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DEVELOPMENT OF A MENTAL MODEL DIAGNOSTIC TEST USING PREDICT, OBSERVE, EXPLAIN (TDM-POE) ON VOLTAIC CELL MATERIALS

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ABSTRACT

Understanding chemical concepts as a whole shows that students can connect three levels of chemical representation. The three levels in chemical representation are related and reflected in students' mental models. A teacher must know the student's mental model as a reflection of learning. This research aims to develop an instrument for students' mental models on voltaic cell materials using the prediction-observation-explanation (TDM-POE) mental model diagnostic test. The method used in this research is the research and development method using the Analysis, Design, Develop, Implement, and Evaluate (ADDIE) development model. The instrument consists of four questions for four concepts: voltaic cell construction, calculating standard cell potential values, voltaic cells in alkaline batteries, and corrosion phenomena. Each question consists of 3 stages, namely, the first stage contains questions about predicting phenomena (predict), the second stage contains video or image observations (observe), and the third stage contains detailed explanations (explanation). The instrument was validated by five validators consisting of four lecturers in the Department of Chemistry Education and one chemistry teacher at school. Validity is determined by content validity response using expert judgment. Then, the instrument was tested on class XII students who had received learning about voltaic cells. The validation results show that the validity of the TDM-POE instrument obtained a score of 1, which is categorized as valid. So, the TDM-POE instrument can be used to understand chemical concepts as a form of teacher reflection in conducting learning.

Keywords: mental model, TDM-POE, voltaic cell

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1. INTRODUCTION

Chemistry is a science that studies matter and its properties, changes in matter, and the energy that accompanies these changes (Devi & Azra, 2023; Whitten, 2014; Silberberg, 2007). This can help students understand the various things that happen around them. Chemistry has the following characteristics: (1) most chemistry is abstract, (2) it is a simplification of the real, and (3) the nature of chemistry is sequential and develops rapidly (Treagust et al., 2018; Sumarni, 2020). In addition, the characteristics of chemistry can be studied by involving the three levels of chemical representation, namely the macroscopic, submicroscopic, and symbolic. The macroscopic level describes phenomena in everyday life; The submicroscopic level shows explanations at the particulate level, which are described in the arrangement of atoms, molecules, and ions; while the symbolic level involves the use of chemical symbols, formulas, and equations to describe matter (Johnstone, 2009; Permatasari, et al., 2022). Therefore, many students consider chemistry a complex subject because chemistry combines many abstract concepts that students must understand.

The difficulties experienced by students are caused by chemistry learning in schools that do not present the three levels of chemical representation in their entirety so that students will understand chemical concepts based on their abilities (Chandrasegaran et al., 2011; Lin et al., 2016). Generally, students in understanding chemistry subject matter tend to learn by rote (Treagust et al., 2018; Chandrasegaran et al., 2008). Therefore, each student will have a different understanding of interpreting and describing a phenomenon. Thus, each student will have a different understanding of interpreting and describing a phenomenon.

In addition, teachers often do not know students' difficulties in understanding chemistry because the learning evaluation tools tend to require students to memorize rather than understand the concept (Cahyani & Sutrisno, 2018). Suppose the teacher only gives chemistry problems based solely on memorization, and students can solve them. In that case, it does not mean that the students thoroughly understand the concepts being tested. This is to the findings of one study that students can often solve chemistry problems that only involve problems at the symbolic level; it does not mean that the students understand the chemistry concepts being tested completely (Linda & Futra, 2024; Chandrasegaran et al., 2008). Evaluation tools are very important learning tools for evaluating student competencies that have been achieved. Therefore, if the evaluation tool is developed by presenting the three levels of chemical representation, the evaluation tool can measure students' chemistry concept abilities as a whole, not just memorization (Wang et al., 2017).

A complete understanding of chemistry concepts can be seen from students' mental models (Yuanita & Ibrahim, 2015). Mental models represent ideas in a person's mind that they use to describe and explain phenomena (Bilir & Karaçam, 2021; Wang, 2007). Mental models are expected to support understanding, reasoning, and prediction in situations when they are involved in everyday life to solve complex problems. The more information or knowledge students receive during the learning process, the different their mental models will be from before. Teachers' knowledge of students' mental models at the beginning of learning can be used to determine learning strategies to suit students' initial knowledge and level of education (Sunyono & Ibrahim, 2015). Information about students' mental models can be explored in various ways (Linda & Futra, 2024). According to Wang (2007), to explore students' mental model profiles, a mental model diagnostic test (TDM) is carried out. Some mental model instruments that are often used include multiple-choice tests (Tier Multiple Choice Test) (Kania et al., 2020), open-ended questions, interviews with guiding questions (probing), interviews using pictures or models, interviews with problems presented, Interview about Event (IAE) model and Prediction-Observation-Explanation (POE) model.

The TDM-POE instrument is an assessment tool designed to identify students' mental models of a scientific concept in more depth (Kiswandari & Ridwan, 2020). Mental models refer to students' internal images of how a phenomenon works, which are formed from learning experiences, intuition, and prior knowledge. The Predict-Observe-Explain (POE) approach allows students to actively predict the outcome of an event or experiment, observe the phenomenon directly, and explain the results of these observations (Febriyanti et al., 2019; Assafuah-Drokow, 2023). At the prediction stage, students will be asked to predict the phenomena that will occur based on their initial knowledge to determine students' initial abilities at the submicroscopic and symbolic levels. The observation stage is in the form of observing phenomena, and students are asked to describe the phenomena according to observations to provide a macroscopic understanding. Furthermore, at the Explain stage, students are asked to explain in detail the initial abilities and the results of observations that are explored submicroscopically and symbolically. Thus, the instrument can explore multiple representation abilities in their entirety.

Several researchers have recorded students' misconceptions of electrochemistry, especially in voltaic cell material (Rogers et al., 2000). Students have difficulty using standard reduction potentials to predict spontaneous and non-spontaneous chemical reactions in an electrochemical cell (Tien & Osman, 2017; Tsaparlis, 2019). The misconceptions among students include the statement that current flows through electrolyte solutions and salt bridges and their electron transfer mechanisms (Ali et al., 2022). Many students can solve quantitative electrochemistry problems in most chemistry exams, but only a few can answer qualitative questions regarding conceptual knowledge of electrochemistry (Karamustafaoğlu & Mamlok-Naaman, 2015). In addition, teachers' alternative conceptions on the topic of voltaic cells, namely in the subtopic of salt bridges, were found, especially in understanding their working mechanisms. However, a measuring instrument for students' mental models in electrochemistry has not been found. Based on the description, a tool is needed to reveal the mental model profile owned by students on the voltaic cell material using the predict-observe-explain (TDM-POE) mental model diagnostic test. This study aims to develop a predict-observe-explain (TDM-POE) mental model diagnostic test to measure students' mental models on electrochemical cell material, especially on voltaic cells.

2. RESEARCH METHODS

The type of research is development research designed to obtain a product. Research and development (R&D) is research used to find a product with a new design and follows the procedure for applying research methods using field trials, evaluations, and revising the product until it meets the criteria for effectiveness, quality, or in accordance with existing standards (Branch & Varank, 2009; Adriani et al., 2020). The product produced in this research and development is a TDM-POE instrument to explore the mental model profile on voltaic cell material. The ADDIE development model is an effective and efficient learning design model. Its interactive process, namely the evaluation results of each phase, can bring learning development to the next phase. This model consists of 5 main phases or stages, namely, Analyze, Design, Develop, Implement, and Evaluate each stage (Branch & Varank, 2009; Ramly et al., 2022) which are shown in Figure 1.

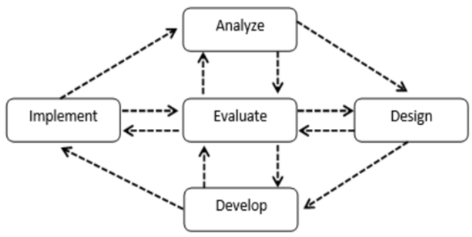


Figure 1. ADDIE Stages

The details of each stage of the ADDIE model development are as follows: The analysis stage is the stage where researchers analyze important concepts in the voltaic cell material that are adjusted to the learning objectives. The analysis was carried out on six chemistry textbooks. Based on the analysis of books and curriculum, researchers divided the concept of voltaic cells into four concepts, namely: (1) construction of voltaic cells that can produce electric current, (2) Calculating the standard cell potential value produced by voltaic cells, (3) interpreting the symptoms or processes of voltaic cells that occur in alkaline battery cells and (4) finding factors that influence corrosion and proposing ideas to overcome them. The design stage is carried out by determining the idea of developing the TDM-POE question instrument. The steps taken are in the form of compiling component requirements at the prediction stage in the form of phenomena based on the surrounding context, the observation stage in the form of videos or images for the observation process, and the explanation stage in the form of more detailed questions to explore submicroscopic and symbolic abilities. The development stage is the realization of the product. The development of TDM-POE was then validated by five validators consisting of four chemistry lecturers and a chemistry teacher at the high school level. The validation results are summarized with suggestions and input as a basis for revising the instrument. At this stage, data analysis is also carried out on the results of the instrument assessment obtained by experts to obtain data on the validity value of the instrument. The validity analysis used uses quantitative data to calculate the CVR value. The test items are valid if the CVR calculation is 0.99 (Rutherford-Hemming, 2015). The implementation stage is carried out on a limited basis on high school students in grade XII who have studied the voltaic cell material. Sampling was done using a purposive sampling technique with the criteria of students who studied the material. At the evaluation stage, the researcher conducted an overall evaluation and final revision of the instrument developed based on input from the assessment.

3. RESULTS AND DISCUSSION

This study developed a mental model diagnostic test instrument, Predict, Observe, Explain (TDM-POE), on voltaic cell material. It consisted of four descriptive questions with the stages predict, observe, and explain. TDM-POE is in the form of a worksheet containing several questions to explore students' mental models on voltaic cell material. The test is a descriptive question. Each student is given four questions; one is about voltaic cell material. The first question concerns the concept of voltaic cell construction that produces electric current. The second question is about calculating the cell potential value produced by the voltaic cell. The third question concerns the symptoms or processes of voltaic cells in alkaline batteries. The fourth question is about the factors that influence corrosion in everyday life. Each question consists of 3 stages: prediction, observation, and explanation. Questions related to the prediction stage reveal students' initial abilities at the submicroscopic and symbolic levels. The second stage is the observation stage, which is related to student's abilities at the macroscopic level to write down the results of observations of experimental videos or images observed. Experimental videos or images are shown after students answer questions at the prediction stage. At the explanation stage, students are asked to explain the phenomena in the experiment and their predictions. Students' answers at the explanation stage can reveal students' ability to link the three levels of chemical representation so that in one question given, there is a relationship between the three levels of chemical representation.

The development procedure used in the study is four of the five ADDIE stages. The four stages are analyzed, designed, developed, and implemented. The four stages are presented in detail as follows.

Analyze stages

Before developing the instrument, the researcher conducted a content analysis of the voltaic cell material, aiming to determine the sequence of delivering the concept of the voltaic cell material according to experts that will be adjusted to the curriculum. The analysis is based on a study of several General Chemistry textbooks with the following details:

1. General Chemistry textbook by Kenneth W. Whitten et al. 10th edition in 2014 entitled "Chemistry."
2. General Chemistry textbook by Martin S. Silberberg, 1st edition in 2007, entitled "Principles of General Chemistry."
3. General Chemistry textbook by Raymond Chang and Jason Overby, 6th edition in 2011, entitled "General Chemistry."
4. General Chemistry textbook by Theodore L. Brown et al., 12th edition in 2012, entitled "Chemistry."
5. General Chemistry textbook by Ralph H. Petrucci et al., 10th edition in 2011, entitled "General Chemistry."

6. General Chemistry textbook by Steven S. Zumdahl et al., 7th edition in 2010, entitled "Introduction Chemistry."

The results of the analysis of several textbooks produced a sequence of presentation of the concept of voltaic cell material, including the construction of voltaic cells that can produce electric current, calculating the standard cell potential value produced by voltaic cells, interpreting the symptoms or processes of voltaic cells that occur in battery cells and finding factors that influence corrosion. The battery cells selected are based on their presence in every textbook, as shown in Table 1.

Table 1. Types of batteries in textbooks

Concepts on textbooks	**1**	**2**	**3**	**4**	**5**	**6**
Primary voltaic cells:	√	√	√	√	√	√
Leclanche dry cell	√	√	√	√	√	√
Alkaline dry cell	√	√	√		√	√
Mercury-Silver cell		√		√		√
Secondary voltaic cells	√	√	√	√	√	√
Lead-Acid Battery*	√		√	√	√	√
Nickel-Metal Hydride (Ni-MH) or Ni-Cd Battery	√	√	√		√	√
Lithium-Ion Battery		√	√	√	√	
Fuel Cell	√	√	√	√	√	
*Ag-Zn Battery			√			

Then, the researcher analyzed the curriculum to determine the position, breadth, and depth of the voltaic cell material. The results of the curriculum analysis were used as a reference for developing question indicators that would be used in the test instrument. The indicators used in this study were analyzing the arrangement of voltaic cell circuits that could produce electric current, calculating the cell potential produced by voltaic cells, interpreting the symptoms or processes of voltaic cells that occur in dry battery cells, and finding factors that influence corrosion and proposing ideas to overcome them.

Design Stages

The question indicators were poured into four questions. Each question consists of one indicator that is used as a reference in developing the TDM-POE instrument on the voltaic cell material. The TDM-POE instrument was developed on the voltaic cell material based on these indicators. Each question consists of three stages: prediction, observation, and explanation. The prediction stage reveals students' abilities at the submicroscopic and symbolic levels. The observation stage explores students' abilities at the macroscopic level. Furthermore, at the explanation stage, students provide reasons by linking the three levels of chemical representation to the voltaic cell material.

Development Stages

The problem-solving ability test instruments were developed based on previously selected indicators. Based on the four indicators, eight questions were developed with details as shown in Table 2.

Table 2. Distribution of indicators on question items

Indicators	**question items**
analyzing the arrangement of voltaic cell circuits that can produce electric current	1
calculate the cell potential produced by a voltaic cell	2
interpreting the symptoms or processes of voltaic cells that occur in dry cell batteries	3
find factors that influence corrosion and propose ideas to overcome them.	4

Question 1

At the prediction stage, four voltaic cell circuits are provided with different component positions in the circuit. Students are assigned to choose a voltaic cell circuit that can produce electric current based on the four circuits and the reasons for their choice. Furthermore, at the observation stage, students observe a video of the previous four voltaic cell circuit experiments at the prediction stage. Observing the video will tell students which experiments can produce electric current. Then, students explain the voltaic cell phenomenon in more detail at the explanation stage related to its components, the correct circuit construction, the particle interactions that occur, and the writing of the redox reaction equation in the form of voltaic cell notation.

Question 2

At the prediction stage, there is a voltaic cell circuit, namely the Zn|Zn2+||Cu2+|Cu cell whose standard reduction potential value is known. Students are assigned to calculate the standard cell potential value produced by the voltaic cell based on the known standard reduction potential data. Furthermore, at the observation stage, students observe a video of the standard cell potential value experiment produced by the voltaic cell. Then the students explain the phenomenon of the voltaic cell in more detail in the explanation stage related to the species that undergo oxidation along with their standard oxidation potential values, species that undergo reduction along with their standard reduction potential values, and how to calculate the standard cell potential value produced by the voltaic cell.

Question 3

At the prediction stage, a case is provided for a student who inserts a battery into a flashlight compared to inserting an iron plate into a flashlight. Students are assigned to choose a treatment that can turn on the flashlight. In addition, data on the standard reduction potential contained in the alkaline battery cell is included at the prediction stage. Furthermore, at the observation stage, students observe a picture of an alkaline battery cell that is cut crosswise so that the components contained in the alkaline battery can be identified. Then the students explain the phenomenon of the alkaline battery cell in more detail in the explanation stage related to the components and their functions, the interaction of particles that occur, writing the redox reaction equation, and the standard cell potential value produced by the alkaline battery.

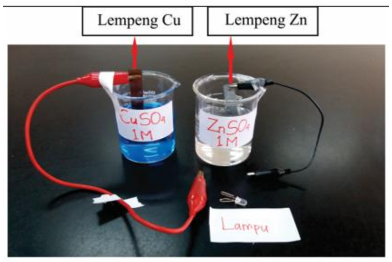
Question 4

At the prediction stage, three experiments are provided to determine the factors influencing corrosion with different treatments. Students are assigned to choose an experiment that can produce rust based on the three experiments and the reasons for determining their choice. Furthermore, students watch videos about the three experiments in the observation stage. Observing the video will tell students about the experiment that produces rust. Then, students explain the corrosion phenomenon in more detail in the explanation stage, related to the factors that influence it and the interaction of particles that occur, write redox reaction equations, and submit ideas or concepts to overcome it. The four questions that have been developed are then validated by experts. Expert validation was carried out by four lecturers in the fields of chemistry and chemical education. The results of expert validation are presented in Table 3.

Table 3. Expert Validation Results

No	N	CVR	CVR table	Result
1	5	1.00	0.99	Valid
2	5	1.00	0.99	Valid
3	5	1.00	0.99	Valid
4	5	1.00	0.99	Valid

The things that need improvement are in question 1, there needs to be a probing question that explores the process requested in the question. This shows the role of the explanation stage, consisting of several detailed questions to help explore students' in-depth understanding (Febriyanti et al., 2019). Then there are improvements to several images that need to be emphasized so that students do not make mistakes in observing (Assafuah-Drokow, 2023). This is shown in Figure 2.



Before revision After revision

Figure 2. Example of instrument revision

Then there is an improvement in question number 2 by eliminating the calculation question using the Nerst equation. This is because students in the high school curriculum do not learn cell potential calculations using the Nerst equation (Ali et al., 2022).

Implement Stages

The researcher conducted a trial on 16 grade XII students who had studied the voltaic cell material. The results of the trial were used to determine the readability of the questions by students. The results showed that the questions' readability level had a score of 4.6, indicating that the instrument was very easy to read.

4. CONCLUSION

The instrument consists of four questions for four concepts: voltaic cell construction, calculating standard cell potential values, voltaic cells in alkaline batteries, and corrosion phenomena. Each question consists of 3 stages, namely, the first stage contains questions about predicting phenomena (predict), the second stage contains video or image observations (observe), and the third stage contains detailed explanations (explanation). The validation results show that the validity of the TDM-POE instrument obtained a score of 1, which is categorized as valid. The implications of developing this instrument are that it can be used to measure knowledge and provide a complete picture of understanding chemical concepts. The measurement results can be used as reflection material to develop further learning.

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