Dataloggers for Inquiry-Based Science Learning
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Introduction

There is a growing awareness among science educators of the need to de-emphasise the memorizing of de-contextualized scientific facts and place greater emphasis on science in the everyday world and developing deep understanding from inquiries (Singer, Marx, & Krajcik, 2000). Likewise, in our curriculum, there has been an increasing emphasis on investigative and discovery modes of science learning in view of the need to develop in our pupils scientific reasoning, critical reflection and analytical skills. With our national science syllabuses anchored on the inquiry-based framework, inquiry has always been strongly advocated as one important aspect in the teaching and learning of science. However, with the many constraints faced by our teachers in meeting the daily demands of school, the inquiry mode of learning is often not fully realised in the delivery of the science curriculum (Seah, Tan, Hedberg, & Koh, 2005).

Inquiry-based learning

Inquiry can be broadly defined as the different ways in which scientists study the natural world and propose plausible explanations from the evidence gathered from their investigations (Singer et al., 2000). Inquiry-based learning anchors on the constructivist approach as it encourages learners to learn inductively through concrete experiences and observation with the help of real-world exemplars (Colburn, 2004). It is vital to situate pupils’ learning in an authentic context so as to expose them to the complexity and ambiguity of real life problems and extend the opportunity for them to solve problems collaboratively, as opposed to just conducting traditional school science experiments in which pupils seek the “right” answers.

The science inquiry model developed by NorthWest Regional Education Laboratory (NWREL) identified four essential traits of inquiry, namely, connecting, designing, investigating and constructing meaning (Hinrichsen & Jarrett, 1999). Connecting the topic studied to pupils’ prior experiences is necessary in order for the investigation to be meaningful to the pupils and for pupils to raise worthwhile questions. Involving pupils in planning experiments and designing data collection methods allows pupils to develop scientific skills and knowledge such as selecting appropriate apparatus and approach, control of variables, concept of fair experiments and sufficient data, and habits of mind such as consistency and accuracy.

During the investigation phase of inquiry, pupils are involved in the process of collecting, organising and displaying data. They can make changes to their planned procedures, take note of these changes and rationalise why the changes are made. They learn to take multiple readings for consistency and present data collected in a logical and meaningful manner, make detailed observations, explain relationships between variables and clarify results. The constructing meaning phase involves pupils in the process of analysing the data collected, examining patterns and trends in the data and using them to formulate explanation. Pupils reflect on their data and deliberate whether to repeat the experiment, alter the experimental design or make mental note of the precautions to take.
Pupils make connections between the data obtained with other information sources and evaluate on the usefulness of the data to address the questions posed. It is in this phase that pupils extrapolate and predict further outcomes that could arise from the results obtained.

Depending on the readiness of the pupil and teacher as well as the intended learning goals, an inquiry-based learning framework can be delivered within a continuum where strategies can be chosen to suit the learning conditions (Colburn, 2004). At one end of the continuum is structured inquiry where pupils focus on one aspect of inquiry, namely, collecting data and deriving conclusions while following detailed instructions from the teacher to carry out the experiment. The purpose of structured inquiry is to instil scientific thinking and initiate pupil responsibility for learning. For pupils who are ready to assume more responsibility, teachers can employ guided inquiry which is in the middle of the continuum. In this form of inquiry, pupils determine the procedure for investigation but the teacher still decides on the question to be investigated. Over at the other end of the continuum is pupil-initiated or open inquiry in which pupils generate their own questions from a topic selected by the teacher, design their own investigation and make sense of the data collected.

It is the interest of this review to examine how technology, in particular, dataloggers, could be tapped to support inquiry-based learning. Studies in UK and Australia have shown that dataloggers, when used in an inquiry context and with proper scaffolding by the teacher, can facilitate pupil’s understanding of science and acquisition of process skills such as data interpretation and analysis of graphs (Barton, 1997a; Gipps, 2002; Rogers & Wild, 1994; Rogers & Wild, 1996). At the same time, the review will also discuss the role of the teacher in facilitating such technology-supported inquiry activities as well as the challenges faced by teachers when they used dataloggers to support science learning.

The Tool – Dataloggers
Dataloggers (as shown in Figure 1) comprise sensors or probes to detect changes in variables such as temperature, pH, light, an interface to collect or store the information, a computer to display the information and a software program for further analysis of the data (Barton, 1997a).
Experiment

Probe/Sensor

Measurement of variables
e.g. pH, pressure, temperature, conductivity, light intensity

Interface/datalogger

Probes/sensors

Software for analysis of data

Figure 1. Dataloggers with supporting probes (picture taken from www.ciderhouse.com.au/education/emasure.html)

Figure 2. Schematic representation of the datalogging process
Such systems enable both instant capturing of data which can be displayed in real time in the form of tables and graphs on a computer screen and remote datalogging which extends practical activities beyond the science laboratory into the field. It allows monitoring of transient phenomena as well as longer term monitoring of variable changes over hours, days or even weeks. The more recent datalogging software supports sophisticated analysis as well as transformation of data and graphs.

Benefits of Dataloggers
The versatility of dataloggers enable them to be used in a wide range of activities to support the various areas of study (e.g. life processes, materials, physical processes) and processes of science inquiry (Osborne & Hennessy, 2003). Studies have shown that the use of dataloggers in an inquiry-based approach is an effective way to acquire science content and develop understanding of the nature of science (Gipps, 2002).

Provide real time display of data
The ability of dataloggers to display graphical representations of data in real time has a role to play in facilitating pupils’ conceptual understanding (Brasel (1987a), Nakhleh and Krajičk (1991, p19) as cited in (Lapp & Cyrus, 2000) ). The immediacy of the graph production enables pupils to draw instant links between the graph and the physical phenomenon. The instant feedback on the graphical display enables pupils to focus more on what is happening in the activity to effect any change in the graph. For example, pupils can see and experience the real time graphical representation of a bouncing ball using a motion sensor which is able to capture the rapid changes in motion. This would be very difficult to measure with normal measuring equipment.

Provide multiple graphical representations
In addition to this, multiple graphical representations of the data afforded by the software can promote pupils’ understanding of graphs (Lapp & Cyrus, 2000). For example, with software associated with the more advanced dataloggers, pupils can be shown a variety of graphs simultaneously or one at a time, which enables them to experience the different ways in which the same phenomenon can be presented, for example, creating the distance-time, velocity-time and acceleration-time graphs by simply walking back and forth once in front of the motion sensor. Such platforms when used to calculate values or compare differences at any point in time are very useful in promoting pupils’ conceptual understanding.

Facilitate data collection and analysis
Dataloggers exhibit great potential in facilitating the data gathering and analysis processes (Rogers, 1997). In conventional practical work, pupils often spend most of the lesson collecting and processing data as well as plotting the graph manually. More often than not, the graph plotting becomes an end in itself during an experiment, with many pupils missing out on the significance of the graph. The use of dataloggers frees pupils from the mundane chores of recording, tabulating and plotting, allowing pupils to concentrate on the design and evaluation of experiments (Rogers & Wild, 1994; Rogers & Wild, 1996). Dataloggers with their software offers another edge over manual methods as it enables quick and complex analysis of the data which allows pupils to focus on the analysis of trends and relationships between variables instead of focusing on
individual data points (Osborne & Hennessy, 2003).

**Promote social interaction among pupils and with teacher**
The instant display of graphs by the dataloggers generates interest and hence promotes ‘graph talk’ among pupils. Researchers also identified the importance of this social dimension in pupils’ personal response to this learning environment (Barton, 1997a, 1997b; Newton, 2000; Price, 2001; Rogers & Wild, 1994). Newton (2000) reported that the SLANT (Spoken Language and New Technology) project done in UK found primary school pupils engaging in educationally useful conversations when learning in an IT-supported environment. The effect which dataloggers has on the ways in which pupils interact with one another and with the teacher during practical work is perceived as one significant contribution to science learning (Barton, 1997a). Case studies of UK teachers who used dataloggers regularly in their lessons indicated that pupils spent much more time talking about what was happening and predicting what would happen next in their experiment (Price, 2001). Pupils were generally found to spend more time discussing their results and moved into this discussion stage faster than in conventional lessons (Rogers & Wild, 1994). This time for thinking and discussion is critical for the investigation and the meaning construction phases of inquiry when pupils can ponder over their experimental designs, make the necessary revisions, make sense of the data collected and derive their own conclusions.

**Using dataloggers for inquiry**
Datalogging methods allow pupils to assume more responsibility and control in their science practical investigations. Newton (2000) quoted findings from the TESSI (Technology-Enhanced Secondary Science Instruction) project in UK, which reported that the use of IT allowed pupils to work more independently in a science environment. The instant display of data allows pupils to set new hypotheses and change conditions to carry out further tests. The viewing of a graph soon after making a prediction greatly facilitates the pedagogical technique of ‘Predict-Observe-Explain’ (Osborne & Hennessy, 2003). Thus, pupils are provided with the opportunity to reflect on the reasons for unsuccessful predictions which could lead to more in-depth learning from the investigations. Instant logging and analysis of data are strong motivating factors for pupils to collect multiple data through repeated measurements. Thus, this combined recording and analysis process enables pupils to experience the entire inquiry process as holistic and cyclical (Rogers & Wild, 1994) which is often not possible in a conventional science practical lesson.

**Role of teacher in datalogging activities**
Barton (1997a) quoted findings from the SLANT (Spoken Language and New Technology) project which reported that the way in which teachers organise the classroom, the instructions they give, the guidance they provide and the rapport they establish with the pupils all influence the course of the datalogging activities and the quality of discussions generated. With proper guidance from the teachers, pupils can be given opportunities in datalogging activities to take on demanding tasks like discussing, analyzing and interpreting data (Barton, 1997a; Newton, 2000; Rogers, 1997; Rogers & Wild, 1994, 1996).
Designing learning tasks
Good inquiry is planned and takes place within the context of the activity (Hinrichsen & Jarrett, 1999). Teachers need to set clear learning goals and foster a learning environment in which pupils ask questions, explore ideas and take responsibility for their own work. They have to design data-logging tasks which map the learning outcomes of the tasks onto the context, pose guiding questions to facilitate the process of inquiry and engage pupils in decision making (Rogers, 1997). There is a need to focus classroom attention on activities in which pupils use software tools to make predictions and explore relationships between variables. Thus, to fully tap the potential of dataloggers, teachers need to have the vision of how the tool could be harnessed for inquiry (Rogers & Wild, 1996).

Promoting productive graph talk
Studies have shown that pupils working in an IT environment have a tendency to go off-task (Newton, 1997; Rogers, 1997; Rogers & Wild, 1996). Pupils also appear to be uncritical of the graphs generated and many of them encounter difficulties in graph interpretation and analysis (Barton, 1997a; Gregory P. Thomas, 2004; Thomas, Fong & Tsang, 2004). In order to fully capitalize on the time freed by the use of dataloggers, teacher must scaffold pupils’ learning by encouraging critical thinking and discussion about the data in connection with their prior science knowledge or theories. Teachers need to ask probing and open-ended questions to encourage pupils to craft and verbalise their responses. They could probe pupils about issues such as whether the experiment is fair, what they expect to happen next, the impact of varying experimental conditions, and what controls would be useful. However, to engage pupils in productive graph talk, teacher would have to equip pupils with the vocabulary to discuss and describe the graphs e.g. patterns and trends, slope, maximum and minimum values, how one variable is dependent on another.

Nurturing a learning mindset
At the same time, teachers need to nurture in pupils a questioning and skeptical view towards the observed data (Barton, 1997a) which could lead pupils to think critically about the data and enable them to better grasp the meaning of the graphs (Newton, 1997). Teachers would have to instil in pupils the quest for knowledge and reasons, a willingness to experiment and learn from mistakes. They must work to change pupils’ perceptions that teachers hold the answers to all questions (Gipps, 2002). Teachers will need to step down from being the ‘sage on the stage’ and be ready to put on multiple hats as they facilitate pupils’ learning in a technology supported inquiry environment as a coach, resource procurer, mentor, learner, innovator and collaborator (Crawford, 2000).

Challenges of using dataloggers for science learning
Despite the well established benefits of using datalogging systems for science learning, studies of dataloggers in UK, US as well as local schools have noted a low adoption rate among science teachers despite the ease of use of hardware and software (Bannasch & Tinker, 2002; Rogers & Wild, 1996; Tan, Hedberg, Koh, & Seah, 2005). The motivation for teachers to adopt technology is greatly influenced by physical, socio-political and educational contexts. Lack of time has been reported as the most significant constraint by 86-88% of primary and secondary science teachers in their use of IT in a survey carried out in UK in 2000 (Osborne &
Hennessy, 2003). In a recent study on the use of dataloggers in Singapore’s secondary schools and junior colleges, 84% of the 593 respondents ranked the time spent on setting up datalogging activities as the number one deterrent to the use of dataloggers (Tan et al., 2005).

Other barriers to the use of technology in UK schools include limited provision and access to the resources and equipment, unreliability of the equipment, lack of support structures like technical support, lack of funds, few training opportunities, lack of organizational and management skills in less IT savvy teachers, and the low confidence level of teachers in using these tools for science learning (Newton, 2000; Tan et al., 2005). Likewise, in Singapore, science teachers encountered difficulties like an inadequate number of notebooks or computers deployed for science learning, time taken to loan IT equipment, technical problems with the dataloggers and time constraints to complete the syllabus. Findings also showed that teachers, especially those who are not very IT savvy, feel they lack the necessary skills to use dataloggers and design appropriate lesson activities to facilitate science learning (Tan et al., 2005).

While IT-savvy teachers recognise the use of dataloggers as an opportunity to experiment with new ideas and develop new teaching strategies, many teachers face practical constraints and uncertainty about the pedagogical relevance and scope of using dataloggers (Newton, 2000; Osborne & Hennessy, 2003). Osborne & Hennessy (2003) cited the interim findings from a major British evaluation, ImpaCT2¹, which reported that relatively few teachers integrated IT into subject teaching in a way that motivated pupils and enriched learning or stimulated higher order thinking and reasoning. Similarly, in our schools, teachers who were past and non-users of dataloggers expressed that they had difficulties incorporating datalogging activities in the science curriculum and lamented the lack of exemplars of effective datalogging activities (Tan et al., 2005).

Implications
To promote the use of dataloggers for science inquiry, it is critical that teachers are aware of the benefits of the technology as well as its relevance for pedagogy and be supported and guided in their technology integration. IT-based activities with clear and concrete curriculum focus which support and enhance learning can lead to their initial adoption and integration into departmental schemes of work and teachers’ lessons (Newton, 2000). Providing time for teachers to design datalogging activities would be one significant support structure to encourage the adoption of dataloggers.

Appropriate and just-in-time training can boost teachers’ confidence level and increase their competency to integrate technology in their science classrooms. Fellow colleagues who can demonstrate and share good IT-based science pedagogical practices can influence and support the novices and early adopters (Finlayson, Wardle, & Rogers, 2002). Thus, to encourage greater use of dataloggers, it might be necessary to highlight good practices and share effective lesson resources among science teachers.

The existing assessment framework which focuses on content knowledge via written tests does not capture the educational outcomes

¹ ImpaCT2 is a DFES/Becta large-scale longitudinal study of ICT and student attainment across the curriculum:www.becta.org.uk/impact2
brought about by technology. Assessment should focus on the process of learning rather than solely on the outcome. Useful indicators could be crafted to assess pupils’ understanding, reasoning and analytical skills and also their contributions in collaborative work. The introduction of School Based Science Practical Assessment (SPA)\(^2\) which allows for greater flexibility in the design and choice of practical tasks is one platform in which the use of dataloggers could be greatly encouraged.

Dataloggers can be fully harnessed by teachers to facilitate an inquiry-based science curriculum, only with enabling support factors, sound pedagogical guidance and appropriate review of the current assessment of practical skills.

\(^2\) School-based Science Practical Assessment (SPA) is introduced as a skill-based assessment for practical science which will replace the “O” and “A” level practical examinations in the near future. For more details, please access [http://intranet.moe.gov.sg/science/SPA/spamain.htm](http://intranet.moe.gov.sg/science/SPA/spamain.htm)
Annex

List of websites on datalogging lesson ideas:

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<th>Technology Enhanced Elementary and Middle School Science (TEEMSS)</th>
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<td><a href="http://teemss1.concord.org/">http://teemss1.concord.org/</a></td>
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<td>(Check out the two instructional units)</td>
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<td>2</td>
<td>Physics lessons on motion and Induced EMF with dataloggers</td>
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<td>3</td>
<td>Story 5 in Engaging IT Website</td>
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References


