<br>Is your school life too busy? | ☐ | ☐ | |

* Note: Let the student gives their response directly.

Remarks: *Please specify any problem occurred, noisy environment or interviewee's special expression*

| |
|---|
| |

Researcher: ________________ Recorded File: ____________________

## Appendix L: The Refined RCL User Guide after Second Iterative Cycle

**Simple Remote-Controlled Laboratory (RCL 遙控實驗) Guideline**

RCL is a real-time experiment *網絡實時實驗* that can be controlled or monitored by user from their computer through the Internet browser. It is also known as Web-Based Laboratory. Moreover, the RCL activity enables more flexible delivery (anytime *任何時候*), distance education (anyplace *任何地方*) and new visualization possibilities (interactivity *互動*).

**Student's Login Card *學生登錄證***

**Group ____:**

You assigned worksheets, date and time*指定的工作紙，日期和時間*:

- **Worksheets: L2 – battery bank** and **Solar experiment**
- **Duration:** 3-day (29/11/2014 – 01/12/2014)
- **Time:** Anytime

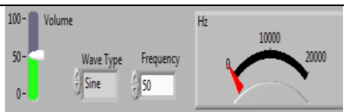
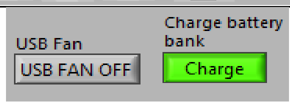
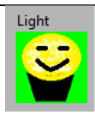
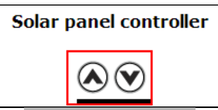
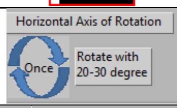
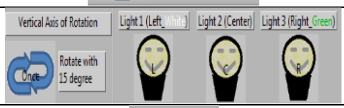
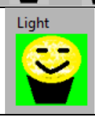
RCL Website information*遙控實驗網站信息*:

- **RCL website:** http://rcl.ied.edu.hk:8000
- **Remote experiments:** http://rcl.ied.edu.hk:8000/page_rcl.html
- **Solar experiment:** http://rcl.ied.edu.hk:8000/page_solar.html
- **Result:** http://rcl1.ied.edu.hk:81/sd

Please enter a username and password below:

- Username *用戶*: **rcl** & Password *密碼*: **rcl**

**Table 1**: The design and content of remote-controlled experiments *遙控實驗設計和內容*

| **RCL Experiment** *實驗* | **Learning Objective** *學習目標* | **Changing Parameter** *改變參數* | **Control Button** *控制按鈕* |
|---|---|---|---|
| Centre: Sound as vibration (jumping beans) | Understand the sound as vibration. | Wave type, sound frequency and volume. |  |
| L1: Electrical circuit (Series & parallel) | Understand the series and parallel circuit connections. | Number of bulbs in series and parallel. |  |
| L2: Battery bank | Explore the efficiency of the battery bank. | Charging-discharging battery & turn on devices. |  |
| L3: Infrared (IR) radiation | Explore the IR light application. | Turn on & off the light for observing different colours. |  |
| Solar energy experiment | Investigate the efficiency of a solar panel. | Changing angle of solar panel. |  |
| R1: Plants experiment – *Gravitropism* | Long-time observation of plant due to gravity. | Plants vertical position at 30° |  |
| R2: Plants experiment – *Phototropism* | Long-time observation of plant due to light source. | Three position of bulbs and plants horizontal position. |  |
| R3: Plants emit carbon dioxide ($CO_2$) | Understand the respiration of plants. | Turn on & off the light for observing plant respiration. |  |

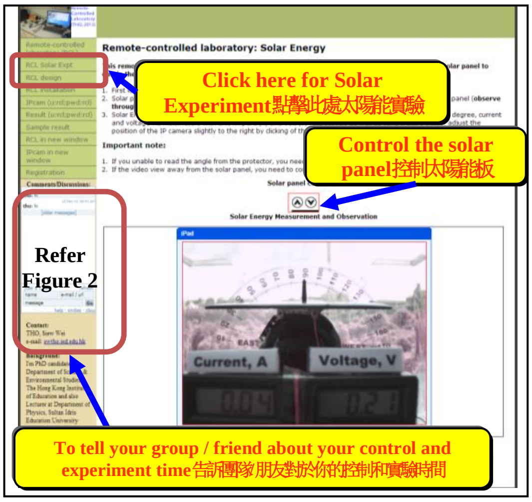



**Figure 1:** RCL – Solar Energy Experiment.
*太陽能遙控實驗*


**Figure 2:** Explain about your RCL Setting
*說明控制和實驗時間*

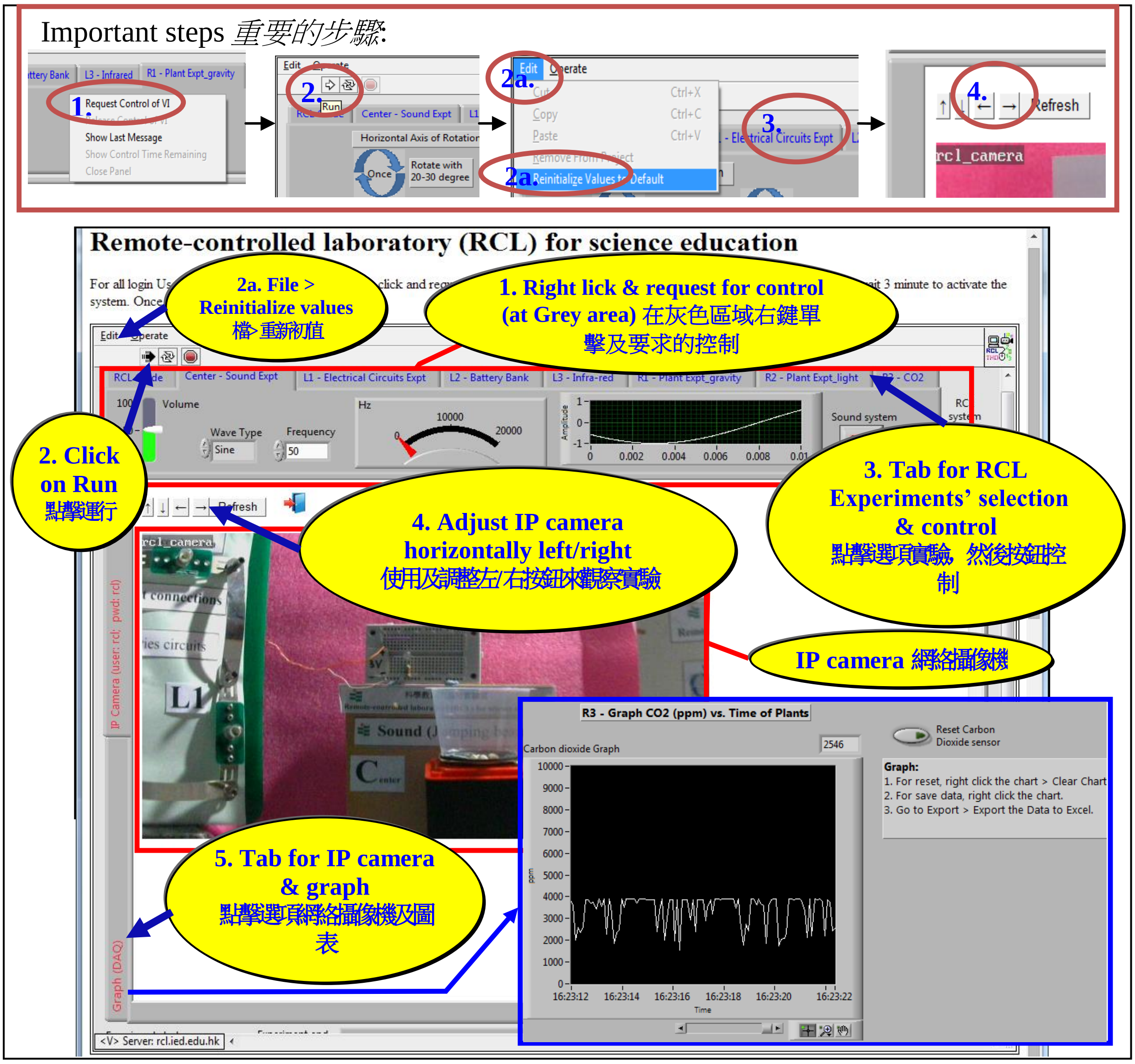



**Figure 3:** RCL software guide *遙控實驗軟件指南*

# Appendix M: Publications
# Appendix M1: RCL Published Papers

Liu, C.-C. et al. (Eds.) (2014). Proceedings of the 22nd International Conference on Computers in Education. Japan: Asia-Pacific Society for Computers in Education

# Remote Laboratory System for Technology-Enhanced Science Learning: The Design and Pilot Implementation in Undergraduate Courses

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**Abstract:** In this study, a new remote laboratory (RL) system is developed through some innovative ideas and methods for practicing technology-enhanced learning of science in schools. The Internet-based RL system will enable students to control the server-side laboratory equipment and to carry out real-time scientific investigation activities at distance places. As a pilot study, a set of newly developed remote-controlled experiments were first tried out by a total of 64 undergraduate students who studied some science education and teacher training courses. The evaluation used mixed research method which included questionnaire survey and interviews as specifically developed by us to collect data on students' perceptions, views and implementation issues related to the use of the RL system. The survey findings showed that the participants agreed with the appropriateness of various educational merits of the RL system but negative comments and suggestions for improvement were also received. Through iteration of Design-Based Research (DBR), we have refined our RL system.

**Keywords:** remote laboratory, technology-enhanced learning, science education

## 1. Introduction

With the rapid advancement of technology and the prevalent use of Internet in education, science practical work in form of web-based laboratory or remote laboratory (RL) has recently been adopted in cloud computing. As a simple definition of the RL system, "the basic idea is for a user to connect via the Internet with a computer from place A to a real experiment carried out in place B" (Grober, Vetter, Eckert, & Jodl, 2007, p. 127). Recent education reforms have identified the importance of technology-enhanced science learning, which can be achieved in science education through RL system (Kong, Yeung, & Wu, 2009; Lowe, Newcombe, & Stumpers, 2013). Using this RL system, students can view and control apparatus/equipment in science experiments, and downloads real-time data in classroom, computer laboratory or even at their homes. Therefore, the RL can be considered as a kind of new development in technology-enhanced learning (TEL) in which appropriate technology and pedagogies are innovatively applied in science education.

The first part of this study is to design and develop of an innovative RL system through technology-enhanced inquiry for Hong Kong science education. Of course, we are aware that it is hard to evaluate this innovative system just based on the design or development itself. As a result, a pilot evaluation in two undergraduate classes was conducted as the second part of the study.

## 2. Research Methodology

### *2.1 The RL System Design*

In developing and designing the RL packages, this study adopts the Design-Based Research (DBR) framework (Design-Based Research Collective, 2003; Reeves, 2006; Wang, & Hannafin, 2005) and it involves four important iteration phases of design, testing, analysis, and refinement.

# Innovative IP camera applications for scientific investigation

*Siew Wei Tho and Yau Yuen Yeung*

ABSTRACT This article describes several innovative but simple ways of remotely observing and conducting science experiments over the internet. It involves technology-enhanced science learning using an Internet Protocol (IP) camera (a monitoring electronic tool, also known as a network camera, that can transmit image or video data anywhere, via the internet) to capture real-time videos and images of the experiments, and to remotely manipulate certain physical variables using its built-in mechanical functions. The article also reports how we actually applied IP cameras in the design of a few remote experiments, such as daytime and night-time gravitropism, and an experiment involving solar panels, through which students can enrich and extend their science learning beyond the school environment and the lesson time.

Recent education reforms have identified the importance of technology-enhanced learning, which can be achieved in science education through computer-mediated or datalogger-based experiments (Deaney, Hennessy and Ruthven, 2006; Spector *et al.*, 2008). There are several research studies on using various digital camera and video camera technologies for educational research and development (Lottero-Perdue *et al.*, 2011; Needham, 2013; Northcote, 2011; Souter and MacVicar, 2012; Sun and Cheng, 2009). It is anticipated that the Internet Protocol (IP) camera will become an important tool for observing, controlling and recording practical work in school science education, as it is now much more affordable, at around US$50–100 (or £30–60). As Needham (2013) remarked, the '*camera provides many opportunities for students to report on their work*'.

IP cameras have been widely used for monitoring and surveillance purposes, and for tracking objects, for many years (Dinh, Yu and Medioni, 2009). However, there are few studies concerning its applications in school science experiments. The main idea of the work presented here is that students can use a computer or mobile device, such as a smartphone or a tablet, to remotely control (by changing certain variables) the IP camera and to observe (with automatic recording of images and/or videos) real-time experiments at any time via the internet. Students can thus perform real-time, practical science experiments within and outside the school environment (i.e. in the classroom, a computer laboratory or even at home); this is especially useful for those experiments that require more time than standard school laboratory sessions. The IP camera can be a solution to the problem highlighted by Souter and MacVicar (2012) that '*experiments that take longer than a standard science lesson may frequently be ignored*'.

## IP cameras: the basics

An IP camera is a monitoring electronic tool that can transmit image or video data anywhere, via the internet. It is also known as a network camera, and is usually bundled with the manufacturer's own monitoring software and easy set-up function/manual so there are no standard set-up procedures. Since the camera requires a specific IP address, the right TCP (Transmission Control Protocol)/IP suite and the routeing permissions for external access to the camera from outside the school network, it will be necessary to involve the school IT technician to get the system working properly. Nevertheless, the basic concept and functions are very similar across brands and models, irrespective of whether the camera is designed for monitoring children, offices, factories or shops.

In this study, we introduce innovative applications of IP cameras for remotely monitoring and/or controlling scientific phenomena or experiments. IP cameras can take time-lapse photographs, which can then be edited into films


Figure 6. Students buying at the "Market" counter during a simulation-based class.

Figure 7. Students presenting during an inquiry-based class.

**Conclusion**

It is never easy to initiate a new behavior in plastic recycling. With a suitable recycling tool, promotion and education, changes in knowledge, attitudes and behaviors towards plastic recycling would be largely enhanced. It is hoped that the above series of studies can provide some insights to educators and teachers to employ appropriate strategies to educate our next generation in plastic recycling and waste management, which will eventually facilitate environmental sustainability.

**Reference**

Environmental Protection Department (2015). *Monitoring of Solid Waste in Hong Kong: Waste Statistics for 2013*. Available at: https://www.wastereduction.gov.hk/en/materials/info/msw2013.pdf

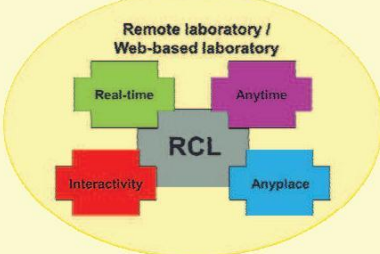
Environmental Protection Department (2011). *Guideline on Plastic Coding System for Resin Identification*. Available at: https://www.wastereduction.gov.hk/en/materials/workplace/guide_plastic_coding.pdf

So, W., Cheng, N., Chow, C., & Zhan, Y. (2014). *Learning about the types of plastic wastes: effectiveness of inquiry learning strategies*. Education 3-13, 1-14.

## Remote-controlled Laboratory for Science Education

Siew-Wei THO[1,2], Prof. Yau-Yuen YEUNG[1], Prof. Winnie Wing-Mui SO[1] & Dr Yeung-Chung LEE[1]
[1] Department of Science and Environmental Studies, The Hong Kong Institute of Education, Hong Kong.
[2] Department of Physics, Faculty of Science & Mathematics, Sultan Idris Education University, Malaysia.

This paper reports the research on the successful development of a novel remote-controlled laboratory (RCL) system through some innovative ideas and methods for practicing technology-enhanced learning of science education particularly secondary school. The Internet-based RCL system enables learners to control and observe the server-side laboratory equipment as well as to perform real-time scientific investigation activities at distant places (Tho & Yeung, 2014, 2015). The following figure shows some important characteristics of RCL system. Thus, this RCL system may overcome some conventional laboratory work problems related to limited class time, places, weather, health, safety, and accessibility (Cooper & Ferreira, 2009; Grober, Vetter, Eckert, & Jodl, 2008; Kong, Yeung, & Wu, 2009; Tho & Yeung, 2014, 2015).




In this study, a series of review processes involving a systematic review of laboratory work and RCL in science education with innovative software (HistCite [http://interest.science.thomsonreuters.com/forms/HistCite/] and CiteSpace [http://cluster.ischool.drexel.edu/~cchen/citespace/download.html]) for visualizing their structure were also conducted (Tho, Yeung, Wei, Chan, & So, 2014). It is believed that the results of this systematic review can provide more insights into laboratory work to inform classroom practices with the existing evidence base and identify areas for further research. Hence, the relationship of the cited works was observed in the historiographs of laboratory work and RCL research studies through HistCite analysis. Then, more information about RCL was obtained with CiteSpace analysis, which identified a manageable number of studies for further consideration. Figures below show the HistCite graphmaker (Left) and the Citespace cluster (Right) displays of RCL studies.

*Australasian Journal of Educational Technology, 2016, 32(3).*

# Technology-enhanced science learning through remote laboratory: System design and pilot implementation in tertiary education

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Sultan Idris Education University, Malaysia

**Yau Yuen Yeung**
The Education University of Hong Kong, Hong Kong SAR

This paper reports the research on the successful development of a new remote laboratory (RL) system through some innovative ideas and methods for practising technology-enhanced learning of science education. The Internet-based RL system enables learners to control and observe the server-side laboratory equipment as well as perform real-time scientific investigation activities at distant places. As a pilot implementation study, a set of newly developed remote experiments were first tried out by a total of 64 undergraduate students in a tertiary institution mainly for teacher education. The evaluation used a mixed research method which included a questionnaire survey, open-ended questions and interviews as specifically developed by us to collect data on students' perceptions, views and implementation issues related to the use of the RL system. The survey findings show that the participants agreed with the appropriateness of various educational merits of the RL system and the ways of conducting those innovative experiments. Furthermore, negative comments and suggestions for improvement were identified. Based upon these, we have refined our RL system and the RL design principles through an iteration of design-based research.

## Introduction

With the rapid advancement of technology and the prevalent use of the Internet in education, science practical work in the form of a web-based laboratory or remote laboratory (RL) has recently been adopted in cloud computing. As a simple definition, the RL system serves "to enable students to conduct real world experiments at a distance" (Scanlon, Colwell, Cooper, & Di Paolo, 2004, p. 154). Using this RL system, students can view and control apparatus/equipment in science experiments, and download real-time data in the classroom, computer laboratory or even at their home. Therefore, the RL can be considered as a kind of new development in technology-enhanced learning (TEL) in which appropriate technology and effective pedagogies are innovatively applied in science education.

The first part of this study designed and developed an innovative RL system through technology- enhanced inquiry for Hong Kong science education (Tho & Yeung, 2014b, 2015). Of course, we are aware that it is hard to evaluate this innovative system based just upon the design or development itself. As a result, a pilot evaluation was conducted in two undergraduate classes as the second part of the study. For this pilot evaluation, we focused our analysis on the undergraduate students' views and suggestions for refinement of the RL system before its subsequent formal implementation and evaluation in secondary schools. The pilot evaluation was essential for ensuring the reliability of our research because students' views and suggestions were highly relevant to us, due to the fact that the participants studied various science education, ICT and teacher training courses. Furthermore, this new RL approach was appropriate for them in practising how to teach laboratory work and it could be applied in their future laboratory work in a school.

In essence, the RL system is composed of two major parts, namely hardware and software. The hardware consists of the data acquisition system, digital input or output, a digital camera, and various types of sensors. The software is used for data logging as well as control and display of the real-time experiment on the learner's computer screen via the Internet. The RL system can be applied for helping students learn scientific concepts comprised of topics from science discipline areas including physics and biology. In particular, the topics of "Plants" and "Electricity" by conducting inquiry experiments through the RL system were developed for the Hong Kong secondary schools science curriculum.

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DOI 10.1007/s10763-016-9740-z

# A Systematic Review of Remote Laboratory Work in Science Education with the Support of Visualizing its Structure through the *HistCite* and *CiteSpace* Software

Siew Wei Tho[1,3] · Yau Yuen Yeung[1] · Rui Wei[2] · Ka Wing Chan[1] · Winnie Wing-mui So[1]

Received: 4 December 2014 / Accepted: 15 March 2016 / Published online: 15 April 2016


**Abstract** Laboratory work, particularly the latest remote laboratories (RLs), has been assumed to have a general positive effect on science education because practical work can provide diverse learning experiences and enhance thinking skills suitable for the 21st century. However, there has not been a synthesis of the science education research to support this assumption. The objective of this study is to systematically review the growth of educational research on laboratory work, particularly in RLs, utilizing a series of review processes with innovative software for visualizing structural relationships. The combined use and support of *HistCite* and *CiteSpace* software enabled the visualization of the citation structure and history of articles. The findings revealed that RLs were a state-of-the-art subset of laboratory work and a new way of conducting laboratory work that has gained fairly wide research attention in engineering education over the past two decades. Thus, this innovative literature review process has established a solid background for future research and development efforts on RLs in science education dealing with scientific and engineering practices.

**Keywords** *CiteSpace* analysis · *HistCite* analysis · Practical work · Remote laboratories · Systematic review

Practical work in a science laboratory is acknowledged as a fundamental part of science learning (Hofstein & Mamlok-Naaman, 2007). The effectiveness of laboratory

**Electronic supplementary material** The online version of this article (doi:10.1007/s10763-016-9740-z) contains supplementary material, which is available to authorized users.

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**Appendix M2: Laboratory-related Published Papers**



# Innovative use of Smartphones for a sound resonance tube experiment


By Siew Wei Tho and Yau Yuen Yeung

A Smartphone is not only a mobile device that is used for communication but is also integrated with a personal digital assistant (PDA) and other technological capabilities such as built-in acceleration, magnetic and light sensors, microphone, camera and Global Positioning System (GPS) unit. This handheld device has become very popular with the younger generation. The price of the device has also dropped as demand has increased and the latest model released. Therefore, Smartphone technology has the potential to serve as an excellent tool for students to conduct scientific investigation and learn scientific concepts. In this study, the research aim is to develop a hands-on activity for the determination of the speed of sound using a Smartphone device.

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# 巧用手机测量重力加速度

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重力加速度的测量是高中物理教学中的一个重要实验,常用的测量方法有单摆法、自由落体法等[1][2]。这些传统的实验法存在以下不足:用量角器测定摆角操作不方便且误差大;测量周期采用人工计时,受人体反应时间影响;只能记录几个数据,无法看到实验图象。数据采集器虽可以解决人工计时以及图象问题,但价格不菲。为克服以上不足,本文基于单摆法的原理,结合手机自带的传感器设计一个测量重力加速度的低成本的新方法。

## 一、手机传感器介绍

手机传感器是手机芯片中能检测加速度、磁场、光、声等各类非电量信号,并将这些信号转化成电信号,供人们测量、传输、处理和控制的元件[3]。传感器是手机的硬件部分,通过一些免费软件的驱动便可使用*。以下介绍本实验用到的传感器。

### 1.磁传感器

手机磁传感器(Physics Toolbox Magnetometer)能够探测周围磁场的实时变化,并以曲线形式显示出来,横坐标表示时间,纵坐标表示磁感应强度,将时间与磁场同步,如图1[4]。

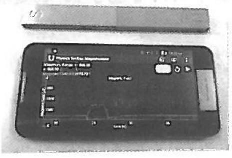

图1 磁传感器软件

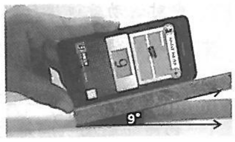


图2 角度传感器软件

### 2.角度传感器

手机角度传感器(Angle Meter)能够探测到手机的长边与水平面夹角的大小,如图2[5]。

## 二、实验原理与步骤

### 1.实验原理

本实验采用单摆法测重力加速度,根据公式 $g=\frac{4\pi^2 L}{T^2}$,只需测定单摆周期 $T$ 与摆长 $L$ 即可求出 $g$[6]。用磁铁充当单摆摆子,实验装置如图3所示。当磁铁靠近手机时,磁感应强度变大;当磁铁摆离手机,磁感应强度变小,则探测到的磁场变化周期等于单摆周期。


图3 手机辅助单摆法测重力加速度装置

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## 四、小结

在光线较好的情况下,也可以实现对曲线运动物体的轨迹拍照,如果在运动物体附近放置参考尺,再把每个轨迹点(在这里就是小车)对应的时间标注出来,就可以实现对位移和速度的定量计算。轨迹点时间可以点击图片属性查看,但不能自动显示。通过开发相应的手机软件,还可以实现位移、速度、加速度等状态量的自动计算和实时显示。

### 参考文献

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* 安卓手可免费下载各种手机传感器驱动软件。

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# Technology-Enhanced Physics Programme for Community-Based Science Learning: Innovative Design and Programme Evaluation in a Theme Park

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**Abstract** In this study, a new physics education programme is specifically developed for a famous theme park in Hong Kong to provide community-based science learning to her visitors, involving her three newly constructed rides. We make innovative use of digital technologies in this programme and incorporate a rigorous evaluation of the learning effectiveness of the programme. A total of around 200 students from nine local secondary schools participated in both the physics programme and its subsequent evaluation which consists of a combination of research and assessment tools, including pre- and post-multiple-choice tests, a questionnaire survey and an interview as specifically developed for this programme, or adopted from some well-accepted research instruments. Based on the evaluation of students' academic performance, there are two educationally significant findings on enhancing the students' physics learning: (a) traditionally large gender differences in physics performance and interest of learning are mostly eliminated; and (b) a less-exciting ride called the aviator (instead of the most exciting roller-coaster ride) can induce the largest learning effect (or gain in academic performance) amongst teenagers. Besides, findings from the questionnaire survey and interviews of participants are reported to reveal their views, perceptions, positive and negative comments or feedback on this programme which could provide valuable insights for future development of other similar community-based programmes.

**Keywords** Community-based science learning · Technology-enhanced learning · Amusement park · Physics education

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## Introduction

The recent world trends of educational reform in science education highly stress on community-based learning or out-of-school learning experience with an aim to link schools with communities for effective teaching and learning of science subjects. The most important reason is that there are some unique opportunities such as rides in amusement or theme parks available in the local community, which can provide profound impact on the students' science learning in terms of their cognitive, affective and psychomotor development (Escobar 1990; Falk et al. 2001; Hofstein and Rosenfeld 1996; Ramey-Gassert 1997). The present research is based on the implementation of a new physics education programme known as "Experiential Learning of Physics in Ocean Park Rides". The programme was developed by the authors through a knowledge transfer project for a very famous park which won the prestigious Applause Award and was recognized as world's best theme park in year of 2012, attracting more than seven million visitors annually (see http://www.oceanpark.com.hk/). Recently, the park constructed several new rides at its "Thrill Mountain", and, at the same time, a new senior secondary (NSS) physics curriculum was introduced into the local schools during the year 2009–2010 with some changes in the content of the physics syllabus (CDC 2007). Hence, the Education Department of the theme park observed a

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