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SCIENCE, ENGINEERING, AND TECHNOLOGY OF DYE SENSITIZED SOLAR CELLS: A DIDACTICAL DESIGN BASED ON TECHNOCHEMISTRY EDUCATION

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ABSTRACT

This research was conducted to build a view of the nature of science and technology (VNoST) chemistry education student's ability through the didactical design reconstruction. The material taken is Dye-Sensitized Solar Cells (DSSCs) topic with technochemistry education model. It is a model that looked at education from the perspective of engineers and scientists who work not only on inquiry but also on a design perspective. Based on literature research, Indonesian students had low academic literacy performance as revealed in PISA (Program for International Student Assessment) study from 2000-2015. This problem can be caused by a weak teacher's abilities of the nature of science and technology (VNoST). This research's method is Research and Development (R&D) through the Model of Educational Reconstruction (MER). The instruments used were the VNoST questionnaire, interview guidelines, and content analysis guidelines. This study's subjects were 25 prospective chemistry education students in the 6th semester for pre-conception study and ten students for implementation study at one of State Universities in Indonesia. The didactical design of learning that has been developed had several advantages, including the prediction of student responses and the anticipation of educators as well as the essential material that is a barrier to student learning. Analysis of the VNoST understanding construction patterns is explored further so that the reasons that underlie students in defining science and technology and their relationship are obtained. The implementation study proved that understanding VNoST students after attending didactical design learning improved by changing students' views on science and technology to be more accurate.

Keywords: didactical design, dye-sensitized solar cells, nature of science and technology, technochemistry

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1. INTRODUCTION

Today's demands bring around people that living in the 21st century must be equipped with various thinking skills. PISA (Programme for International Student Assessment) have done a lot of research concerned with science literacy assessment. The result shows that Indonesian students did not in line with these demands. Thus, between 2002–2015, Indonesian students are still at a low level in mastering science literacy. For instance, a study in 2015 showed that only 1.6% of students could work effectively with situations and problems involved explicit phenomena that require them to make conclusions about the role of science or technology (OECD, 2016).

That's problem needs to be seen as a serious problem and must be looking for a good and comprehensively solution. Vesterinen et al. (2013) and Tala (2013) propose that the solution can be started from teachers to be master like science and technology (Nature of

Science and Technology, NoST) as the primary and vital element of science literacy. Science teachers who do not comprehend NoST will be challenging to teach and help learners gain a good understanding of science concepts (Tairab, 2011).

According to Tala (2013) and Chamizo (2013), in order to build a better comprehending of NoST, techno-science education activities can be applied. Techno-science provides an understanding of physical and chemical regularity phenomena and gives the ability to create a phenomenon and devise ways to control, manipulate, and engineer it.

In this study, the topic of Dye-Sensitized Solar Cells (DSSCs) was chosen as a techno-chemical model. Solar cells of DSSCs type can be engineered using organic dyes extracted from plants to mimic certain plants and algae's processes, converting sunlight into energy like photosynthesis processes. Although DSSCs are still in the early relative stages of development, it can promote solutions for obtaining electrical energy at low cost and relatively quick manufactured, compared to other electrical energy recovery alternatives such as cheap silicon solar cells. DSSC is also an attractive candidate as a new renewable energy source.

There are previous researches related to learning DSSCs. The first research was conducted by Chien et al. (2018). It is oriented towards learning DSSCs through laboratory work to provide visualization of changes in light energy into electrical energy and understand the working principles of solar cells add to the concept of plant use. The second study about DSSCs learning was discussed by Smith et al. (2013), it is oriented towards solar energy demonstrations using environmentally friendly household materials to demonstrate the ease of technology that is easy for learners to understand. The third, the DSSCs learning research, was exercised by Enciso et al. (2018); this relates to the applicative learning of basic chemistry through open-source microcontrollers and solar cells as a switch that depends on room lighting conditions. All the complete research above has not been implemented in the classroom and its relation to VNoST (View of Nature of Science and Technology). Also, the students of the chemistry department who become chemistry teacher candidates have not been studied. The present research is conducted to produce a didactical design based on a techno-chemical learning framework that has proven the strengths and weaknesses of VNoST that are completely done by experimental studies. The didactical design here means a lesson plan designed to solve and direct students in order to create an entirety comprehending, not only limited to one context.

2. RESEARCH METHOD

Design of research used in this study is the Model of Educational Reconstruction (MER). According to Duit et al. (2012) and Niebert & Gropengiesser (2013), MER is a model with a relevant research framework in science education to improve the quality of the learning process rearrange the concepts which have been presented.

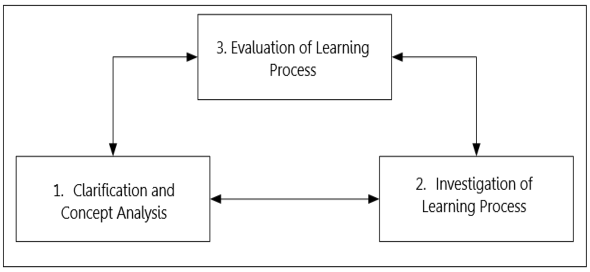


Figure 1. MER Components (Duit et al., 2012)

MER consists of three main components: clarification and concepts analysis, investigation of the learning process, and evaluation of the learning process. In the early stages, clarification and analysis of the concepts will be taught, and the learning process will be carried out. At the investigative stage, the learning process is carried out to find out the views of learners and the conception of educators during the learning process. The evaluation stage is carried out to find out the problems that occur during the learning process. The relationship of the three MER components can be seen in Figure 1.

This research was conducted by involving students of the chemistry education department in one of the State Universities in Indonesia as respondents who have studied basic chemistry, inorganic chemistry, and organic chemistry. Twenty-five student respondents attended the pre-conception study (learning barriers).

Implementing the DSSCs learning didactical design was carried out in a limited experiment involving ten student respondents. The didactical design was validated by four experts in the field of chemistry and chemical education, and the results were given in an expert judgment. The instruments used in this study are shown in Table 1.

Table 1. Research Instruments and Data

No.	Instrument	Data Obtained	Data Analysis Techniques
1.	Content Analysis Guidelines (Mayring, 2014)	Scientific Conceptions related to DSSCs, chemical content-related, and both relationships.	Content Analysis (Mayring, 2014)
2.	Clinical Interview Guidelines.	Student pre-conception related to DSSCs, chemical content-related, and both relationships.	Content Analysis (Mayring, 2014).
3.	Validated VNoST questionnaires from Aikenhead & Ryan, 1992 and Botton & Brown, 1998.	View of Nature of Science and Technology (VNoST), in early before and end after learning.	Percentage changes in each category (Naïve, Has Merit, and Realist).

3. RESULT AND DISCUSSION

3.1 Scientific Conception of DSSCs, Related Chemical Content and The Relationship Between The Two

There are following monographs and journal articles used in the content analysis to obtain scientific conceptions of DSSCs, chemical concepts related, and both relationships.

a. Book "Solar Cells Dye-Sensitized Devices" (Kosyachenko, 2011).
b. Journal Article "Dye-Sensitized Solar Cells" (Hagfeldt et al., 2010).
c. Journal Article "Sub-Micrometer-Sized Graphite As a Conducting and Catalytic Counter Electrode for Dye-sensitized Solar Cells" (Veerappan et al., 2011).

Based on the text's content analysis, there were two basic texts from element-tarization: The Components of DSSCs and The Principles of DSSCs. The results of this content analysis are presented in Table 2 and Table 3.

Table 2. Components of DSSCs

Basic Text of Content Analysis Results	Aspects of VNoST and Related Chemical Concepts
The DSSC structure consists of materials glued to two conductive oxides (TCO) transparent glass that acts as anode and cathode. Anodes/electrodes are conductive glass coated with mesoporous semiconductors that are coated with organic dyes. The cathode or electrode comparison is a conductive glass coated with inert metal. There is an electrolyte solution among the conductive glass, usually the electrolyte pair of redox iodide/triiodide (I^-/I_3^-). The components that make up the DSSCs are: 1. Substrate/Oxide Conductive Glass. 2. Semiconductors. 3. Color substances. 4. Electrolytes. 5. Electrodes/Catalysts.	**VNOST Aspects** Characteristics of science and technology, objectives of science and scientific research, characteristics of scientific knowledge and scientific theory, and relationships of science and technology. **Related Chemical Content** Aromatic compounds (electron delocalization), atomic theory of quantum mechanics, covalent bonds, London dispersion force, periodic elemental properties (semiconductors), electrolyte solutions, and ion bonds.

Table 3. Principles of DSSCs

Basic Text of Content Analysis Results	Aspects of VNoST and Related Chemical Concepts
The principle of solar cells can be explained by changing chemical reactions of sunlight radiation into electrical energy. The DSSC device consists of electrodes/anodes and cathode electrodes. In electrodes/anodes occur the oxidation process/occurrence of electron transfer, while in the electrodes, comparison/cathode occurs electron reception. When sunlight radiation hits the DSSC device, photons are absorbed by color molecules (D). Photons that hit color molecules interfere with π bonds and cause their electrons to be excited from the ground state (HUMO) to the excited state (LUMO). $D + hv \rightarrow D^*$ (photoexcitation) Electrons in the excitable state are then transferred to the TiO_2 conduction band, causing the color substance to lose one of its electrons. $D^* \rightarrow D+ + e^-cb$ (charge injection into TiO_2 conduction tape)	**VNoST Aspect** Characteristics of science and technology **Related Chemical Content:** Galvanized cells, reduction and oxidation reactions

Basic Text of Content Analysis Results	Aspects of VNoST and Related Chemical Concepts
Electrons in the TiO_2 conduction band then move to the SnO_2 conduction band on the conductive glass and towards the external trajectory, resulting in an electric current.	

3.2 Student Pre-Conception of DSSCs, Related Chemical Content, and Relationship

An interview method between interviewers and students can be used to investigate mental construction and get a glimpse of various aspects of learner conception to obtain the full aspect (Holbert et al., 2015). This methodology has been successful and can widely used to test conceptual learning in science, either a formal or informal context. The results of pre-conception interviews of prospective chemistry teachers are showed in Table 4.

Table 4. Student Pre-Conception Study Results

No	Questions	Response	Number of Respondents
Knowledge of Technology DSSCs			
1	Definition of organic dye-based solar cells	Solar cells that use organic compounds	8
		Solar cells use organic color substances	1
		Solar cells from plant extracts	2
2	Solar cell technology	Solar panels, garden lights, mesh lights, calculators	12
3	DSSC component functions	One component function	
VNOST Knowledge in the Context of DSSCs Technology			
4	Solar cells are undergoing development	Make it better.	14
		Repair previous generations	11
5	The scientific model with original object	Not same	5
		Look like or same.	20
6	Technology usage decisions	Because the electric current is small	15
		Because of the lack of absorption	10
Knowledge of DSSC Related Chemical Concepts			
7	Redox Reaction	Related to the release and reception of electrons	25
		Related to electric current	13
		Be able to generate electricity due to electron movement	13
8	Galvanized cell components	Three or more components	6
		Two components	10
		One component	9
9	The appearance of color on organic color substances	Presence of light absorption	20

The first category explains that from students' answers can be concluded information about the existence of solar technology has been known. However, the extent of the technology's language and its benefits for daily life is still poorly understood. DSSCs are completely foreign for students. Its shoud be presented with illustrations of DSSC arrangement drawings, images of objects using DSSCs applications, illustrations of the working principles of DSSC. Even video of making DSSCs still can not provide a proper picture of DSSCs. From the results of student interviews, it can be concluded that the context of technology, especially the latest technology such as DSSCs, still very rare, they have never heard of, nor do they know the principles of work and its benefits for life. These results are the reason for the choice of learning didactical design in the context of DSSCs material.

The second description explains that the analysis results explain that students have not realized that technological developments, especially in the context of DSSCs, are motivated by scientific findings. Knowledge of the scientific model's epistemological aspects is still widely distinguished between native objects and scientific learning models. Meanwhile, technology decisions provide a good but incorrect response.

The third category explains that from the analysis results can be interpreted all students answered the benefits obtained through the context of DSSCs based on their views after they have obtained information about the composition, working principles, tools with DSSCs application, and video creation. As for the chemical content in the DSSC itself, students can only associate 2-3 electrochemical content, redox reactions, and chemical reactions.

Analysis of student pre-conception study results is shown in Table 5.

Table 5. Analysis of Student Pre-Conception Study Results

No.	Preconception Analysis	Alternative Solutions on Learning (Planned Didactic Situation)
1 and 4	Students do not know what organic cell-based solar dyes are	Researchers show images of the development of solar cell generation. Students were asked to analyze the development of science on solar cell technology.
3	Students do not correctly mention the function of components in solar cells	Researchers re-excavated knowledge related to galvanized cells. Students were asked to analyze the parts and functions of components of galvanized cells. Students asked to compare how and function of solar cells Furthermore, galvanized cells where both have similar changes in chemical energy into electrical energy.
5	Students do not distinguish between scientific models and the model of the original object precisely	Researchers showed two models of images between complex and straightforward solar cells. Students were asked to compare the two models
7	Students cannot relate to the presence of electrical current caused by the propagation of electrons or the movement of electrons	Researchers aired the DSSC's working principle process. Students are asked to explain the concept of electron excitation on the working principle of DSSC.
8	Students unable to mention complete galvanized cell components	Students are asked to explain the working principle image on galvanized cells.
9	Students have not been able to explain the appearance of color in organic color substances	Researchers show images of electron excitation in DSSC dye.

3.3 Scientific Conception versus Student Pre-Conception

Table 6 shows how students' scientific and pre-conception of DSSCs, related chemical concepts, and relationships are integrated to get a basic picture of their didactical design.

Table 6. Integration of Scientific Conception and Student Pre-Conception

No	Pre-Conception Questions	Scientific Conception	Student Conception
1.	Dye-sensitized solar cell (DSSC)	A sandwich-shaped semiconductor device that uses color substances to absorb sunlight radiation and convert it into electrical energy through chemical reactions.	An electrical energy replacement device that uses organic dyes
2.	Chemical Photo Electron	Changes in solar radiation energy into electric energy through chemical reactions with color substances.	Photon-energy that hits an object causes chemical energy to become electrical energy
3.	Conductive glass	The glass that changes bond structure due to the addition of semiconductor casters allows electrons' movement.	Semiconductor glass due to the addition of electron dopping
4.	Galvani salt	Changes in spontaneous reduction-oxidation reactions into electrical energy.	Changes in chemical energy into electrical energy
5.	Anode	Electrodes where oxidation reactions (electron transfer) are occurrence.	Metals where oxidation is an occurrence
6.	Cathode	Electrodes where the reduction reaction (receiving electrons) is an occurrence.	Metal where reduction is an occurrence
7.	Electrolyte solution	A solution consists of perfectly dissociated/partially dissociated ions in the solvent to conduct electrical current.	Solutions that can conduct electricity

3.4 Didactical Design of Dysenterized Solar Cell Learning Dyes

Figure 2 shows the main part of developed didactical design. This didactical design has been validated with the acquisition of average CVR (Content Validity Ratio) as follows: (a). Suitability indicators with the planned didactic situation obtained a CVR value of 0.92; (b). The VNoST aspect's suitability with the planned didactic situation, CVR value is obtained by 0.94; (c). Suitability of indicators with Anticipation of Educators (scaffolding) obtained CVR value of 1; (d). Suitability of predicted response of learners with Anticipation of Educator (scaffolding) obtained CVR value of 1. The acquisition of CVI (Content Validity Index) values related to the suitability of indicators and the suitability of VNoST aspects with the planned didactic situation is 0.93.

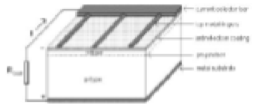
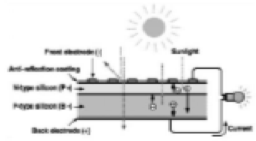
Learning Indicators	VNOST Aspects	The Didactic Situation that Planed	Learner Response Prediction	Anticipation of ***Educators /Scaffoldings***
2.3.3 demonstrates support for DSSC technology as an alternative electrical energy provider	The purpose of science and scientific research	Educators air video of energy crisis Educators ask questions about solutions to the energy crisis	1. Learners answer the solution to the energy crisis, one of which is with solar cells 2. Peseta educated did not answer the solution of the energy crisis with solar cells, or answer other energy sources.	Responses that arise from learners are directed at renewable energy that has the following conditions: • Cheap • Abundant • Environmentally friendly
2.1.2 2.2.1 2.3.1 2.3.3	The relationship between science and technology	Educators ask whether learners know solar  cells?	1. Learners answered to know the solar cells are: tools that can convert sunlight into electrical energy. 2. Learners did not answer solar cells	The response that arises from learners is directed at tools that use solar cells such as in calculators, street lighting lamps and others. Educators display images of tools that use solar cells
		Educators display images and video about solar cell applications and ask how solar cells work  Figure 1. Silicon-based solar cells (source: Wikipedia)	Learners observe images and videos about solar cell applications and: 1. Answering the question of how solar cells work: When *junction* is illuminated, *photons* that have energy equal to or greater than the width of the material energy band will cause electron excitation from the ribbon valence to the conduction tape and will leave a hole in the valence band. These electrons and holes can move in the material resulting in a pair of electron holes. If a barrier is placed in the solar cell terminal, the electrons from the n-area will return to the p-area causing potential differences and the current will flow 2. Not answering how solar cells work	The response that arises from learners is directed at converting sunlight energy into electrical energy. Displays conventional solar cell schemes and how they work:  Figure: Silicon-based solar cell scheme  Figure: Silicon Solar Cell Working Scheme
	Characteristics of scientific knowledge	Educators explain the development of solar cells from generation I to generation III from the way they work, their advantages and weaknesses so that new generations are discovered. Educators ask why is solar cell technology constantly evolving?	Learners receive an explanation of the development of solar cell generation 1. Learners understand the principle of development of solar cell generation that is looking for alternative solar cells that have high efficiency, low price, durable and easy to make / produce 2. Learners do not understand the principle of development of solar cell generation	The response of learners was directed at a group discussion on the factors influencing the development of solar cell technology Educators give the analogy that scientific discoveries are developed such as building a wall where it is built from various findings towards better findings.

Figure 2. Main Parts of Didactical Design

3.5 Effect of Didactical Design Implementation on VNoST Students

Implementation of didactical design is carried out through a limited scale test. VNoST's ability was conducted on a limited scale, testing ten students who had attended basic chemistry, organic chemistry, and inorganic chemistry. The results of student VNoST data can be seen in Table 7.

Table 7 shows that students' understanding of VNoST undergoes a more accurate change of view with the use of the design of didactic learning DSSCs. Sub aspects of the overall definition of science undergo more accurate changes from naïve (N) to has merit (HM), from naïve to realist (R), and from merit to realist. This shows that although students have long studied science, understanding the nature of science has not been meaningful in the knowledge they have (Novak, 2002). Therefore, it can be concluded that learning activities in the sub-definition of science can be applied to strengthen VNoST for chemistry teachers. The reason for choosing the answer to choose a realist statement on the definition of science is. The student explained through the reason they choose one of them is "science is held after seeing the phenomenon that is then investigated and produces facts, concepts, and laws further obtained the theory." The second sub-aspect defines technology that changes views to be more accurate realists than five from ten students.

Table 7. VNoST Ability of Students 1-5 before and after Implementation of Didactical Design

NOST Sub-Aspects	Student 1		Student 2		Student 3		Student 4		Student 5		Total
	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST	
The definition of Science	HM	R	HM	R	HM	R	R	R	HM	R	4
The definition of Technology	HM	HM	HM	HM	R	R	HM	R	HM	R	2
The Relationship of Science and technology	R	R	HM	HM	R	R	HM	R	HM	HM	1
The nature of the scientific model	HM	R	R	R	R	R	HM	R	N	R	3
The Nature of Classification	HM	R	R	R	R	R	HM	R	HM	R	3
The Nature of Scientific Decisions	N	HM	HM	HM	R	R	HM	R	HM	R	3
The Nature of Technology Decisions	HM	HM	HM	HM	HM	R	R	R	HM	HM	1
The Relationship of Technology Science and Society	R	R	HM	R	R	R	R	R	HM	R	2

HM = Has Merit; N = Naive; R = Realist

Students still find difficulties to distinguish between science and technology. Student 1 still choosen the has merit statement, which is "the application of useful science to improve the quality of life." based on the reason that "technology was created to help people in doing activities / various things in life." This didactical design is facilitating enough to strengthen VNoST students but needs to be developed again. The reasons expressed by these students are accurate, but what improves the quality of human life is not just the application of science.

In addition, some have understood that technology is an instrument used in human life. However, student 7 choose the has merit option, so students choose the has merit statement. There is an option to statement various human-made objects such as devices, tools, and instruments. The student explained, "the end product of technology is an instrument that can be used in human life."

The third sub-aspect is relationship between science and technology. That's has changed the view of 5 from 10 students, with a total of 7 students already on the realist view. The designed didactical design situation can already change the view to be more accurate for almost half of students. This means that this didactical design is valid to strengthen VNOST students, mainly associating science and technology in the context of DSSC learning. Students argue that "science is used to develop technology, then technology can develop science through scientific research."

The fourth sub-aspect, the scientific model's nature, changes the student's view to be more accurate, namely having a realist view. A total of 7 students experienced changes in the meantime. Three others have been on a realist view, which means that all students have an accurate view of the scientific model's nature. This didactical design means that it can facilitate students to view scientific model is different from the original object. The reason students in defining the scientific model are "the model is more easily for us to understand something that we find difficulties to see the details. With the model we can used estimates."

The fifth sub-aspect, the nature of scientific classification, shows that 8 from 10 students accurately view the realist. Students can classify a compound in their group. The didactical design situation and anticipation of the researchers' design have been in accordance with the expected results. The reason students define scientific classification is "many indicators are used to classify such as physical properties or chemical properties, but it is necessary to use the same standards to classify them until the results are more valid."

The sixth sub-aspect, the scientific decision, shows that 8 from 10 students have to change their accurate view. It is a realist. Six students experienced a changing view to be more accurate. Students can define that scientific decisions must be tested many times until no one disputes them. The didactical design situation and anticipation of the researcher's design have been in accordance with the expected results. The reason students define scientific decisions is "a decision must prove successful if it has been tested many times until it can be called true and can be used as an indisputable theory."

Table 8. VNoST Ability of Students 6-10 before and after Implementation of Didactical Design

NOST Sub-Aspects	Student 6		Student 7		Student 8		Student 9		Student 10		Total
	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST	
The Definition of Science	HM	R	HM	R	HM	R	HM	R	HM	R	5
The Definition of Technology	HM	HM	HM	R	HM	HM	N	HM	R	R	2
The Relationship of Science and technology	HM	R	N	R	HM	R	N	R	R	R	4
The nature of the scientific model	N	R	N	HM	N	R	HM	R	R	R	4
The Nature of Classification	N	N	HM	R	N	R	R	R	R	R	2
The Nature of Scientific Decisions	HM	R	N	HM	HM	R	HM	HM	R	R	3
The Nature of Technology Decisions	N	HM	HM	R	N	HM	HM	R	HM	HM	4
The Relationship of Technology Science and Society	HM	R	HM	R	N	R	HM	R	R	R	4

HM = Has Merit; N = Naive; R = Realist

In the seventh sub-aspect, technology decisions showed that 6 from 10 students were inaccurate view calling realists. Students can define that technological decisions hang on to the well-off condition of a person. The didactical design situation and anticipation of the researcher's design have been in accordance with the expected results. The reason students define scientific decisions is "decisions using technology pay attention not only to the impact but also to all aspects."

The eighth sub-aspect, the relationship between science and technology, shows that as many as nine from ten students are, on an accurate view, realists. Students can define that technology decisions depend on a person's well-off condition. The didactical design situation and anticipation of the researchers' design have been in accordance with the expected results. The reason students define scientific decisions is "the existence of science and technology can help people's lives, but the needs of society make technology and science development to meet the needs of society."

4. CONCLUSION

Scientific conception study shows that on the topic of Dyes-Sensitized Solar Cells (DSSCs), several important chemical concepts can be applied to the lecture of Material Chemistry, such as Galvanized cells on working principles, the theory of quantum mechanics atoms on the excitation of color substances, electromagnetic radiation in the type of electronic spectrum, periodic properties of elements in semiconductors, aromatic compounds through electron de location in color substances, electrolyte solutions through electrolytes used in DSSCs, ion bonds in ionic fluids, covalent bonds in conductive glass, London, and reduction and oxidation reactions in reactions occurring in anodes and cathodes.

Students' pre-conception study through interviews shows that students still have different views with scientific conceptions, especially on related chemical content such as redox reactions, galvanized cell principles, semiconductors, and electron excitation in organic color substances.

Implementation studies show that didactical design has a significant effect, especially for sub-aspects of the definition of science and the nature of scientific models, by reinforcing the change of view in the realist category. Meanwhile, it is good enough for the sub-definition of technology and the nature of technology decisions.

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