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Microclimate Studies in a STEM-Based Curriculum Using Open Source Hardware and Software

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ABSTRACT

This project presents a design for schools in developing countries such as Indonesia. It encourages a networked mesh of open source environmental sensors to help teachers surface students' evolving intuitions and conceptions about their local microclimate through a Science, Technology, Engineering, and Mathematics (STEM)-based curriculum. The objective is to afford teachers in resource-poor environments the means to design curriculum which would permit and encourage empirical investigation of environments familiar to learners, to increase task authenticity and context. Two cycles of Lesson Study were conducted, and results were analyzed in terms of teacher engagement and learner dispositions such as creativity. Teachers found the journey rewarding. The project continued through 2017 and into 2018.

Keywords: *STEM, open source, environmental science, lesson study, inquiry-based learning*

I. INTRODUCTION

In 2013, the Indonesian government introduced a new school curriculum. Named Kurikulum 2013, the new curriculum is not Science, Technology, Engineering, and Mathematics (STEM)-based, but included some aspects of STEM content. Unlike the previous curriculum, it gave little room for teachers to change content and modify lessons, because it is structured in a way that prescribed the content, the time allotment, and the teaching strategies. As a result, teachers tended to follow the curriculum to avoid problems related to the coverage of the content.

Despite a number of teacher professional development (PD) programs organized by the government, there was no improvement of teaching practice in the classroom. It seemed the PD programs conducted did not bring change to teaching practice. A survey on the impact of teacher PD programs identified a number of weaknesses in previous programs (Widodo, Riandi, Amprasto, & Wulan, 2006). First, a limited number of teachers actively participated in the programs. In many cases, the same teachers participated in different PD programs, while others rarely took part. Due to a number of reasons, teachers appointed to participate in the programs were very often teachers involved in the previous programs. As a result, although there were a number of PD programs, the participants were the same teachers. Second, many PD programs did not sufficiently address practical issues. PD programs were usually top-down in nature, with predetermined subjects, strategies, instructors, and time. Subsequently, teaching problems encountered by the teachers in their teaching practice were not sufficiently addressed. Third, subject matter and methodology were not addressed in an integrated way. Training on the subject matter usually did not involve pedagogical aspects, and vice versa. As a result, teachers might have a good understanding of the subject matter and teaching methods, but were unable to combine them to improve their practice. Fourth, PD programs were conducted in training centers, resulting in teachers having to leave their school to participate. For a school that could find other teachers to take over the class, this might not be a problem. However, many schools were not in such a position and, consequently, students were left without a teacher.

One large scale PD program funded by the government was arranged through the teachers' club. The program was considered successful in improving teacher competencies (Adey, Hewitt, Hewitt, & Landau, 2004). However, like other PD programs, sustainability was an issue. As the project ended, the PD programs were no longer run intensively. In many cases, project-based PD programs initiated by the government ended as the project finished.

In 2004, Lesson Study was introduced by the Japan International Cooperation Agency (JICA), and a pilot project was conducted at a number of schools in Bandung. Lecturers and teachers were very enthusiastic, since it offered a new approach to teacher PD. Rather than provide training for teachers on certain competencies, Lesson Study required participants to observe lessons at schools. Participation in Lesson Study provided opportunities for teachers and lecturers to share and to cooperate, something that rarely happened in the past.

II. OBJECTIVES

The objective of this research is to put context back into learning by affording empirical investigations of learners' local environments through real-time data obtained from a network of low-cost open source environmental sensors. These objectives were met. Through this network, teachers would be able to design a curriculum which would permit and encourage empirical investigations of familiar environments.

III. REVIEW OF LITERATURE

3.1 Lesson study

A pilot project between Indonesia and Japan, the preparation phase for the introduction of Lesson Study was considered successful for improving learning environments by conducting more student-oriented teaching approaches (Saito, 2004; Saito, Harun, Kuboki, & Tachibana, 2006; Widodo, Irfan, Ihsanudin, & Warianto, 2010).

Since 2005, the Faculty of Mathematics and Science Education at the Indonesia University of Education conducted Lesson Study with a number of partner schools in Bandung, West Java. From 2006 to 2009, an intensive Lesson Study program was conducted at Sumedang district in West Java. Every week, lecturers worked together with groups of teachers at schools. There were two strategies for applying Lesson Study, one school-based and the other teacher forum-based. The former involved all teachers of certain schools (multi-school subjects), while the later involved teachers of certain school subjects (Mathematics, Biology, Chemistry, or Physics).

As part of their study, pre-service teachers were required to do teaching practice at school for one semester. The teaching practice program was supervised by a lecturer and an experienced teacher. Although at each school there was more than one student, they rarely observed each other's teaching. Since 2006, the Faculty of Mathematics and Science Education introduced Lesson Study for students doing teaching practice at schools. As part of the teaching practice programs, students were required to do a Lesson Study. It meant they must plan the lesson together, observe each other's teaching, and do reflection at the end of each teaching practice. Although the application of Lesson Study in the student teaching practice did not improve student teaching competencies, the Lesson Study students compared to those not involved in the program revealed that their participation motivated them to improve their competencies, and enriched their teaching repertoire (Widodo, Sumarno, Nurjhani, & Riandi, 2007).

Stigler and Hiebert (1999) identified factors that made Lesson Study work in improving the quality of education in Japan. Lesson Study focuses on: 1) little but lasting improvement; 2) student learning rather than teacher teaching; 3) improvement that is real and contextual, therefore innovation can be applied easily in the classroom; and 4) facilitating collaborations among teachers, lecturers, and other school members. Teachers who took part in Lesson Study contributed not only to their professional development, but also to the knowledge of teaching.

Unlike the common practice of classroom observation, such as teaching supervision where teachers were treated as objects, in Lesson Study, teachers played an active role. A model teacher, the one whose teaching was observed, was actually part of a group of teachers who wanted to improve their teaching. Lesson Study was a learning community where teachers shared their ideas and experiences, observed each other, and learned from each other's teaching. Observing the teaching of others gave teachers an opportunity to reflect on their own teaching (Widodo, Riandi, & Supriatno, 2010), and therefore helped them identify their strengths and weaknesses. A teacher is unlikely to change their teaching if they do not realize a shortfall in their own teaching practice. Lesson Study enhanced teacher motivation to improve their teaching practice.

Research by Davis (2003) suggests that it is difficult for teachers to change their teaching practice. Lectures or workshops are often insufficient to change this. Teachers need a real example or a model that they can imitate. Research on the teaching of pre-service teachers (Mellado, 1998) indicates that students tend to teach as they were taught themselves, rather than by applying strategies or models taught by their lecturers. Since Lesson Study provides an opportunity for teachers to observe real teaching in real context, teachers should learn the application of strategies or methods in real teaching. Innovations that teachers observe in the classroom should be easier to apply than innovations that teachers find in journals or textbooks.

3.2 Understanding the local geographies of children

Studies have argued that children and adolescents in highly-urbanized Singapore view nature as something which is orderly and well-maintained (Kong, Yuen, Sodhi, & Briffet, 1999; Kong, 2000). Kong (1999) notes that this rather limited perception arises from the fact that nature is:

> A 'waste of time'. All the teenage members of the school group acknowledged that nature was not very much a part of their consciousness. When bored and thinking about places to visit and what things to do, the tendency was not to think of activities associated with nature. When thoughts about the natural world did surface in their minds, it was often in the context of school work - for example, their geography lessons, during which nature was more about conceptual issues and scientific processes than everyday environments of potential fun and enjoyment. (p. 3)

Kong's observations are important. It is the considered position that such "everyday environments of potential fun and enjoyment" (p. 3) constitute the substrate upon intuitions about geography, and how these intuitions about the nature of the man-land relationship are formed and developed. Such intuitions, in turn, shape geographical ways of knowing, and are thus critical in informing how novice geographers such as students in school approach and understand the world.

One of the seminal researchers on children's conceptions about weather phenomena is Henriques (2002). Her review of the literature was initiated based on relatively few studies carried out to understand what children think about topics on the earth sciences. One of her most salient findings is that while the weather is ostensibly a topic within the earth sciences, many of the misconceptions students hold regarding the weather originate from the natural sciences. Examples include properties of water, phase changes, and the water cycle. Her often-cited cautionary conclusion was that "in many cases, students' misconceptions are not addressed in the curriculum, allowing them to exist unchallenged" (p. 202).

Some of the studies which Henriques unearthed in her review were Sere's (1985), and Driver, Squires, Rushworth, and Wood-Robinson's (1994). These studies highlight particular misconceptions which students held, for example, that air has weight, which was challenging even for high-school students (Sere, 1985), and that air exerts pressure only when it is moving downward (Driver et al., 1994). Regarding humidity, Bar (1989) commented on the difficulty children have in understanding air as a permanent substance, and how this in turn led to what Russell and Watt (1990) observed was the difficulty that fifth-graders had in identifying air as the final location of evaporating water. Lee, Eichinger, Anderson, Berkheimer, and Blakeslee (1993) built on this work to suggest that such difficulties of understanding persist into students' middle-school years. Likewise, when Aron et al. (1994) conducted a study on participants ranging from pre-service teachers and students of various ages (from middle-school to college) on topics such as air pressure, humidity, and cloud composition, they concluded that across all age levels, people did not understand weather concepts.

This pattern of results arising from research into children's understanding of weather events has continued beyond Henriques's study and into the early 21st century. In their 2008 study on middle-school and college students' conceptions of extreme weather events and hazards, Polito, Tanner, and Monteverdi (2008) came to the conclusion that:

> Conceptual research in science education has advanced during the past fifty years… conceptual research in meteorology is clearly lacking… for example, there are apparently no research articles about alternative conceptions of weather in the Journal of Geoscience Education, the main publication of educational research in the geosciences. (p. 1)

Rappaport (2009) did publish in that same journal a year later a paper which is relevant to the present proposal. Echoing Henriques's original critique, he remarked that "little exists in the literature to specifically address how students understand weather, particularly at the secondary and undergraduate levels" (p. 145). He went on to say that:

> Along with formal instruction, young people possess a lifetime of observational experience with the water cycle. They have all seen kettles boiling, bathtubs steaming, and the accumulation of clouds in the sky before a rainstorm… to the instructor, this suite of common examples represents a windfall of opportunity. Any classroom with a window and a thermometer may become a laboratory for the discussion of weather. (p. 146)

Critically, Rappaport ended this promise with the lament that:

> Personal experience suggests that these connections are not being made in many classrooms. Consequently, undergraduates are unable to connect theories with actual phenomena. (p. 146)

A study by Ku, Ho, Peng, and Tsai (2012) is noteworthy in the context of the proposed research, not only because of its possible cultural affinities to local contexts (the study was conducted with third-graders in Taiwan), but also because it investigated pictorial representations of data regarding natural hazards (in the case of the Taiwanese study, not of haze, but of typhoons). The researchers concluded that when children were presented with weather data, they tended to focus more on the pictorial representation rather than the textual information. Critically, in the context of the present proposal, they also cautioned that it could not be ignored that "charts might also result in alternative conceptions and negative effects". (p. 6)
Such an approach echoes Ben-zvi-Assaraf's (2005) observations

that students in a broad, context-based unit on the water cycle showed a “distinct improvement” (p. 147) in their ability to form mental models of complex processes, and were better able to identify and anticipate relationships.

3.3 Experiential learning

An examination of the literature reveals variability in definitions of experiential learning. We begin with some general definitions in an educational context:

> (The) active participation of learners in events or activities which leads to the accumulation of knowledge or skills. (Yount, 2001, p. 276)

> The insight gained through the conscious or unconscious internalization of our own or observed experiences which build upon our past experiences or knowledge. (Beard & Wilson, 2002, p. 16)

> In its simplest form, experiential learning means learning from experience or learning by doing. (Lewis & Williams, 1994, p. 5)

> The contrast between non-experiential and experiential learning is one between more or less abstract and more or less linguistic sets of symbols that are employed in the transactions in which learning takes place. (Tumin, 1976, p. 41)

There are two general ways of looking at learning. First, there is a traditional, absorbed, and retained view, where the teacher’s role is to give information to the student. The material is absorbed by the learner, and retained in the same form it is encountered. Learning is efficient if the learner has absorbed the material and is able to represent it reasonably close to the form in which it was presented. Second, there is the constructive view, which focuses on the activities of the learner in making sense of the world or meanings in their experiences. Learning becomes the development of a vast and flexible network of ideas and feelings, with groups of more tightly associated linked ideas (Moon, 2004). Basic characteristics of constructivist learning include: 1) learners as active participants in their learning; 2) the acknowledgment of prior learning as foundational to current learning; 3) interaction with others leading to greater understanding and shared meaning of concepts; and 4) as opposed to abstract learning, a focus on real-world tasks, called “authentic activities” (Hedin, 2010).

Often described in comparison or in opposition to the traditional method, experiential learning has two distinguishing features: 1) engaging the learners directly in the phenomena related to their studies; and 2) requiring them to reflect on the experience, analyzing it, and learning from it (Hedin, 2010). Experiential education differs from other learning approaches in that it provides an intentional process of experience and reflection about the experience to develop new knowledge or skills (Lewis & Williams, 1994). Emphasis is placed on the nature of the participants’ subjective experiences and the meaning they derive from reflection in those experiences.

Methods associated with experiential education include internships, apprenticeships, work/study programs, cooperative education, laboratory studies, and field projects. In all these methods, learning is experiential in the sense described by Keeton and Tate (1978):

> The learner is directly in touch with the realities being studied. It involves a direct encounter with the phenomenon being studied rather than merely thinking about the encounter or only considering the possibility of doing something with it. (p. 2)

In 1984, Kolb published the book *Experiential learning: Experience as the source of learning and development*, which exposed the principle that a person would learn through discovery and experience. Kolb identified John Dewey, Kurt Lewin, and Jean Piaget as the “foremost intellectual ancestors of experiential learning theory” (p. 14). Kolb argued that experiential learning theory is soundly based in social psychology, philosophy, and cognitive psychology. Kolb, with Dewey, Piaget, and Lewin, believed that learning occurs in a cycle. Although differing in expressions of the learning cycle, all agreed on the two basic tenets that:

> Learning takes place as individual changes thinking based on an experience and, most importantly, by reflecting on that experience. Learners revisit that thinking again and again as they experiment in new situations, modifying their thinking through the results of new experiences. (Menaker, Coleman, Collins, & Murawski, 2006, p. 2)

Experiential learning involves steps that offer the student a hands-on, collaborative, and reflective learning experience. An example of experiential learning would be fieldwork. Ooi (2008) argued that conceptual understanding is derived most effectively by learning as directly as was practicable from interacting with local environments. In this, she was aligned with Saunders (1998), who suggested that fieldwork fulfils many of the goals that schooling is meant to address, beyond intellectual, academic, and technical achievement, such as “the development of insight and empathy; the encouragement of creativity and imagination; and critical reflection about social and personal values” (p. 2).

3.4 Scientific visualization in education

Experience-based learning can be a powerful approach to pedagogy. Central to, and compatible with, the rationale of experiential learning is the belief that the use of a concrete representation of the objects or concepts being learned leads to better outcomes. Scientific Visualization (SciV) is one such method that helps concretize the learning process. SciV refers to the creation and use of dramatic scientific images and their animation to aid in the process of scientific inquiry, and/or help make classroom learning a more authentic experience (Gordin & Pea, 1995).

By linking the abstract qualities of weather (e.g., humidity and temperature) to easily intelligible visual representation, students can analyze data in a manner consistent with the principles advocated for experiential learning. Gordin and Pea (1995) outline the ways in which scientific visualization can help science education: 1) making a scientific view of the world more accessible; 2) providing a means for authentic inquiry; 3) empowering students with tools they can use in a wide variety of fields; and 4) laying the groundwork to enable students to understand and critique scientific policy (p. 261).

Indeed, empirical studies have shown the advantages of using SciV in classroom settings. The Chemviz project (Koker & Rowe, 1993) used SciV for the teaching of atomic interactions, and found that students became more motivated and were able to increase access to difficult scientific concepts. The IPT project likewise introduced the idea of teaching science through image processing. The approach was able to encourage a teaching style of active inquiry and produced a significant increase in student motivation, especially for the underrepresented and at-risk student groups (Greenberg, 1992; Greenberg, Kolvoord, Magisos, Strom, & Croft, 1993).

3.4.1 An example of scientific visualization: Dataloggers in inquiry-based learning. Numerous studies have been carried out, in the United Kingdom and Australia for example, which show that dataloggers, when used in an inquiry context and with proper scaffolding by the teacher, can facilitate both the pupil's understanding of science and their acquisition of process skills such as data interpretation and analysis of graphs (Barton, 1997; Gipps, 2002; Rogers & Wild, 1994; Rogers & Wild, 1996).

Gipps (2002) argued:

> Scientific inquiry cannot be made independent of the context, observer or means of observation, and its successful prosecution will usually require creativity and intuition…by (actually) 'doing science', students can get some idea of the thinking and planning skills required by professional scientists. (p. 32)

He concluded that datalogging is well-suited to this style of learning. The facility to watch real-time plotting of a graph as the experiment proceeds is a particularly powerful tool for developing a picture of what is happening. Doing science in this way helps to promote an understanding of science as a way of inquiry, and not just as an accumulation of facts and theories.

Choo, Tan, Hedberg, and Seng (2005) pointed out several benefits of dataloggers, and recommend them as a good tool to acquire science content and develop an understanding of the nature of science. They noted the following benefits of dataloggers in their study:

- The ability to display graphical representations of data in real time has a role to play in facilitating conceptual understanding. The immediacy of the graph production enables pupils to draw instant links between the graph and the physical phenomenon.
- Multiple graphical representations of data can promote understanding of graphs. For example, 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.
- The use of dataloggers frees pupils from the mundane chores of recording, tabulating, and plotting, allowing them to concentrate on the design and evaluation of experiments. In conventional practical work, pupils often spend most of the lesson collecting and processing data, as well as plotting the graph manually. Often, the graph plotting becomes an end.
- The use of dataloggers also promotes social interaction among pupils and with the teacher. The instant display of graphs by the dataloggers generates interest, hence promoting graph talk among pupils. Researchers also identified the importance of this social dimension in pupils' personal response to the learning environment.

Tan, Koh, and Seah (2006) reported the findings of a nationwide survey on the use of dataloggers in secondary schools (Grade Seven to Grade 10), and junior colleges (Grades 11 to Grade 12) in Singapore. They explored the types of learning activities that teachers conduct using dataloggers, the support structures they deemed necessary, and the difficulties they faced. Of the 593 respondents, 394 (67%) had used dataloggers in the preceding two years. The main difficulties which deterred the respondents from using dataloggers included the logistics and time taken to set up datalogging equipment and activities, insufficient number of computer workstations, and the mishandling of equipment by students, leading to equipment malfunctions.

3.4.2 GIS: An extension of dataloggers. In this section, the authors reflect on Geographical Information Systems (GIS) and its impact, and imagines its place in a school curriculum. The use and capabilities of GIS are so broad that there is no clear and short definition, but a generic and general one could be:

> A geographic information system is an organized collection of computer hardware and software, people, and infrastructure that makes possible the acquisition and storage of geographic and related attribute data, for the purpose of retrieval, analysis, and display to promote understanding and assist decision making. (Kennedy, 2013, p.4)

In the past decade, weather programs, news reports, newspapers, and maps including popular applications like Google Maps have made use of streaming technologies to compile information from local areas. Educators have also recognized the promise of GIS as a technology to support learning through inquiry across various social and natural sciences (Milson & Alibrandi, 2008). However, this technology is not widely considered locally, and the percentage of teachers who have received training and then went to implement lesson plans is small. The goal of letting students use GIS to engage in something approaching authentic inquiry is rarely realized.

One reason GIS has achieved neither broad use nor the kind of use many have hoped for is that educators have access to GIS tools that were already in the commercial market. Many of these tools are developed for other uses and contexts, and require training on the part of the teachers and the students. The customization of GIS tools for educational use has been limited, first by cost, and second by vendor reluctance to produce low-cost alternatives to their software.

IV. METHODOLOGY

Implementing a STEM-based curriculum using open source hardware and software requires more than just using weather sensor equipment in the lessons. The research team identified three challenges in implementing STEM-based curriculum in the schools: modifying the curriculum, setting up the open source hardware and software to the school context, and building teacher competencies.

Since most teachers in Bandung are familiar with Lesson Study, it was decided to adopt principles and phases of Lesson Study called "Plan–Do–See." Lesson Study always starts with a planning session during which teachers together develop a lesson plan, followed by an open lesson, and finally a reflection session to see the effectiveness of the lesson.

4.1 "Plan"

These steps include the planning of a lesson by teachers. In school-based Lesson Study, this step may include teachers from different school subjects. Since there are teachers with different backgrounds, the lesson can adopt several ideas and perspectives. However, there are also difficulties for the model teacher to accommodate ideas that come out during the session. In addition, the model teacher cannot consult the content since they may be the only teacher for the subject. In teacher-forum-based Lesson Study, the session is conducted by a group of teachers from the same school subject. Since the teachers teach the same subject, they can share their experiences and discuss the concepts more accurately.

Planning a lesson means teachers design everything related to the lesson they are going to present, which may include goals, strategies, methods, experiments, equipment, and assessments. To ensure the plan works, teachers may need a session to try out the equipment, and to do a trial run. In some cases, it may take up to three planning sessions, depending on the subjects and the readiness of the teacher.

"Since most teachers in Bandung are familiar with Lesson Study, it was decided to adopt principles and phases of Lesson Study called 'Plan-Do-See'."

4.2 "Do"

Lesson Study focuses not only on teachers, but also on the school management. School principals, vice principals, and school intendants may play a limited role during the planning of the sessions, but they play an important role during the session. In school-based Lesson Study, all teachers must participate as observers, which means that classes other than the one participating in the open lesson should leave school earlier for the day. The school principal should communicate this to the parents and the education authority. The situation is less complicated in subject-based Lesson Study, where only teachers of particular subjects leave the school. In Indonesia, there is a teacher forum day once a week, during which teachers of the same subject do not have to teach, but are required to attend the forum. Subject-based Lesson Study is therefore conducted on teacher forum day.

Prior to the open lesson, the school principal chairs a briefing session for all observers. In this session, the model teacher explains the topic of the lesson, the activities students will do, the sequence of the lessons, and the grouping of the students. Such information is important for observers so they can do the observation more efficiently without disturbing the lesson. During this briefing, the school principal will remind the observers of what they may or may not do.

Guidelines for the observers

Observers are not allowed to intervene in the lessons. They may be involved in the planning of the lessons, but are not allowed to help the students or interrupt the teacher. If approached by students, observers may not respond to queries.

They are not allowed to do things that may disturb the lesson, such as talking to other observers or to the students. They should take note of incidents or other points for discussion during the reflection session. They should also focus on the students learning rather than the teachers teaching, since the aim of the lesson study is to improve the former. To help observers, teachers may supply them with the seating arrangement and the names of the students.

4.3 “See”

The session is chaired by the school principal. To begin, the model teacher explains the lesson they have just conducted. In this session, observers are given the opportunity to share their observations. It is important for observers not to criticize or to discourage the model teacher. The main aim of this session is for all participants to reflect on the lesson and their own lessons, and find an alternative way to improve them.

The “Plan–Do–See” cycle is a powerful strategy to encourage teachers to improve their teaching. However, there are issues that need to be carefully addressed to maintain the effectiveness of the cycle. These include the following:

- Some teachers do not sufficiently participate in planning the lesson. This is the session for teachers to share ideas and think of innovation for their teaching.
- Some think that Lesson Study is the open lesson. The open lesson is only a part of the cycle. Lesson Study has lost its meaning if participants are not involved in all steps.
- Since teachers must participate in open lessons, teachers must leave their class. In school-based Lesson Study, where all teachers in the school have to participate, many classes are sacrificed because students have to leave the school earlier.
- To be a good observer, a teacher needs to have a good understanding of the lessons. Many times, observers do not know what and how to observe. As a result, their observation is superficial and do not get into the essential part of a lesson.
- Reflection session is supposed to be a session for all to reflect on their own practice. Very often, it becomes a session either to criticize the model teacher or to show appreciation. When this happens, little is learned by the observer.

4.4 First cycle of Lesson Study

Plan 1: Workshop for introducing the sensors to the teachers

The aim of the session was not only to introduce the sensors to the teachers and how they work, but more importantly to deconstruct and reconstruct teacher perception of technology. Most teachers perceive technology as something beyond their capacities. Therefore, in this project, the research team kept on trying to present the sensor as a simple equipment. Teachers were given opportunities to explore and play with components of the sensors.

“The aim of the session was not only to introduce the sensors to the teachers and how they work, but more importantly to deconstruct and reconstruct teacher perception of technology.”

Plan 2: Workshop on how to integrate the equipment into school curriculum

Once teachers had developed an understanding of the sensors, and were confident to use them, the next workshop was conducted. As previously mentioned, the new curriculum gave little flexibility to the teachers. Therefore, introducing new ideas

“Teachers were given opportunities to explore and play with components of the sensors.”

to the school curriculum required a lot of consideration. In the workshop, the researchers helped teachers identify possibilities of integrating the sensors into topics in the curriculum. By the end of the workshop, a topic was identified to be taught by the teacher, as shown in Table 1.

Table 1: Topics identified for each teacher

No.	School	Topic	Approximate time to teach
1	Lab School	Adaptation	Starting in September 2016
2	SMP 12	Characteristics of living things	Starting in September 2016
3	SMP 1 Lembang	Scientific objects and observation	Starting in September 2016
4	SMP 2 Lembang	Changes of matter	Starting in October 2016
5	SMP 3 Lembang	Photosynthesis	Starting in October 2016

Plan 3: Workshop on developing lesson plans

This session was mainly aimed at helping teachers develop lesson plans. The research team supported them in developing lesson plans by suggesting teaching methods, and giving advice on the arrangement of the sensors, the time allotment, and the assessment procedure. At the end of the third workshop, it was agreed that three schools (SMP Lab School, SMP 1, and SMP 3) would implement the lessons.

4.5 Second cycle of Lesson Study

Plan: Workshop on developing lesson plan

To promote students’ STEM competencies, the teacher deliberately designed the lesson to adopt STEM teaching strategy. Prior to the lesson, the teacher planned a challenge for the students. They had to find a way to make crickets sing during the day. The teacher’s plan included the following steps:
Step 1: Think. Students were facilitated to work in groups to think about the solution to the challenge. They were free to decide how to use the sensors.

Step 2: Design. Students worked in their groups to design the cages. The teacher encouraged them to use accessible daily life materials.

“The research team supported them in developing lesson plans by suggesting teaching methods, and giving advice on the arrangement of the sensors, the time allotment, and the assessment procedure.”

Step 3: Make. Based on their design, each group made their cage.

Step 4: Test. The groups then tested their cages.

The teacher expected that through this STEM-based teaching strategy, student competencies in Science, Technology, Engineering, and Mathematics would improve.

STEM-based teaching is a strategy believed to be capable of building a creative learning environment, giving the students opportunities to think of a solution for a problem in hand. Designing, making, and testing products can foster students into becoming creative persons. The lesson was analyzed using the creative disposition framework (Lucas, Claxton, & Spencer, 2013).

- Inquisitive: Includes wondering and questioning, exploring and investigating, and challenging assumptions.
- Persistent: Includes sticking with difficulty, daring to be different, and tolerating uncertainty.
- Imaginative: Includes playing with possibilities, making connections, and using intuition.
- Collaborative: Includes sharing the product, giving and receiving feedback, and cooperating appropriately.
- Disciplined: Includes developing techniques, reflecting critically, and crafting and improving.

V. KEY RESEARCH RESULTS AND FINDINGS

Analysis of the lesson plans shows significant variations among the teachers, as shown in Table 2. Initially, only the SMP 3 teacher had a clear idea on how to integrate the sensors into the curriculum. Although the researchers did not specifically discuss STEM, the teacher designed and based their lesson around a STEM-based teaching strategy.

Table 2: Analysis of lesson plans

No.	Aspect of lesson plan	SMP Lab school	SMP 12	SMP 1	SMP 2	SMP 3
1	Integration to the curriculum	–	–	√	–	–
2	Clarity of the learning goals	–	–	√	–	–
3	Inclusion of STEM	–	–	√	–	–
4	Appropriateness of the usage of the weather sensor	√	√	√	–	√
5	Appropriateness of the teaching stratgy	√	√	√	–	√
6	Step by step teaching sequence	√	√	√	√	√

5.1 First cycle: “Do”

Analysis of the video of the lessons shows some variations, as seen in Table 3. While teachers at SMP Lab School and SMP 3 used the sensors just as an attached tool, the SMP 1 teacher integrated the sensor into the lessons.

Reflection

A reflection session after the lessons identified areas for improvement. First, the internet connection at the schools did not work as expected, and online access to the data could not be done properly. During the research team’s discussion, it was decided to modify the equipment, so that the internet was no longer needed. Consequently, they were unable to generate real time data. Second, teachers had issues related to management of students and time. Students worked in different areas of the school. In addition, lessons also lasted longer than expected.

Third, teachers intended to use a STEM-based teaching strategy, but needed support on how to run such lessons. At the end of the reflection session, it was decided that the next lessons would be specifically designed to follow a STEM-based teaching sequence.

Inspired by the SMP 1 teacher, the SMP Lab School teacher wanted to run a similar lesson at their school. In the subsequent workshop, they asked for a suggestion from the researcher team on the strategy to implement the STEM-based lesson.

“Inspired by the SMP 1 teacher, the SMP Lab School teacher wanted to run a similar lesson at their school.”

Table 3: Differences between lessons at SMP Lab School, SMP 1, and SMP 3

No.	Aspect of lesson plan	SMP Lab school	SMP 1	SMP 3
1	Focus of the lesson	Using the weather sensor to identify the relationship between climatic factors and the condition of living things	Using the weather sensor to test student ideas about the suitable cages for crickets	Using the weather sensor to identify the relationship between climatic factors and the photosynthesis rate
2	Teaching model	Prescriptive inquiry activity	STEM-based teaching (Think – Design – Make – Test)	Prescriptive laboratory activity to prove that climatic factors influence photosynthesis rate
3	The roles of the sensors	Attached to the lesson as additional tools	Integrated into the lesson as an essential tool for the laboratory works	Attached to the lesson as additional tools
4	The roles of data collected using the weather sensor	As information to interpret natural phenomena (adaptation)	As information to see the condition of the cage	As information to prove the knowledge presented in the books

5.2 Second cycle: "Do"

As the teacher from the SMP Lab School conducted the lesson, the lesson was video-recorded and analyzed, to see to what extent the lessons followed the STEM teaching sequence. The profile of the lesson is presented in Table 4.

As presented in Table 4, time was spent on presenting the problem to the students to test the cages. Students were not used to the inquiry type of laboratory activities, therefore, presenting a problem and formulating observable questions were demanding tasks for them. The step of testing the cages was one of the most exciting parts for them, since they were able to see the effectiveness of their designs. The research team observed that students were very creative when they realized that their designs did not work. They made extra treatment using their mobile phones to play and record the sound made by crickets.

Analysis shows that STEM-based lessons can create a learning environment that facilitates the development of students' creative disposition. In this lesson, two criteria of creative dispositions were developed: inquisitiveness and collaboration skills. This is shown in Figure 1.

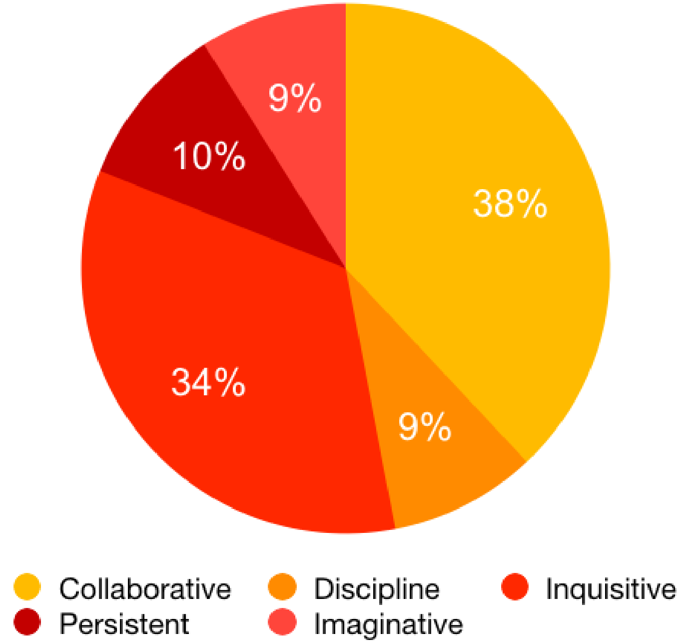

Figure 1. How lessons develop creative disposition

Table 4: Profile of the lesson based on STEM teaching sequence

STEM teaching sequence	Activity	Duration
Presenting the problem	The teacher presented facts about crickets that sing at night, and that farmers use crickets to deter mice from feeding crops. The teacher then raised a challenge on how to make crickets sing during the day.	30 minutes
Think	The students proposed several ideas, but at the end came up with two: 1) Making the cage dark by using black cardboard; and 2) Cooling down the cage using ice cubes.	5 minutes
Design	The students worked in groups, and each group drew a design for their cage.	8 minutes
Make	The students worked in groups, and each group drew a design for their cage.	10 minutes
Test	The students tested their designs. They observed that none of their crickets were singing. Some groups modified their experiment. One group made a flashlight using their mobile phone camera to imitate the dark night with flashes of light. Another group used their mobile phone to play a recorded sound of a cricket. The group was very excited when their cricket responded to the recording and started singing.	37 minutes

At the end of the lesson, students were given a questionnaire to measure their perception of their creativity. As presented in Figure 2, students of IXC who were taught using STEM-based teaching had the highest scores compared to the other classes. This suggests that the use of the sensors in STEM-based teaching had had a positive impact on students' creativity.

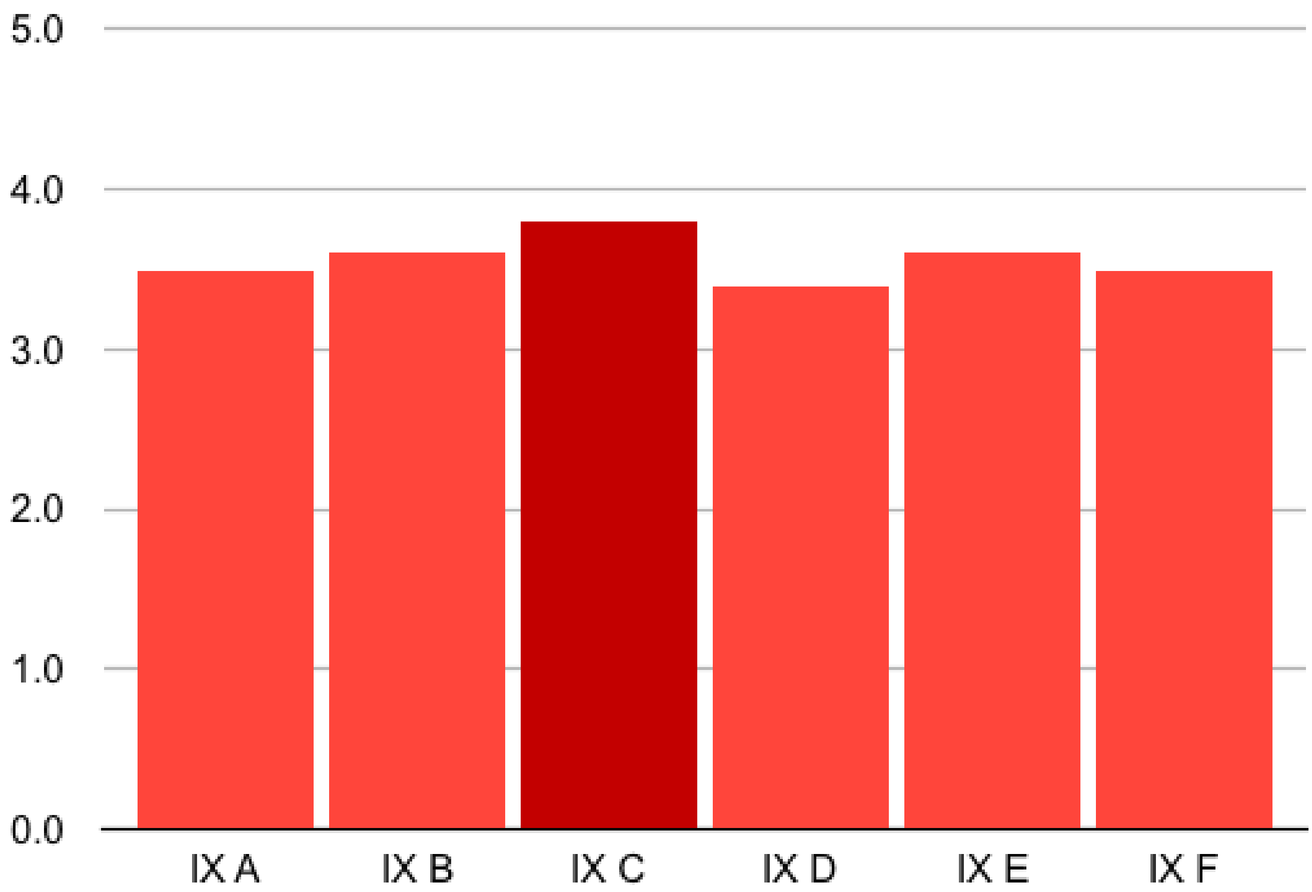

Figure 2. Students who received STEM-based teaching scored the highest

VI. IMPLICATIONS AND RECOMMENDATIONS

The study has shown the viability of using low-cost self-sufficient open source environmental sensors as an enabling infrastructure for learning in environments which do not have ready access to reliable networks of connectivity. Teachers were still able to design learning activities which made use of local contexts to make learning more authentic for their students. This study has secured the second tranche of funding through 2017 and into 2018.

VII. CONCLUSION

The cyclical approach to Lesson Study helped teachers realize that lessons sometimes do not run as smoothly as expected. For example, the testing phase lasted longer because none of the crickets sang. However, the teacher was surprised with the students' creativity to use their mobile phone to create a flashlight and to play a recording of a singing cricket. Time-permitting, the students would have appreciated the opportunity to further refine their hypothesis-testing.

After hearing the experience of STEM-based teaching, the SMP 12 teacher also wanted to try it. For SMP 12, the topic chosen was how to grow tempe (fermented soy) and oncom (fermented peanut), two traditional foods common in West Java. The teacher challenged the students to use the sensors to find the best condition for the growth of tempe and oncom. Unfortunately, the research team cannot include this in the report, since it is still in process.

Integrating the sensors into STEM-based lessons was a long process. At first, the teachers used them as additional activities to their lesson. As they gained more experience and learned from other teachers, they began integrating them into a STEM-based teaching strategy. The adoption of the Lesson Study approach was helpful, since it created an informal yet fruitful environment for the teachers to share and learn from each other in a small learning community.

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