Developing an Interdisciplinary Bio-Sensor STEM Module for Secondary School Teachers:
An Exploratory Study

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Abstract. Educators have suggested that citizens need the ability to engage in self-directed inquiry and problem solving. In line with the trend, current reforms in Taiwanese schools advocate the development of these core competencies. One way to achieve this goal is through STEM education. STEM modules which integrate science, math, technology, and engineering have become a prime catalyst for inquiry-based multidisciplinary teaching and learning. Although the demands and the benefits of STEM modules are often highlighted, the challenges of the development and implementation of such an interdisciplinary module are less discussed. This paper describes the process of the development of a bio-sensor module that uses Arduino to analyze glucose level of concentration. This multidisciplinary module integrates physics, chemistry, biology, mathematics, electronics, and programming. The goal of the program is for students to construct a device that imitates a commercial glucose meter. Teacher workshops were conducted for educators to learn the concepts and the procedures. A set of questionnaires collected from 21 workshop participants revealed that teachers face various challenges in the process of understanding and modifying the STEM module, as well as preparing students so they are ready to learn with the module. A group interview after the workshop revealed the teachers' difficulties in implementing a module that requires advanced technical skills and materials. The potential usefulness for the students, and the emergence of a different goal than the original plan, provide challenging and enlightening lessons. Rather than an engineering-centered model, this study proposes an alternative science-centered model for STEM material development.

Keywords: Models of STEM material development, secondary school, glucose bio-sensor SEM module, teaching science and engineering.

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1. Introduction
1.1. The STEM education quest

Hands-on activities have been advocated as an important means to helping students learn science [Holstermann, Grube, Bögeholz 2010].

Guiding students through hands-on activities not only facilitates their understanding of the science concepts but also increases their interests in learning science. The integration of the technology component, as exemplified in the models integrating science, technology, engineering, and mathematics (STEM), has provided an addition to single-disciplinary model of hands-on science [English 2016]. The characteristics of STEM education emphasized not only the interdisciplinary content areas, but also the methods of inquiry as an instructional approach, as well as the goal of problem-solving [Holmlund, Lesseig, Slavit 2018]. Such engagement of students in authentic problem-solving experiences were thought to promote students' talents and interests in the STEM area including engineering [Moore, Smith 2014].

In Taiwan, the recently reformed curriculum has called for inquiry and hands-on design to be integrated in subject-teaching [Ministry of Education 2014]. In an effort to promote the development of core competencies in students that encompass disciplinary learning, schools are encouraged to develop more interdisciplinary programs as required courses or electives for the new curriculum. Combined with the new field of technology that includes living technology and information science, STEM lessons serve as a vehicle for interdisciplinary course design. However, there are problems in the design and development of STEM lessons. One of the problems is the source of the STEM material, or how the STEM material or modules are developed. Because of its interdisciplinary nature, the STEM material could be developed by different agents, such as teachers, university professors, or companies. Several models are listed below, and a case of STEM material development is presented for discussion.

1.2. Current models of STEM material development

The development of teaching materials is essential for building viable STEM lessons, but it also presents major challenges. STEM materials are typically interdisciplinary in nature, but the development of STEM materials often requires cooperation of several agents, such as university or training agency representatives [Pinnell et al. 2013]. In addition, companies which have product lines that require R & D participate and help to develop STEM material [Crowley 2017]. At least three types of collaboration are commonly found (see Table 1).

The first model (Model I) is that teachers use existing materials or tool kits, such as Lego and robotics, from science product companies [Afari, Khine 2017; Leonard et al. 2016]. Commercial tool kits are common in STEM education because good materials are difficult to develop. Commercial kits have many advantages, such as being sturdy and attractive, accommodating different levels of proficiency, and incorporating other skills such as programming. Most of all, it is relatively easy for teachers to design and build lessons around them [Kim et al. 2019]. The major problems include the platform, environment,

Table 1. **Models commonly found for STEM material and lesson development**

Models	I	II	III
Main mediators	C	U	T
Science and technology knowledge provision	CU	U	UT
Integration framework or pedagogical methods	CT	U	T
STEM material development	C	CUT	UT
Teacher professional development	CT	CUT	UT
STEM lesson implementation	T	T	T

Note: C = company; U = University/Agency; T = Teacher

and cost [Karim, Lemaignan, Mondada 2015]. Most of the materials are too expensive for teachers to offer to all the students in the class.

The second model (Model II), probably the most common one, is derived from the engineering technology studied in higher education, and focuses on some particular science or engineering areas [Ernst, Busby 2009; Stohlmann, Moore, Cramer 2013]. Engineering professors may work alone or with the education professors to develop the STEM material. School teachers may or may not be involved at the material development stage. The content and methods are often developed and delivered by the university professors, government training agents, and occasionally by business or enterprise employees. In this case, teachers are expected to receive training via workshops and to develop the ability to "change" and adapt the new pedagogical ideas as presented by the agents.

The third model (Model III) is the development of material and lessons mainly by teachers. This could be regarded as the key purpose of STEM education because the inquiry and problem-solving pedagogy is embraced by teachers who are capable of developing and implementing the STEM lessons. In this model, teachers will take an active role in developing STEM material and lessons on their own [O'Neill et al. 2012]. They are able to seek help from various sources and achieve their pedagogical goals, which may be in line with, but not necessarily match perfectly, the reform goals of the government. Teachers may attend a workshop from the university or government agency, but they can adapt the material, pedagogical approach, or the lessons from the work to their teaching circumstances.

In sum, all the above models have benefits and limitations. To implement a ready-made STEM module, Model I offers the best material sets and convenient instructional steps, but it has the most restricted use in terms of curriculum and pedagogy, not alone the requirement of healthy budget. Model III has the best customization of the modules to the subjects, curriculum, and pedagogical preferences of the teachers, but it requires teachers with expertise in multiple disciplines as well as an interest in developing hands-on learning material. With limited financial support and resources, moreover, it could be difficult for teachers alone to develop integrated STEM material. Model II which is built on collaboration between the university and the teacher, may provide the support and flexibility needed in STEM material development. Therefore, it deserves further examination.

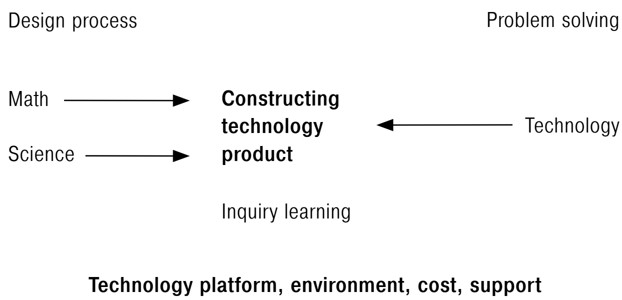
1.3. Support and constraints in collaborative STEM material development

In Model II, during the collaboration between the university and the teacher, a university faculty member who has the knowledge and resources regarding engineering and education often serves as an initiator or a principle investigator of a collaborative STEM program. The support provided by the university prior to the development of the STEM module often includes the integration framework, the pedagogical orientation, and the procedure for the design and development of the material.

Regarding the integration framework and the pedagogical orientation, many STEM lessons were built with an eye on enhancing students' inquiry and problem-solving ability. Thibaut, Knipprath, Dehaene & Depaepe [2018] analyzed nine STEM education papers, and found five common elements as integration of STEM content, problem-centered learning, inquiry-based learning, design-based learning, and cooperative learning. One of the common strategies of integration was to use an existing technology as a catalyst, and build the engineering concepts and strategy in the process in inquiry learning and problem-solving. The end result of the STEM lesson would involve the construction of a miniature or a simulated version of a technology product (see Figure 1). This type of integration is beneficial because it connects the learning of STEM lessons to a real-world problem and surrounding engineering products. Whether it is teaching the students about the iteration of considerations of building an earthquake-sustainable building [English, King, Smeed 2017], or asking the students to work in group to consider the plant abiotic factors and material needed to construct a green-house prototype [Moore, Guzey, Brown 2014], the projects embedded interdisciplinary STEM knowledge and pedagogical strategies in one complete lesson. This type of lesson, however, usually requires extensive class time to implement, and in-depth knowledge on the part of teachers. The lack of knowledge of teachers and the rigidity of the curriculum are often considered constraints to such projects [Moore, Smith 2014].

To overcome the problems in STEM lesson implementation, one of the methods is to increase the participation of the teachers in the design of STEM lessons. Some researchers proposed that the university professors can provide the engineering framework and the teachers develops the lessons and material. For example, Billiar, Hubelbank, Oliva, and Camesano [2014] proposed an eight-step procedure to

Figure 1: **STEM lesson development with technology product construction as end product**



create STEM lessons using the Engineering Design Process (EDP), including identifying the problem, researching and ranking objectives and constraints, developing possible solutions, selecting best solutions with constraints, constructing a prototype/model solution, testing/evaluating the solution, communicating the results, and finally reassessing and revising. The framework was helpful and many teachers who attended the workshops were able to develop STEM lessons using existing material. In a case, a technology teacher guided his students in teams to think of the problem of designing an ACL substitute to replace a torn ligament. The students worked collaboratively to refine the problem using paper and string, chose the best design, developed a physical prototype with low-cost custom-made mechanical device, and evaluated the solutions. In this case, the integration framework and pedagogical orientations provided the teacher guidance in lesson design and flexibility in lesson implementation, but not material construction.

The collaboration of the university and the teacher in creating integrated STEM lessons has the potential to create rich STEM lessons. However, teachers who are the implementors of the STEM lessons are not always the ones who design or create the module and material. Therefore, there could be a discrepancy between design and implementation. Several issues, such as subject inclusion, curriculum flexibility, pedagogical matching, and material adaptations, are often encountered in the process of design and development of STEM lessons. How to find the area of support of the university and yet provide flexibility for teachers continues to be an issue.

1.4. The research project of bio-sensor construction

The recent curriculum reform in Taiwan calls for the development of students' competence in inquiry-based learning and problem solving in the area of science and technology. Integrated STEM lessons which echo the goals of the curriculum reform serves as a model for lesson development. Surveying the choices for STEM module and material, the three models listed in Table 1 were found. The STEM material available in Model I, such as robotics, was readily available, but it mainly offered technology curriculum, such as programming, and relatively few science components were involved. Developing lessons in Model III, on the other hand, required someone with a strong background and expertise in multiple disciplines, which was still rare among the teachers. Therefore, Model II was chosen to be the method of development.

To search for the area of STEM material development, special attention was given to the science teachers. Because science is a long-standing academic field in Taiwanese junior high and high schools, which is also an important subject of high-stake test. The traditional focus of knowledge learning and the test-taking practices has made its curriculum at the center of reform. Moreover, within the four subjects of STEM, physics and math are relatively easier found in STEM projects, chemistry and biology were less available. As a result, bio-sensing with biology and chemistry content was chosen as a focus for STEM material and module development in a project supported by the Ministry of Science and Technology in Taiwan.

Following the STEM development model of Model II described above in Table 1 as well as that presented in Figure 1, the theory of bio-sensing was extracted, a protocol of bio-sensor was built. With the suggestion of collaborative science teachers, glucose bio-sensor was developed because glucose was widely available in school science labs. To facilitate the development of an affordable STEM material and module for school teachers, open-source of Arduino was selected. Finally, teacher workshops were held and the possibility of integrating it with the science curriculum was explored.

1.5. The research purposes

A module of glucose bio-sensor was built to help teachers develop STEM material. The module integrated science, math, biology, physics, electronics, and programming to construct a sensor that can capture the hard-to-detect current produced by the glucose oxidation. A case study was conducted to investigate the usefulness and problems perceived by teachers after professional development workshops on the sensor.

2. The research method

2.1. Method and data

The case study method is used when a closer examination of a situation is warranted. Whether analytically or holistically, or using mix-methods, evidence can be collected from either qualitative or quantitative sources (Stake, 2005). The central question is what can be learned about a single case.

The glucose biosensor represents a case of an integrated STEM module development, following the structure depicted in Model II and Figure 1. The first stage was the creation of a sensor protocol at the

Table 2: **Content areas associated with the Arduino glucose sensing module**

Subject matter	Content	Curriculum level
Biology	Glucose and diabetics	10th grade
Chemistry	Sugar-level testing	8th grade
Physics	Current, voltage, and resisters	9th grade
Electronics	Wiring, amplifying, and optimizing	10th grade at vocational high school
Programming	Logic and calculation	10th grade
Other	Glucose oxidation and its curves	College

university level, and then the potential for instructional usage was explored with the teachers attending a professional workshop.

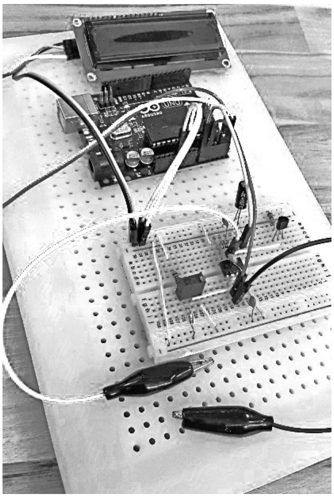
Several data sources were used, such as workshop questionnaires and group interviews, to explore teacher's background knowledge, the learning of the module during the workshop, the perceptions of the potential use for classroom teaching, and problems they may encounter if they were to use the module in their classes.

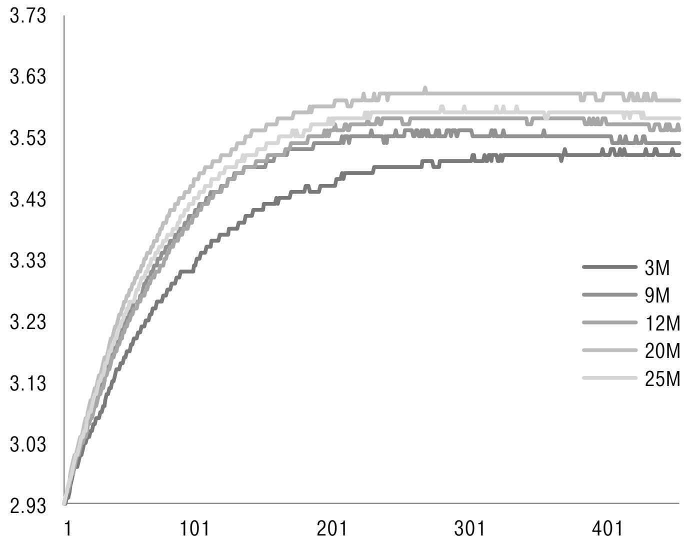
2.2. The STEM material

The Arduino glucose meter module used in this study was created by a team of university professors from engineering and education. A bio-sensing framework was used to develop a glucose sensor. The bio-sensing concepts can be observed in various technology such as enzyme detector or wearable devices with life-signal detection. The sensor module integrates many concepts from biology, chemistry, and physics, including glucose detection, oxidation reaction, electric current and resistance (see Table 2). These concepts are associated with the curriculum in junior and senior high school level science and technology subjects. This glucose biosensor can be constructed from scratch with generic electronics parts, and can serve as the end-product of a STEM module, as depicted by Figure 1.

Several challenges lie in the process of building this STEM protocol, which in turn suggest the potential to develop hands-on inquiry or problem-solving activities around these problems. First, the electrical current produced by glucose oxidation during the room temperature is extremely small, only around 10^{-6} ampere. In order to capture such small current, amplification is needed in the circuit design. Second, the small current, even with the appropriate level of amplification, is extremely dedicate. The electronics parts, such as the filter and resisters, have to be calibrated to minimize the influence of noise and other types of interference. Third, the glucose oxidation happens in a fraction of a second. It takes a very fine sampling rate with associated programming language and countless repeats of experiments to find

Figure 2: **the Arduino glucose sensor and the curve of glucose solution with different concentrations produced by the data generated by the module**





the timing for the occurrence. Thus, the points of regression needed to predict the level of glucose of a solution with an unknown concentration is hard to capture. Fourth, to sense the glucose concentration, an object of specificity to glucose such as enzyme was needed. This glucose-sensor uses commercially available testing strips as the carrier of the enzyme to detect glucose. After the module was constructed, various level of glucose concentration can be detected by the module and the data can be recorded automatically by the Arduino program (see Figure 2).

2.3. The teacher training workshop and follow-up group interview

After the glucose sensor protocol and module was developed at a university, two professional development workshops for teachers were held. During the three-hour workshops, teachers were presented with the knowledge of glucose and blood glucose, as well as the current technology of glucose measurement. The range of blood glucose levels as indicators of diabetes was specifically addressed. Following the glucose section, the electronics parts and a circuit design for assembling the components needed to amplify the small current produced by glucose oxidation were explained. Finally, teachers were given hands-on lessons on the procedures for assembling the Arduino glucose module from scratch. After the glucose sensor was constructed, it was used to test glucose solutions of various concentrations. At the end of the workshop, teachers were encouraged to take a glucose module for use in their classes.

During the professional development workshops, two questionnaires were distributed to the teachers. The pre-workshop questionnaire asked about teachers' background in terms of science and technology teaching experience and instructional methods. The post-workshop questionnaire asked the teachers about the difficulties assembling and using the glucose module and the potential uses for the classroom implementation.

About one semester after the workshop, a follow-up group interview was conducted. Teachers were recruited to share their school experience with the Arduino glucose meter. The five teachers who took the module back to their schools after the workshop participated in the meeting. Every teacher wrote reflection notes as a starting point of discussion. During the meeting, questions were asked regarding the teachers' reasons for their use or nonuse of the Arduino glucose meter.

2.4. Participants

A total of 28 teachers attended the two teacher professional development workshops, but only 21 completed the questionnaires during the workshops. Among the 21 teachers, 13 were senior high school teachers, six were junior high school teachers, and two were vocational high school teachers (see Table 3). Most of the participants were science teachers, mainly in biology, but some were in physics, chemistry, or general science. Although glucose is a biology-related content area, two vocational high school teachers came from computer and electronic engineering departments.

Regarding the five teachers who attended to the follow-up meeting and participated in the group interview, there were three senior high school science teachers, one junior high school science teacher, and one electrical engineering teacher in vocational high school. They were two female and three male teachers. The teaching experience of the five attendees ranged from 4 to 24 years.

3. Results

3.1. Understanding STEM knowledge during the workshop

The majority of the participants were secondary school science teachers. Although most of the teachers had a moderate amount of experience with hands-on science activities, and some knowledge about current and voltage, they had limited experience with bio-sensing concepts, electronics parts, Arduino boards, and programming languages (see Table 3).

The three-hour workshop did not offer extensive training on handling of electronics parts and techniques for programming. Although teachers found the explanation about the importance of glucose interesting, and the measurement of it crucial to detect diabetics, many of them had difficulty assembling and operating the glucose module.

In the post-workshop questionnaire, a majority of the teachers (14/21, 67%) indicated that they were overwhelmed by the complexity of the circuitry, which involved a reference electrode, a working electrode, and an operational amplifier. The concept of the circuit design

Table 3: **Teachers' previous teaching experience**

Activity	Mean1	SD
Using hands-on activities	2.81	1.12
Teaching science inquiry	2.67	1.11
Using hands-on technology activities	2.24	1.26
Explaining current and voltage	2.57	1.33
Explaining bio-sensing concept	1.95	0.97
Connecting electronic components to breadboards	1.95	1.26
Using Arduino	1.81	1.12
Teaching programming	1.86	1.06

Note 1: Ranking of previous use of specified activities in teaching, 1–5. 1 = never, 2 = seldom, 3 = sometimes, 4 = quite often, 5 = proficient and can be a lecturer on the topic.

was extremely hard for the science teachers to comprehend, and the electronics parts were too many in quantity and too complicated in functionality to handle correctly. Several teachers reported that the programming language was also too difficult to understand, and they suggested that the procedure of the oxidation data processing should be simplified. One teacher noted that glucose solution should be handled with more precision by using pipette instead of a dropper.

3.2. Anticipated challenges for implementation

After the workshop, teachers were asked about the difficulties they anticipated or assistance they needed for classroom implementation. When envisioning activities including the module, teachers felt they needed a lot more information to learn the concepts about electronics and a detailed description about the function of the parts (see Table 4). In addition, some teachers were concerned about the preparation of the glucose solution, which requires a high level of purity for both water and glucose quality. Due to the complexity of the module, other teachers over-generalized and stated that it is not suitable for junior high school students to engage in any bio-sensing activities. One teacher felt that on-site assistance would be needed during the lesson. The majority of the participating teachers had reservations about the utilization of the glucose module.

3.3. Potential usage of the STEM module

During the follow-up group interview, several teachers voiced their opinions about the glucose sensor module. In general, teachers liked the module as an interdisciplinary concept and material, as well as the fact that it measures the glucose level with precision and produces data for calculation.

Table 4: **Help anticipated for classroom implementation**

#	Summary	Excerpts from the questionnaire
1	Detailed guides about electronics knowledge and skills	Provide more detailed instruction on the functions of each electronics parts, and upload all the handouts on the cloud drive/ Provide detailed explanation about the design of the circuit/ Provide theory about electronics/ Provide instruction on the assembly of electronics parts and programming design.
2	Simplified glucose solution preparation	Need instruction on the preparation of the glucose solution and the interpretation of the experiment results/ Need simplified method for preparing the solution
3	Experimental procedures	Still unclear about the many factors that can influence the results/ The oxidation curve still needs to be calibrated.
4	Funding for material	Funding to buy the material/ The glucose test sheets are costly.
5	Prior knowledge for students	Too much information for junior high school students. This lesson required much more prior knowledge. / This module can be used for demo only for junior high school students.
6	Assistance during class	Need someone to provide on-site assistance

Regarding its usage in classroom activities and curriculm plans, teachers thought of several areas of application in a broader concepts, such as carbohydrate level or electron activity analyses.

> I thought about the usage of the glucose sensor... I thought it can be used in the part about hormones. For example, maybe I can use to measure students' blood glucuse level before and after meal, or it can be adopted to measure other carbohydrate level. If so, it then can be used to measure the carbohydrate level of seed germination or the change of enzyme activity. Then my students don't have to just look at the one boring chart in the textbook. (Biology teacher, 10th grade).

> I can't take students' blood... and buying the blood glucose test strip was too expensive. I thought maybe I can use the module in the chapter about photoreaction, examning the relationship between the variables and the electrons during the reduction process. Perhaps I can develop an inquiry-and-practice course to replace the existing content that can only use indicators for qualifying observation. (Biology teacher, 12th grade)

Teachers also saw the potential of the glucose sensor module in providing students with important training in measuring solutions in experiment. For example, during the preparation of the glucose solution, the concpets of weight percentage concentration was put into practice. Most of the students learned the concept in 8th grade, but many never had the opportunity to apply it.

> I was impressed about the attention to detail in this glucose module. I felt that my students can learn about carefulness during the process, such as in preparing the solution (8th grade), in handling the electronics when building the curcuit (9th grade), and in pluging in and calculating the numbers in Excel spreadsheet. Perhaps the module is a bit too difficult in the regular junior high classes, but it may work in a science club or gifted program (Science teacher, 7–9th grade).

These teachers saw the potential usage in a much different light than the original idea of the glucose sensor construction. Teachers were interested in applying the sensor in their science curriculum in a variety of ways, rather than constructing the glucose sensor as an engieering concept.

One teacher who taught electronics in vocational high school, however, actually tried to construct the sensor as suggested in the glucose sensor workshop. He was inspired by the talk about the importance of blood glucose on health, so he tried to use the module to conduct experiments with the students. Since he did not have glucose at school, he made modifications to the module to test sugar level of solutions. His adaptation of the module required development of a new lesson plan. He removed the glucose test strip, which is only available commercially, and rebuilt the circuit. With minimal cost, he was able to show the students the varying voltage with different sugar levels using the modified module. The teacher used the revised module and tested a variety of liquids, including popular drinks available from convenience stores. The students found the experiment engrossing and valuable.

4. Discussion

4.1. The construction of a STEM module for teachers

The demand of interdisciplinary STEM module was great due to quest for reform curriculum for inquiry-based and problem-solving activities [Ministry of Education 2014]. The commercially available STEM material (as presented in Model I) was convenient but costly and restricted in its connection to science and math curriculum. The teachers alone may not have the expertise and resources to develop a viable STEM module (as described in Model III). A STEM module developed at a university by a team and with the participation and feedback of the teachers seems to be a viable means (as seen in Model II). The Arduino glucose sensor module described in this study presents a case of advanced STEM material development for senior high school teachers. The module succeeded in using readily-available electronic components to build a generic module capable of capturing the weak current produced by the oxidation process of glucose interacting with glucose oxidase. Construction of this bio-sensor represents various opportunities for developing inquiry and problem-solving activities in multiple disciplines. The building of the circuit involving operational amplification requires testing and adjustment to filter out the electronic interference and stabilize the signal, which is an advanced feature even for vocational high school electronic majors. Finally, the capture of the voltage data should be done in a short window of time before the glucose oxidase was used up and the oxidation process reached balance. The Arduino glucose module can be considered a successful attempt to develop a bio-sensor that is usually not available in the market, and teachers can create one with minimal cost.

Construction of the glucose sensor module, as depicted in Figure 1, can provide the catalyst for teachers to engage the students in the authentic problem solving activities with inquiry in multiple disciplines, as advocated by researchers of STEM education [Honey, Pearson, Schweingruber 2014].

4.2. Problems perceived by the teachers about STEM module

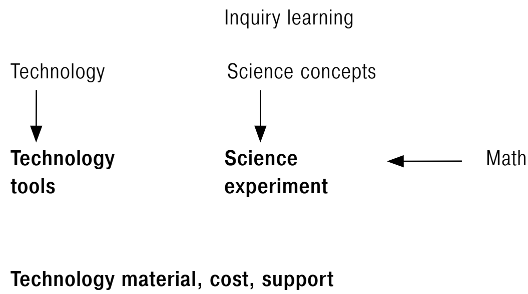
After the glucose sensor module was developed, teachers were recruited to attend workshops and providing feedback about the sensor. From the workshop questionnaires, it can be seen that teachers felt that this module is still difficult to use. Many areas of concerns were voiced by the teachers.

The first concern was the difficulty of the interdisciplinary content of the module. As shown in Table 3, most of the science teachers have relatively little experience in teaching technology-related content such as bio-sensing, connecting electronics, using Arduino or teaching programming. Although teachers know about physics such as electrical current and voltage, they did not have electronics background and experience with hands-on science activities. Although teachers understand the process of glucose oxidation, how to detect it using electronics was unfamiliar territory. To construct a module which requires operation of various electronic components, as well as to lead the students through the assembly in class, can be difficult for science teachers.

Lacking expertise in STEM disciplinary knowledge, especially in engineering area, is a common problem reported by researchers [Yaşar et al. 2006]. Teacher training workshops were usually held to supplement related knowledge and skills to teachers. In fact, in order to help teachers learn as much as possible about the framework and materials the researchers have developed, various guidelines for effective teacher training workshop have been proposed [Bautista, Ortega-Ruíz 2015]. However, the effectiveness of teacher-professor workshops in terms of supplementing teachers' knowledge in engineering area has yet to be investigated.

In this study, however, not only the teachers lacked the experience in teaching technology-related knowledge and skills, teachers were

Figure 3: **The anticipated STEM module usage by science teachers**



also concerned about the knowledge of students. They felt that the students may not have the level of STEM knowledge needed to carry out the construction of the glucose module. This area of concern was less explored and thus can be further studied.

4.3. The anticipated uses of the STEM module

Many STEM programs were set to improve the knowledge and competencies in the engineering area. Teachers' lack of engineering knowledge has often been perceived as a drawback or constraint for STEM implementations. In this study, however, the glucose sensor was only created as a protocol of STEM module, how to use it is still open.

In the results of this study, only one teacher who had an electronic background and familiar with Arduino used the glucose sensor module as part of the project-based learning. This use is similar to the original design (as seen in Figure 1). However, according to the feedback from the science teachers, their perceived potential uses of the module of glucose sensor shows a different model (see Figure 2). The process depicted in Figure 1 can be called an engineering-centered model or Model IIA, and the one below can be called a science-centered model, or Model IIB.

In this model (Model IIB), the central focus is the science experiments, and the technology was devised to help teachers conduct the experiment or hands-on science activities. Teachers in science disciplines may not have the time for nor the expertise in constructing a STEM module. Having a STEM module as a tool for a science inquiry lesson, however, may enhance the preparation of material, the process of inquiry, the result of interpretation, and even students' interest in science.

5. Conclusion

STEM education is on the rise because of a goal of educational reformers. The development of STEM material and modules aims to help teachers and students engage in hands-on and inquiry activities while learning integrated science and technology concepts. How to develop STEM materials so it offers support for teachers yet allows flexibility for teachers to adjust and adapt has been a struggle for those who wish to develop viable STEM materials.

Various means of STEM material development are available. As presented in this study, Model I uses commercial material sets and pre-set modules, offering greater support but little flexibility. Model III offers the best flexibility in matching teachers' subjects, curriculum, and pedagogy, but provides limited support for the design and development effort to produce STEM material. Model II provides the support of expertise and resources of universities and keeps the adaption open for teachers to participate seems to be a better approach to this challenging process.

From the review of the literature and the results of this study, there seems to be at least two different type of concentration in terms of the design and development of the Model II cooperative model of STEM material development. Model II A proposes a technology-centered approach to STEM material development, where the framework, design, process, and product simulates the job of an engineer. Model II B, however, revealed a science-centered design of STEM material development, where the technology plays an important role in aiding the process of science inquiry. Researchers of STEM education have also attempted similar lesson designs [Huri, Karpudewan 2019]. According the result of this study, this seems to be preferred model for STEM material development for science teachers.

This study described an effort by a of university researchers who developed a bio-sensing module for high school teachers. The multidisciplinary contents of physics, chemistry, biology, mathematics, electronics, and programming were integrated to create a glucose sensing module. After the module was successfully developed, teacher training workshops were held to test the viability of the STEM module for classroom instruction. The results of the questionnaires and small-group interviews suggested that teachers were inspired by the idea and the module, but their understanding of the module was limited and the development of subsequent instructional activities was halting. The finding revealed that the only teacher who felt comfortable about the electronics was able to modify the module to his class use. The results suggested that teachers' understanding precedes classroom application.

Two ways may be proposed to solve the problem. The first direction is to offer extensive and continuous training to teachers regarding all the necessary disciplinary knowledge and skills. The second direction is to redesign the module so it will be more accessible to teachers and students in secondary schools. As researchers in professional development have suggested, the professional development activities should be open for teacher's customization and adaption [Fishman, Krajcik 2003]. Using Model IIA, it is likely to take the first direction, and using Model IIB, there would be a lot more to be explored.

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