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INTEGRATION OF INFORMATION COMMUNICATION TECHNOLOGY INTO INQUIRY-BASED SCIENCE EDUCATION: RELEVANCE IN STIMULATING LEARNERS' AUTHENTIC INQUIRY PRACTICES

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Abstract. Inquiry-Based Science Education (IBSE) and Information Communication Technology (ICT) applications are integral components of the intended science curricula in many countries. The article reviews the theory of IBSE and presents practical explorations of ICT tools for data logging with sensors, video measurement, and dynamical modeling. These tools help realising authentic inquiry practices of pupils within the IBSE approach by enabling more opportunities and time for learners to think back and forth between the physical and theoretical worlds. However, inquiry goals (i.e. understanding of the methods of scientific inquiry and the ability to carry out scientific inquiry) cannot just be achieved by doing only. This article recommends an effective way to help learners in comprehending inquiry and doing inquiry with ICT. This recommendation might be useful for the Vietnamese educational context where the coming comprehensive innovations will yield opportunities for sustainable IBSE incorporation in the school science education, but will also present challenges for teacher education and training in this field.
Keywords: Authentic inquiry practices, ICT, Inquiry-Based Science Education.

1. Introduction

Science educators have been aware of the potential benefits of an inquiry-based approach in science teaching and learning at both primary and secondary levels. Inquiry-Based Science Education (IBSE) is an integral component of the intended science curricula in many countries. In such school science curricula, "inquiry" refers to learning goals (i.e. understanding of the methods of scientific inquiry and the ability to carry out scientific inquiry). "Inquiry" also refers to teaching strategies that stimulate and support pupils to exercise inquiry practices, including hands-on activities, minds-on discussions, and meaning making [1].

To reflect on the complex nature of inquiry skills and the entanglement with domain knowledge, the Next Generation Science Standards (NGSS) in the United States uses the term: "inquiry practice" [2]. It distinguishes the following crucial practices of inquiry-based science activities in the classroom:

- Asking questions
- Developing and using models
- Planning and carrying out investigations (incl. experiments)
- Analysing and interpreting experimentation/modelling data

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- Using mathematics and computational thinking
- Constructing explanations
- Engaging in argument from evidence (i.e. experimentation/modelling outcomes)
- Obtaining, evaluating, and communicating information

The NGSS described the essentials of these practices as follows:

Engaging in the practices of science helps students understand how scientific knowledge develops; such direct involvement gives them an appreciation of the wide range of approaches that are used to investigate, model, and explain the world [2].

According to the Vietnam Ministry of Education and Training [3], the educational reform in Vietnam from 2016 will place more emphasis on inquiry skills in science education. The focus of assessments and examination will be shifted towards competency-based evaluations. Furthermore, the learner research project will be apart from traditional school subjects like physics, chemistry, and biology and aimed at learners' investigation of real-life problems in consultation with school teachers. These innovations will yield opportunities for sustainable IBSE incorporation, but will also present challenges for teacher education and training in this field.

We studied literature as well as recent educational technology to a) clarify inquiry practices and b) explore how technology can be used to stimulate such inquiry practices of learners. Presented in the following sections are outcomes of these theoretical and practical studies and our recommendations for the Vietnamese educational context.

2. Content

2.1. Authentic inquiry of science and how learners learn

Inquiry and how learners learn

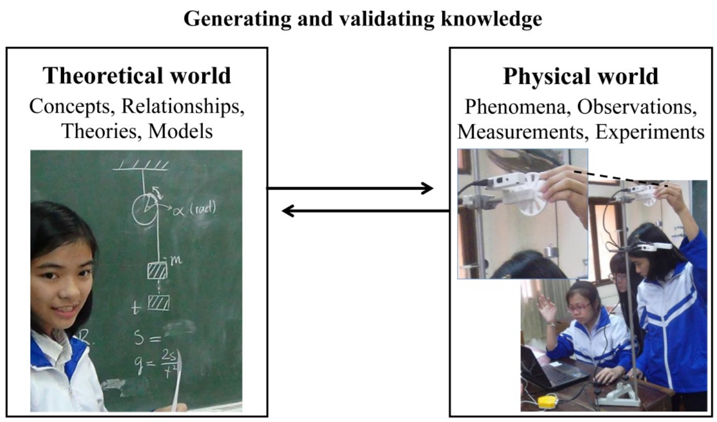

Figure 1. Moving back and forth between the theoretical world and the physical world is the inquiry way to generate and validate scientific knowledge.

In an article published in 1910, Dewey remarked that science is not only a body of knowledge to be acquired, but it also includes inquiry methodologies to generate and validate knowledge [4]. We consider inquiry as a process of generating and validating knowledge through moving back and forth between the theoretical world (ideas, concepts, relationships, theories, and models) and the physical world (objects, phenomena, observations, measurements, and experiments) (Figure 1). According to Van den Berg [5], ideally, IBSE will engage learners in thinking back and forth between these two worlds like scientists; and "the phenomena and experiments serve as a source for validating ideas and theories and as a playground for generating new ideas and theories in a complex mix of inductive and deductive mind play". Illustrative photographs in Figure 1 are about an inquiry activity of three Vietnamese learners. In the theoretical world, these learners proposed a conceptual design of an experiment (by sketching) to verify the value of the acceleration due to gravity (g). Next, they moved into the physical world to set up and carry out the experiment, following their own design. After collecting sufficient data, they moved back to the theoretical world and used kinematics to analyse these data and validate the value of g, which was given in the textbook.

In the book: "The scientist in the crib", Gopnik, Meltzoff, and Kuhl implied that from young ages, children can create new knowledge by inquiry, and scientists make the most of this capacity, which lets "children learn so much so quickly" [6]. Consequently, we are convinced that learners are able to "engage in and profit from instruction that incorporates relatively complex scientific practices from the very beginning of their schooling" [7].

Authentic inquiry of science

The science-education community has suggested making authentic inquiry of science more accessible to pupils [8]. Authenticity of inquiry in the school can be interpreted as resemblance of learner activities to experimentation/modelling activities of practicing scientists in constructing new knowledge. Authentic inquiry is close to real science, so it makes school science more attractive and relevant. This might be a part of a solution for the fact that there has been a decline in interest for science at high school [9]. Moreover, considering the "learning as participation" metaphor [10], learners can appreciate the inquiry as a scientific method of generating and validating knowledge through being engaged in practices which are similar to those of scientists.

Learning to do inquiry

Although engaging in inquiry practices is crucial to understand scientific inquiry and to learn inquiry skills, it is not enough. According to Chinn and Malhotra [11], many inquiry activities replicated in the classroom fail to help learners to appreciate inquiry as a scientific method. Moreover, the first review of research on effectiveness of teaching in the laboratory [12] concluded that there was no evidence for better conceptual or inquiry skill achievement for learners with as compared to without laboratory experience. Recent reviews [13] have showed that the objectives for laboratory teaching (incl. inquiry skills) – just as with other teaching methods – are still often not achieved. For learners really acquiring inquiry skills and understanding about scientific inquiry, as Akerson, Abd-El-Khalick, and Lederman argued [14], there must be an explicit emphasis on the method of scientific inquiry and reasoning as learners are exercising such inquiry skills in the classroom. Especially for the first time, inquiry skills have to be explicitly taught and scaffolded [15].

2.2. Integration of technology and stimulation of inquiry practices

Since the 1980s, advances in technology and science education research have stimulated intensive development of Information Communication Technology (ICT) for a) data logging with sensors, b) video measurement, and c) dynamical modelling. These tools resemble those of scientists and engineers, but are designed for educational purposes and primarily aimed at classroom use. In this section, we describe characteristics of this ICT as constructional tools for science education. Furthermore, we explain how these ICT tools can enhance opportunities and time for learners' inquiry practices in the science class.

ICT tool for data logging with sensors

a) Characteristics of data logging with sensors

The ICT tool for data logging with sensors enables learners' experimentation activities in which the sensor, connected to an interface, measures a quantity (e.g. temperature, voltage, and pH) in the physical world and transforms this quantity into a voltage or other signal(s), which is then read by the interface. The interface converts the signal into digital data that are transferred to, then interpreted and processed by the connected computer or other devices with dedicated software (Figure 2). A computer equipped with an interface and ample sensors becomes a universal measuring instrument, which has a wide range of sampling frequencies from very low to very high (e.g. 10000 samples per second). This computer-based instrument certainly can take the place of instruments such as thermometers, voltmeters, pH meters, used in conventional practical work. It enables automatic, accurate, conditional measurements and includes ample ways of storing, displaying, and analysing data. During the measurement, real-time data can be represented in graphs, tables or displayed as digital values. Data logging with sensors is a generic experimental tool for physics, chemistry, and biology.

Figure 2. Diagram of the tool for data logging with sensors (incl. sensor, interface, and computer with dedicated software).

b) How does the data-logging tool stimulate inquiry practices of learner?

First, the tool for data logging with sensors enhances new possibilities and contexts for science experiments that might not be otherwise possible due to time constraints and technical difficulties [16]. This increases access to real-life phenomena, facilitates new classroom experiments, and allows measurements in the field. Second, the tool enables collecting, recording, and representing of many data and even repeating this process several times in short time (physical world). Consequently, learners will have time in the classroom to design the experiment, interpret data, and/or explain relationships (theoretical world). Third, the "real-time graphing" feature of the data-logging tool stimulates pupils to move back and forth between the physical world and the theoretical world. For example, a learner walks in front of a motion sensor, and immediately the software shows in the graph her or his position and/or velocity in real time. By observing the learner walking and the graph showing up at almost the same time, other learners in the class can easily realise the connection between the motion of their classmate and the kinematics concepts. Last but not least, the incorporation of the data-logging tool enables learners to participate in aspects of scientists' experimental inquiry, considering that the data-logging tool is similar to those used by scientists. According to Ellermeijer, Landheer, and Molenaar [17], once learners get used to the data-logging tool, they can decide and reflect at any time about what to measure, how to calibrate, and what readings should be taken. This shows that such participation in authentic inquiry with the data-logging tool will stimulate learners to comprehend scientific inquiry.

ICT tool for video measurement

a) Characteristics of video measurement

The ICT tool for video measurement enables learners to conduct experiments in which, for instance, position and time data of a moving object, registered in a digital video, are collected in the successive video frames by mouse clicking. Among different softwares, there are common steps to gather real-life data from a video. First, the user has to define the video scale, time calibration and coordinate system. The video clip is scaled by specifying which distance on the video screen corresponds to which actual distance (e.g. 1m viewed in the video frame in Figure 3). A video is a collection of rapidly displayed pictures called video frames. The time interval between two successive frames shown in the software is calibrated by entering the actual frame rate of the video (i.e. how many video frames were taken in a second as the video was recorded). Next, the user moves the cursor over the video screen to locate the point(s) of interest (e.g. a baseball) and then click to store the first video point (i.e. first coordinate and time data). The video clip automatically advances to the next frame, and then the user continues clicking on the reference point. This procedure with the software is repeated until the user obtains a desired number of data points. Figure 3 illustrates an experimentation activity facilitated by the video-measurement tool. In this activity, position and time of a baseball is collected from a high-speed video and displayed in the graph and table by the software. The dotted cross in the graph indicates that the scan feature of the software is activated. In this illustration, the data point (-0.7284 m, 0.1498 s) on the graph and the table is scanned, and the video advances to Frame 74, which shows the corresponding position of the baseball.

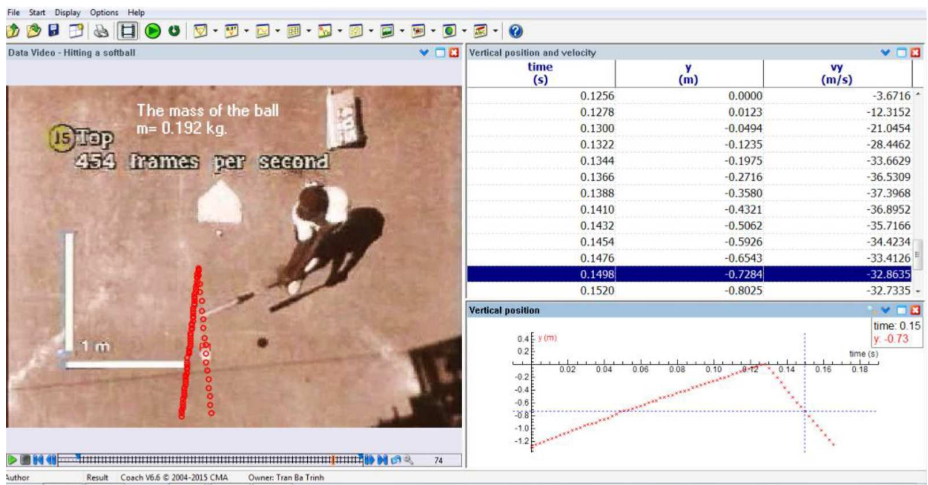

Figure 3. Screenshot of an experimentation activity facilitated by the video-measurement tool.

Some softwares (e.g. Coach) allow automated tracking of the movement of objects and enable collection of different video points in a single video frame. Like the data logging with sensors, during the manual measurement and automated tracking from a video, the collected data are simultaneously displayed in a diagram or table (real-time graphing) (Figure 3). Other dynamics quantities such as velocity, acceleration, momentum, kinetic energy, force can be numerically computed based on the collected data. Finally, collected and computed data are analysed and processed further by the software.

b) How does the video measurement tool stimulate inquiry practices of learners?

First, like the data-logging tool, video measurement creates new possibilities and contexts for experimentation activities. With the video-measurement tool, the teacher can bring real-life, attractive scenes of motion into classroom activities that show learners the relevance of science concepts and theory in everyday life [18]. Such realistic scenes of motion can be quite ordinary (e.g. basketball shots, amusement-park rides, dancing) or unusual (e.g. car crashes, jumps on the Moon, rocket launch). With high-speed videos (i.e. up to 1200 frames per second), the teacher and learners can quantitatively explore many more situations of realistic motions (e.g. multi-dimensional collisions between billiard balls, gun recoil) that would be mostly impossible to investigate with traditional instruments and even with sensors for school science. Additionally, the video-measurement tool can serve as a cost and time effective instrument for the school laboratory, which might replace rulers, timers, photo gates, and motion sensors in motion-related experiments.

Second, the tool enables the collection and representation of many video data from different realistic situations in a short time (physical world). Consequently, learners will have time in the classroom to interpret data and/or explain relationships (theoretical world). Third, the "real-time graphing" and "scan" features of the video-measurement tool stimulate learners to think back and forth between the physical and theoretical worlds. This becomes more likely as images of these two worlds are shown in the same software interface (Figure 3). When pupils scan a particular data point in one of the graphs, the corresponding video frame, where the data were collected, displays simultaneously. This feature enables learners to identify events during the realistic situation (physical world) and connect them to abstract representations in the graph (theoretical world).

Last but not least, the incorporation of the video-measurement tool makes it possible for learners to exercise experimental inquiry practices similar to those of biomechanics and movement-science scientists [18]. Learners can participate in many aspects of experimental inquiry using video measurement. For example, formulating problems; designing the scenario and setup for appropriate video recording by a webcam, a smartphone, or a video camera; calibrating time and scale of the video; defining from which frames to get data and with which techniques to collect data; and processing and interpreting the collected video data.

ICT tool for dynamical modelling

a) Characteristics of dynamical modelling

Modelling has different meanings for different communities; depending upon the context in which it is discussed. In science education, the term "modelling" will refer to computational, dynamical modelling that is a tool used by scientists in many different fields (e.g. science, technology, economics, sociology) to describe, explain, and predict complex dynamical systems. It helps to understand a system's structure, the interaction between its objects, and the behaviour it can produce. Many of such systems can be built as models on the computer, which can carry out many more simultaneous calculations than human mental models and which can enable solution of differential equations. These differential equations cannot be solved with secondary school mathematics.

The ICT tool for dynamical modelling provides the teacher and learners with possibilities to be engaged in the modelling process in science: "analyse a situation in a realistic context and reduce it to a manageable problem, translate this into a model, generate outcomes, interpret these outcomes, and test and evaluate the model" [19]. First, a realistic context (e.g. a tennis ball bouncing on the floor) is analysed and simplified to be manageable by ignoring realistic effects or situational factors (e.g. the ball moving vertically without rotation, air resistance, and aerodynamics effects); the stripped-down, mental model is then translated into a computational model. Next, the computational model is constructed by graphical elements: state variables (e.g. height, velocity); in- and out-flows of state variables (i.e. rates of change); auxiliary variables; constants (e.g. acceleration due to gravity); events (e.g. bounce) that provoke discrete, instantaneous changes of state variables; and relations that are visualised by connectors between variables, constants, events (Figure 4) and are specified by mathematical formulas. As the model is executed, differential equations behind the model are automatically solved by numerical iteration methods and so result in values of variables as a function of time. To interpret these modelling data, the modeller needs to choose relevant representations of the resulting values of variables such as a) graphs that show more explicit, comprehensible relationship between variables; b) animations that visualise behaviours of modelled objects. To validate the model (i.e. evaluating its descriptive, predictive, and explanatory quality), the modeller compares modelling outcomes with their counterparts in the physical world (i.e. standards, measured data, empirical graphs). Figure 4 illustrates a modelling activity facilitated by the modelling tool. In this activity, bouncing of a solid, rubber ball is modelled, and the modelling result is compared with data obtained from video measurement of the bouncing ball. The graph shows the modelling result (solid curve) and the measurement (dots) for height versus time.

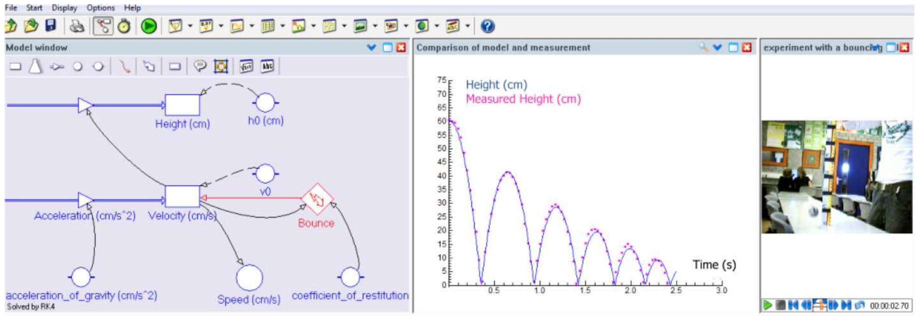

Figure 4. Screenshot of a modelling activity facilitated by the modelling tool

b) How does the dynamical modelling tool stimulate inquiry practices of pupils?

First, the modelling tool holds the potential to enlarge possibilities for pupils' theoretical inquiry of realistic, dynamic phenomena (e.g. motion with air resistance, charging and discharging capacitors, combustion of carbon monoxide, and chemical equilibrium). These phenomena are difficult to describe with school mathematics but relatively easy to model with software [18]. There are different patterns in which learners can move back and forth between the theoretical and physical worlds and so learn with the modelling tool. For example, learners run a given model (e.g. a parachute jump with air resistance) to understand a phenomenon and/or explore its structure to gain insight into interactions between the model elements. Based upon their understanding, learners can also make a small change to a given model, try out various modelling ideas, and then evaluate if the revised model describes the phenomenon better. For example, "unfortunately, the parachute does not open right away. Therefore, there is first free fall for two minutes and then fall with air resistance while the parachute already opens". With a certain mastery of the modelling tool, learners may construct a new model from their mental model of the realistic phenomenon and validate the model by comparing modelling outcomes with experimental results. Patterns for teachers to prepare a lesson, using the modelling tool are similar; the teacher might use a ready model, modify it a bit, or develop a new model.

Second, the software allows importing measured data and graphs to the modelling activity. This enables simultaneous observations of the modelling graph (i.e. an outcome from the theoretical world) and the experimental graph (i.e. an outcome from the physical world) in the same diagram (Figure 4). It is convenient for pupils to compare these outcomes of the two worlds. If the modelling result does not fit real data, then learners can adjust the model (e.g. changing parameters, adding variables, correcting relationships), execute it again, and compare new modelling results with the real data. The modelling tool enhances opportunities for many rounds of thinking back and forth between the theoretical and physical worlds.

Last but not least, the incorporation of the modelling tool enables learners to a) get used to modelling as a scientific tool in computational science (doing science with computer), b) appreciate what modelling is as a way of thinking and c) understand how important it is in science. Heck and colleagues showcased learners' research projects (i.e. yoyos, bouncing balls, alcohol metabolism, beer foam) in which learners could build models from simple to more complex (i.e. progressive modelling approach) by incorporating more factors aimed at better matching between the model and reality [18, 20].

2.3. Recommendations for the Vietnamese educational context

Considering above outcomes of our theoretical and practical explorations, we suggest the following recommendations for the Vietnamese educational context. There must be a focus on learners acquiring inquiry skills as one of the crucial goals of the science lesson. To realise this goal, explicit inquiry-based teaching should be applied as the main approach. With "explicit" we mean that a) learners consciously exercise intentional inquiry practices and b) the teacher guides and scaffolds this process. In particular, teachers should operationalise opportunities for practising inquiry practices within the ICT-enhanced experimentation/modelling activity (i.e. lesson plan) and then guide pupils to consciously exercise such practices (i.e. lesson implementation). This integration of ICT with IBSE is not trivial. Research has shown learners' perception that doing experiment means manipulating equipment and software but not manipulating ideas [21]. Use of ICT has a tendency to make learner activities more prescriptive while we want to make them more investigative. Therefore, teachers must aim at the shift from manipulations of equipment and software to manipulations of ideas. For example, if the teacher just uses the sensor measurement for the practical work in which learners follow the given worksheet with step-by-step instructions to set up the experiment, collect and analyse data to validate Boyle's law, then the data-logging tool does not add much to IBSE. It does not stimulate learners' inquiry practices much. If the learners themselves have to design a verification experiment and carry it out according their own design, then the learner exercises a wider array of inquiry skills, so not following a recipe.

3. Conclusion

What we have learned from the literature study are: learners' acquisition of inquiry skills is an important goal of science education. Ideally, participation in inquiry practices similar to those of practicing scientists will enable learners to understand scientific inquiry. Inquiry fits the way learners learn from young ages, but to really master inquiry as a scientific method, learners need explicit teaching of inquiry while exercising inquiry practices. Just like the learning of any complex practices, the acquisition of inquiry skills needs to be carefully designed and scaffolded. Therefore, the way for learners to understand inquiry is to get them involved in the knowledge creation activity and to make this inquiry process explicit to them. It has been demonstrated that the ICT tools for data logging, video measurement, and modelling can help to implement this approach and so realise inquiry goals by providing more meaningful opportunities and more minds-on time for learners to move back and forth between the physical and theoretical worlds. These enable learners to exercise more inquiry practices within experimentation/modelling activities.

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