JTK: Jurnal Tadris Kimiya 5, 1 (Juni 2020): 91-103
Website: http://journal.uinsgd.ac.id/index.php/tadris-kimiya/index
ISSN 2527-9637 **(online) ISSN** 2527-6816 **(print)**

DEVELOPMENT OF STEM (SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATIC) INTEGRATED CHEMICAL MODULE ON VOLTAIC CELLS

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Received: 11 May 2020; Accepted: 26 June 2020; Published: 30 June 2020

ABSTRACT

21st century requires generation to have high competitiveness and competence in various aspect. Moreover, challenges in the teaching and learning process on chemical subjects, such as voltaic cells, which has abstract and contextual characteristics, as a problem to be solved. This study aimed to produce an integrated chemical module STEM Project Based Learning on the topic of valid and practical voltaic cells. The development of STEM integrated chemical module on the topic of the Voltaic cell used ADDIE model namely Analyze, Design, Development, Implementation and Evaluation. Data was collected through needs analysis, expert testing and student questionnaire responses. At the expert review stage, using 7 material experts and 7 media experts. The implementation phase was carried out in one of the high schools in Serang City. The result of the expert test stage obtained a final score of material validation of 88.25% (very feasible or very valid) and media validation of 82% (very feasible or very valid) with an average score of validity of 87% (very feasible or very valid). For the final score of feasibility obtained from 81% limited trials (very feasible). The characteristics of the developed module was STEM module which follows the Laboy-Rush PjBL-STEM syntax namely refelection, research, discovery, application, and communication. It was made by A5 paper size to make it easy to carry and prepared by various illustrations, interesting features and STEM-Project and design log to complete Voltaic cell project. Furthermore, it is hoped that this module can be used as an alternative STEM teaching material on voltaic cell topic.

Keywords: development research, chemical modules, STEM, project based learning, voltaic cells

DOI : https://doi.org/10.15575/jtk.v5i1.8127

1. INTRODUCTION

Challenges of industrial revolution 4.0 in the 21st century has encouraged various countries including Indonesia to improve the quality of science learning as it requires a generation who have high competitiveness and competence in many aspects (Sulcius, 2014). Hence, young generation must master various skills and abilities to survive. The skills are digital literacy, critical thinking, communication, collaboration and creativity in problem solving. Therefore, to prepare students to be able to have the skills, learning process must be oriented to students (student center); learners must be able to collaborate, innovate, and have a critical thought; as well as the learning material taught must be based on real life (Noeraida et al., 2018). STEM-based learning, will be able to create a generation that has the competence to compete (Juanggo, 2018).

STEM is an integration of learning between two or more of the four STEM fields of science, namely science, technology, engineering and mathematics (Ismayani, 2016). Students are expected to have the skills needed in the 21st century including critical thinking, innovative, creative, and able to communicate and collaborate through STEM learning. In addition, students can also develop their scientific and technological literacy that can be observed from the activities of reading, writing, observing, and doing science (Research, 2011). These skills were used as provisions to solve problems related to the STEM field in real life.

Chemical education faces many challenges in most countries at the secondary level. These challenges cannot be overcome only by considering chemical material. Nevertheless, it requires a comprehensive effort to assess students' conceptual knowledge of chemistry in secondary schools (Lamanauskas et al., 2007). One of the chemicals that has challenges is electrochemical materials, such as Voltaic cells. Voltaic cell material has abstract, complex, and conceptual characteristics that are considered difficult by some students, as reported by Sulcius (2014). Students have difficulties in understanding the reactions that occur at the cathode and anode, the processes that occur on Voltaic cells, it is difficult to apply the concept of redox reactions and Voltaic cells to explain chemical phenomena experienced in daily life. This problem results in a tendency towards lack of student motivation so that it impacts on low student achievement as well (Moslem et al., 2019). Therefore, it is needed to make learning innovations that can change students' thinking and understanding of science learning, especially Voltaic cells according to the demands of the 21st century.

The success of learning, not only depends on the methods and models used, but the learning tools used also have a big influence in achieving the success of learning (Tjiptiany et al., 2016). The use of appropriate learning tools can transform abstract teaching materials into concrete and realistic learning (Muzana et al., 2015). Understanding and reasoning of students will be developed well if they are given a learning device that is able to direct the mindset and foster students' independence, all of that can be realized by presenting modules (Utami & Jatmiko, 2018). The use of learning tools in the form of modules is more effective and efficient in learning because it can attract students as teaching material and use less time (Astiti, 2014).

Research on the development of STEM-based teaching materials is still being developed. Adlim et al. (2015), has developed an integrated entrepreneurial STEM module with the theme of LED strips modification with the LED Raincoat theme. The STEM module developed is proven to be able to change and improve students' science process skills. Noeraida (2018) has developed STEM-based science teaching materials according to the 2013 curriculum called STEM Learning Unit, which includes STEM Science Learning Unit, STEM Biology High School Learning Unit, STEM Physics High School Learning Unit. Utami & Jatmiko (2018) has developed a mathematics module with a STEM approach that is equipped with a mini-lab and project activities. The modules in this study have fulfilled the valid and practical criteria so that it is feasible to use.

Meanwhile, there has been no research on the development of STEM-PjBL integrated chemistry modules for high school level on the topic of Voltaic cells as an alternative solution to the source of electrical energy that is equipped with NGSS to increase the involvement of students in STEM learning. Thus, it is necessary to conduct research into the development of integrated chemistry learning modules for STEM on the Voltaic cell topic for high school. Chemistry learning experience with teaching materials in the form of integrated STEM modules, is expected to simultaneously be able to develop students' understanding of chemical content and its applications, the ability to engineer for innovation and problem solving independently.

2. RESEARCH METHOD

The research was a research development with the ADDIE model (Analyze, Design, Development, Implementation, and Evaluation). Procedures that were structured, systematic, simple and in accordance with the theoretical basis are the reasons for choosing the ADDIE model (Tegeh & Kirna, 2014). The analyze phase, which consists of analysis of literature studies (needs analysis), curriculum analysis, and material analysis. Design, which is the process of designing the initial module design through self-evaluation, so that a specific prototype is obtained. Development, the development stage that goes through an expert review process so that prototype I is obtained. Implementation is the implementation phase of a limited trial and then through the evaluation stage, which is an evaluation of the overall results and a product called prototype II. This research aimed to produce an integrated STEM chemical module on the topic of Voltaic cells.

Data collection techniques used (1) needs analysis, (2) validation sheets and (3) questionnaires to get empirical data in this study. The research instrument used a questionnaire of module validation sheet and questionnaire of student response to test the feasibility and practicality of the module. This instrument was arranged according to the modified BSNP criteria.

The STEM integrated chemical module on the topic of Voltaic cells had been validated by experts consisting of seven material experts and seven media experts. A limited trial was conducted to determine the response of 12 students of class XII Mathematics and Natural Sciences who were studying Voltaic cells. Samples were selected using a purposive sampling technique with three categories, each consisting of four students with high, medium, and low ability so that the results obtained representative of the feasibility and practicality of the modules developed.

The data analysis technique used quantitative descriptive analysis technique, which described the results of product development in the form of STEM integrated chemical module on the topic of Voltaic cells. Data were obtained through questionnaires from experts and students in the form of quantitative data was converted into qualitative data. From the results of data analysis using a Likert Scale and score interpretation, conclusions will be obtained the feasibility of the module

Validation results contained in the validation sheet and student questionnaire responses were analyzed using the following formula:

$$NP = \frac{R}{SM} \, x \, 100$$

Where NP is percent value, R is raw score obtained, SM is ideal maximum score and 100 is fixed number. The categories can be seen in Table 1.

Table 1. Eligibility Categories of STEM Integrated Chemical Modules

Score (%)	Category
76-100	Very decent
51-75	Worthy
26-50	Inadequate
0-25	Very Inadequate

(Arumsari, 2014).

3. RESULT AND DISCUSSION

This study aimed to produce a STEM integrated chemistry module on the topic of Voltaic cells as an alternative teaching material that can be used in the STEM learning process at the high school level. The development of this module was carried out through a number of stages aimed at obtaining a valid and practical STEM integrated chemistry module for high school students of class XII majoring in Mathematics and Natural Sciences. The development of this teaching material uses the ADDIE development model which consists of analysis, design, development, implementation, and evaluation (Tegeh & Kirna, 2014).

3.1 Analysis Phase

The analysis phase includes the needs analysis, curriculum analysis and material analysis activities. The needs analysis was carried out by reviewing literature studies such as research journals to identify problems and needs at the high school level and teacher interviews. The results of the needs analysis from various references found problems in education, namely (1) the challenges of 21st century education, in line with the 4.0 industrial revolution which urged the improvement of the quality of science learning, and (2) students had difficulty in Voltaic cells learning (Sulcius, 2014), so there are many different misconceptions about Voltaic cells (Lin et al., 2003). This is because the complexity of the material is quite challenging (Butts & Smith, 1987) and characteristics of abstract material concepts with concrete, contextual examples. In addition, misunderstanding occurs because of class instructions and textbooks used by students (Sulcius, 2014).

Curriculum analysis was carried out by analyzing Basic Competence (KD) and indicators of Voltaic cell material which aims to have the developed module in accordance with the revised 2013 curriculum which integrated STEM learning. Material analysis is the activity of selecting essential material from the whole subject matter of a lesson which is the minimum subject matter that must be mastered and possessed in the learning process. The chosen topic was the Voltaic cell in the electrochemical cell chapter which in addition to having several concepts, aspects of knowledge that could be developed were able to define terms, explain working principles, and analyze reaction processes and mathematical calculations. In this Voltaic cell topic, there are also four aspects of STEM which are coordinated with each other. Where the scientific aspects contained in the concepts and working principles of Voltaic cells, technological aspects which are the product of the application of Voltaic cells in life, technical aspects can be applied in the design process of Voltaic cell projects, as well as mathematics in terms of mathematical calculations for example in the calculation of potential cell values. This is what makes Voltaic cells suitable as STEM content in the modules developed.

3.2 Design Stage

After conducting the analysis phase, the module was designed by gathering various relevant references and sources such as from international and national journals and articles, books, and so on. During this stage, project determination and NGSS (Next Generation Science Standard) analysis were also carried out. NGSS is a science learning standard that has been introduced in science education that seeks to clarify the incorporation of engineering design as a new strategy for teaching scientific inquiry (Wells, 2016). The presence of NGSS serves to increase student contributions in integrated STEM education. NGSS will help students strengthen aspects of engineering and explain the relevance of science, technology, engineering, and mathematics to everyday life through the STEM project. There are three dimensions that form the NGSS framework; scientific and engineering design practices, disciplinary core ideas, and cross-cutting concepts.

3.2.1 Scientific Practices

Scientific Practices explain the behavior of scientists when they conduct investigations and create models and theories about nature while engineering practices are the tips for engineers to develop or create a model and system. NRC (National Research Council) emphasizes that the implications of scientific investigation require specific skills and knowledge for each practice (NSTA, 2014). The projects contained in this STEM module were directed so that students are able to develop models by making Voltaic cells within the boundaries of the project by using tools and materials that have been prepared with a time limit. The investigation was carried out by testing and redesigning Voltaic cells (remakes and retests) to produce a better product. The practice of analyzing and interpreting power was done using Voltaic series data to get the right electrode so that it can run the motor and fan blades. The practice of using mathematics and computational thinking was done by determining the concentration of an electrolyte solution needed for a Voltaic cell and calculating a hypothesis from a standard reduction potential value. Designing a solution was done by identifying the best Voltaic cells based on data, feasibility, cost, and security (discovery). Obtaining, evaluating, and communicating information was done by sharing (presentation) Voltaic cell design and the results of the design process with colleagues.

Table 2. Scientific and Engineering Design Practices of STEM Integrated Chemistry Modules on the Voltaic Cell Topic

No.	Scientific and Engineering Design Practices	Activity
1	Develop a model	Making Voltaic cells within project boundaries
2	Investigate	Testing and redesigning the Voltaic cell
3	Analyze and interpret data	Use data to determine the effectiveness of Voltaic cells to power a fan
4	Using mathematics and computational thinking	Determine the concentration of salt solution needed for Voltaic cells, calculation of the hypothesis Eo
5	Design a solution	Identify the best Voltaic cells based on data, eligibility, cost, and security.
6	Obtain, evaluate, and communicate information	Share Voltaic cell designs and results from the design process with colleagues.

3.2.2 DCI (Diciplinary Core Ideas)

DCI has power to focus on curriculum, teaching and assessment of science on the most important aspects of science. DCI provides an organizational scheme to interconnect knowledge from various fields of science into a coherent and scientifically based worldview (NSTA, 2014). DCI contained in the STEM module that was developed into the domain of matter and its interactions include chemical reactions; and energy including the definition of energy, energy conservation and energy transfer, as well as energy in chemical processes and daily life, which is shown in Table 3. Students were expected to answer questions about chemical reactions in this case about the redox reactions involved in Voltaic cells. Students were also expected to answer questions about the definition of energy produced by Voltaic cells, motors and fans then able to understand the transfer of energy generated from the Voltaic cell so that it can move the fan blades. Students were able to understand how the use of chemical reactions as energy sources from Voltaic cells that was designed from the idea of energy discipline in chemical processes and daily life.

Table 3. Disciplinary Core Ideas of STEM Integrated Chemistry Modules on Voltaic Cell Topics

No.	Disciplinary Core Ideas	Activity
1	Chemical reaction	Reduction-oxidation reaction in Voltaic cells
2	Definition of energy	Voltaic cells, motors, fans
3	Energy conservation and energy transfer	Voltaic cell energy transfer with fan blades
4	Energy in chemical processes and daily life	The use of chemical reactions as an energy source

3.2.3 Crosscutting Concept

Crosscutting concept is a way of connecting various domains of knowledge including patterns; cause and effect; scale, proportion and quantity; system and system model; energy and matter; structure and function; and stability and change (NSTA, 2014). Crosscutting concepts in the energy sector contained in the STEM integrated chemistry module on Voltaic cell topics included (1) scale, proportion, and quantity, (2) systems and system models, (3) energy and materials. Details of the crosscutting concept of the

STEM integrated chemistry module on Voltaic cell topics are listed in Table 4.

Proportionality and ratio can be used to understand quantity and scale, as well as the relationship between physical characteristics, in this case it includes the minimum amount of chemicals used, the scale of Voltaic cells for use in the industrial world, at least get results that have higher efficiency and effectiveness. In creating and using models, it is important to define the system described. Therefore, it is done first how students can define what needs are needed to make a model (fan of a Voltaic cell), then explain how the Voltaic cell system can work. Students can build understanding of models and systems, starting with pictures, diagrams, and plans in class.

It is known that energy and matter cannot be destroyed, it can only change shape, according to the Law of conservation of energy. Energy and matter are often recycled in a system, and various forms of matter and energy can interact. In the module that had been developed, students were expected to understand and explain the energy flow between the voltaic cell and fan, as well as the flow of electrons in the voltaic cell.

Table 4. Crosscutting Concept of STEM Integrated Chemistry Module on Voltaic Cell Topics

No.	Crosscutting Concept	Activity
1	Scale, portion, and quantity	The minimum amount of chemicals used; scale of Voltaic cells for use in industry
2	System and system models	Define what requirements are needed to make the fan blades move using Voltaic cells; explain the Voltaic cell system
3	Energy and matter; flow, cycle, and conservation	Explain the energy flow between Voltaic cells and fans; describes the flow of electrons in a Voltaic cell

Furthermore, the module was designed with material and various features that help complete this Voltaic cell project using the Xara Photo & Graphic Design and Microsoft Office 2007 applications. In this process, a self-evaluation stage and several repairs were made. Improvements were made by finding more sources of reference, finding more up to date problem cases, revising the writing that was less precise. The results of these improvements are called specific prototypes.

3.3 Development Phase

Specific prototype then was validated by a validator called the expert review stage to do media validation and material validation. The expert test results on the material expert test section obtained a value of 88% for content eligibility, 90% for presentation eligibility, 87% for language, and 88% for STEM assessments. So that if averaged for the validation of the material the value of 88% is obtained with a very high eligibility category. The results of the analysis of the media expert test data obtained a value of 82% with a very high eligibility category. Based on the results of the expert review validation it can be concluded that in terms of the material in the product being developed it is already very feasible and valid. This is supported by Lasmiyati & Harta (2014), which suggests that a good module is designed systematically to achieve learning objectives with a series of activities that are associated with specific material content, relatively brief and have a good evaluation. The validation data can be seen in Table 5.

Table 5. Expert Review Validation Results

No	Aspect	Score (%)
1	Theory	
	Content Feasibility	88
	Presentation	90
	Language	87
	STEM assessment	88
2	Media	
	Grafting	82
Average score		**87**
Criteria		**Very decent**

From the result of the expert review, there were many suggestions for the improvement of the module. Based on the results of discussions with the validators (expert review) modules must be improved or revised in several parts so that they can be tested further. In general, improvements that need to be made are in terms of material deepening, graphic, symbolic writing, image clarity, type, and font size. The design of cover module before and after revision can be seen in Figure 1. The case revision can be seen in Figure 2.

Figure 1. Cover Design Before and After Revision.

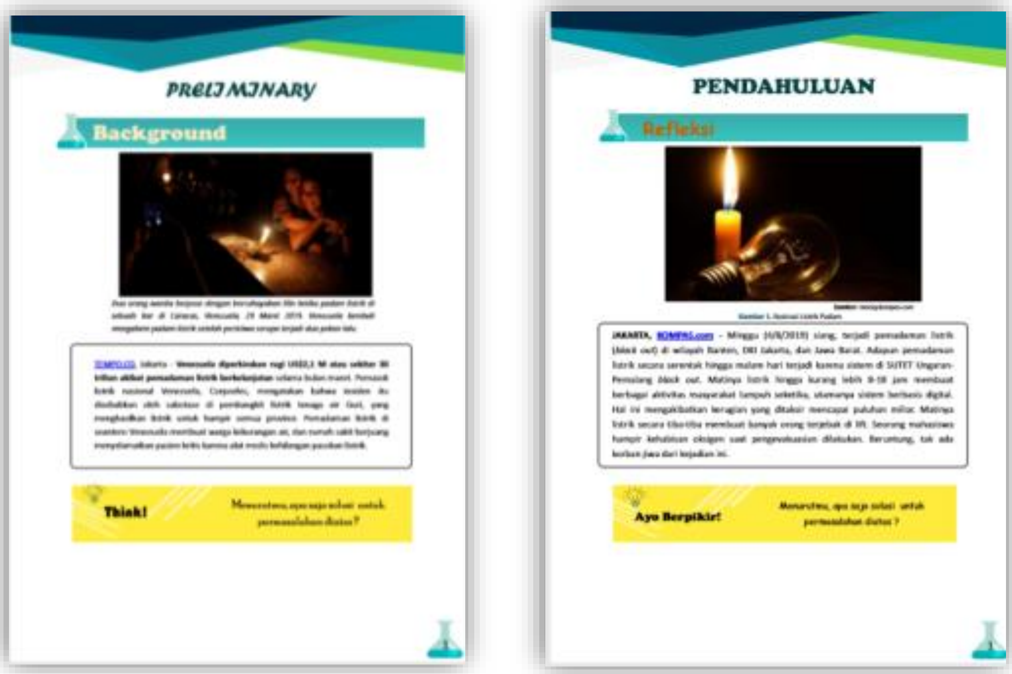


Figure 2. Title Revision from English to Indonesian and Case Revision Being More Up to Date.

3.4 Application Stage

The result from the development stage are called prototype I. During the implementation phase, a limited trial was carried out on this product. Then the prototype I product was given to students to study and fill in each practice question in the prototype I product on the first day. Then on the next day, there was a practicum to do the project in the module. The Voltaic cells can be seen in Figure 3.

After doing the project, students were given a student response questionnaire to assess the practicality and attractiveness of the module. The aspects assessed included aspects of appearance, presentation of material, and aspects of usefulness shown in Table 6.

Table 6. Result of Student Response Questionnaire

Aspect	Score (%)	Category
Display	82	Very practical
Presentation of Material	81	Very practical
The benefits	81	Very practical
Average	**81**	**Very practical**

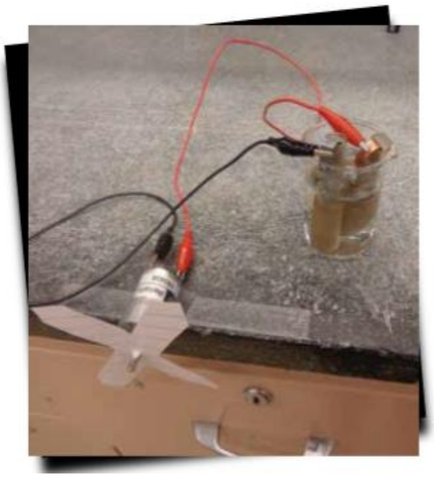
The result of the analysis of student response data, first, for display, the score obtained by 82% with a very high category. It is because the developed modules were designed with an attractive appearance (eye catching), color, and equipped with illustrations that support the material so that it can foster student motivation and make it easier to learn the material in more depth (Lasmiyati & Harta, 2014).

Second, for the material presentation aspect, it was found that the category was very high with a score of 81%. It is because the designed modules have the characteristics of user friendly and self-contained in the presentation of material. The language was used in accordance with the level of student knowledge, simple, and used general terms. So, it is easier for students to use modules in learning Voltaic cell topic. The material is designed in one whole and specific unit so that students can study the material thoroughly (Daryanto, 2014). Finally, for the aspect of benefits also obtained a score of 81%. The score was very high category provided an indicator that the use of this module can provide benefits to its users, in example, the material can be easily studied and can increase motivation in chemistry learning especially Voltaic cells by using this integrated STEM chemical module. If averaged, the score obtained from the results of student responses in the limited test phase (small group) was 81%. This percentage when converted into a conversion table has a high practicality and attractiveness category.

In the practicum process (conducting the Voltaic cell STEM project), the products from the STEM Project produced by each group are not the same, in terms of design, or the combination of electrodes and electrolyte solutions, so as to produce different potential cell values shown in Table 7. It can give students freedom to explore and plan learning activities, carry out collaborative projects, and ultimately produce a product result (Jauhariyyah et al., 2017). In addition, it can foster students to think critically, creatively, analytically, and improve higher-order thinking skills (Capraro & Scott, 2009).

Table 7. Student Project Results Data

Group	Trial	I	II	III
1	Anode	Al	Fe	Al
	Cathode	Fe	Sn	Fe
	Solution	NaCl	NaCl	3NaCl + 2 CocaCola
	Qty. Glass	5	5	5
	E (V)	**1,4**	**0.2**	**1**
2	Anode	Al	Al	Al
	Cathode	Sn	Sn	Sn
	Solution	NaCl	NaCl	NaCl + Cocacola
	Qty. Glass	4	5	5
	E (V)	**0.4**	**1,2**	**0.6**
3	Anode	Fe	Al	-
	Cathode	Sn	Fe	-
	Solution	NaCl	NaCl	-
	Qty. Glass	2	2	-
	E (V)	**0.4**	**0.6**	-
4	Anode	Al	Al	Al
	Cathode	Sn	Sn	Sn
	Solution	Cocacola	2Cocacola + 1 NaCl	3NaCl + 2Cocacola
	Qty. Glass	2	3	5
	E (V)	**0.2**	**0.4**	**1,1**



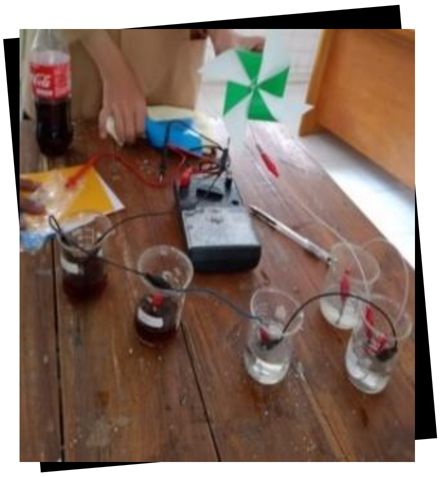


Figure 3. Voltaic Cell Products Connected by Motors and Fans

3.5 Evaluation Stage

Evaluation is the process of analyzing developed modules at the implementation stage and revising prototype I products based on evaluating the results of student responses. Based on the data, the module's eligibility and practicality was very high. The integrated chemical module STEM on the topic of developed Voltaic cells can be said good.

It was supported by suggestions and comments given by students, which almost all of them stated that this module was very good, interesting, and concise so that it is easier to understand. The product results from this evaluation stage were referred to as prototype II with results that can be declared to have high feasibility, practicality, and attractiveness.

The STEM integrated chemistry module on the topic of Voltaic cells is organized according to the STEM-PjBL step Laboy-Rush (2010) namely reflection, research, discovery, application, and communication. In this module can be seen the characteristics of STEM project-based learning where students are invited to do meaningful learning in understanding a concept. Students are invited to explore through a project activity, so students are actively involved in the process (Ismayani, 2016). This can increase students' sensitivity to real-world problems, involve students in inquiry, get students to provide various solutions, and involve students in applying design process skills. Integration between several fields of science (chemistry, physics, mathematics with technology and engineering) in STEM project-based learning helps students give the meaning that chemistry is closely related to other fields of science. This developed module can attract students to be more motivated in learning and at the same time develop the 4C skills expected in the industrial revolution 4.0 (Juanggo, 2018).

Advantages STEM integrated chemistry modules on the topic of Voltaic cells developed include: (1) as a learning resource that can build students' independence, in accordance with Anggoro (2015) which states that the module encourages students to learn independently; (2) the module is presented with STEM content, equipped with a Chemical Mini Laboratory, which can help students to find a concept on voltaic cell material and as an initial exercise before the actual STEM project, in addition there are project activities (STEM-Project) that can increase students' knowledge to implement the knowledge possessed in real life (Utami & Jatmiko, 2018), there are also chemical concept features, web links, chemical info, dialogue, and other features that can help students learn in more detail about Voltaic cells; (3) in the module is equipped with many illustrations so that it can facilitate students in understanding the material (Lasmiyati & Harta, 2014); (4) this module is designed with user friendly characteristics (Daryanto, 2014) namely the full color theme to make it more attractive and B5-sized so that it is very simple, making it easy for students to take them anywhere to learn.

As for the shortcomings in this module, the material contained in this module was still limited of topic about Voltaic cells so it needs to be developed more broadly, especially electrolysis cell material so that it can become integrated STEM integrated chemistry learning units (electrochemical cells).

4. CONCLUSION

The STEM integrated chemistry module on Voltaic cell caps that had been developed through the stages of the ADDIE development model has the characteristics of following the syntax of project based learning-STEM Laboy Rush (reflection, research, discovery, application, and communication), in the form of A5 size, simple, and easy to carry, equipped with various illustrations that support the material, interesting features to add insight, STEM-Projects and design logs to help complete the project. The STEM integrated chemistry module feasibility test on the topic of Voltaic cells was declared very valid and feasible from expert review validation of 87% and the practicality test of the integrated chemical module STEM on the topic of Voltaic cells from the results of student responses (small groups) was declared very practical with a score of 81%.

The module only presents material on the topic of voltaic cells and it is expected for further to develop STEM modules with learning models and other topics in order to obtain a complete STEM module. Then the material in the project is suggested to be in accordance with student development and it is easy to be found. Problems (challenges) and project activities in the module should always be updated with the times so that students can find out more about the benefits of science, especially chemistry in real life.

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