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Effectiveness of Multimedia based on Multiple Representation of Hess' Law: Concept and Skills of Pre-service Science Teachers

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The purposes of this study were to determine: 1) the attitudes and motivations of pre-service science teachers in learning Hess' Law using multimedia based on multiple representations (macroscopic, microscopic, and symbolic) of Hess' Law; 2) the learning outcomes of the participated pre-service science teachers after experiencing the learning through the multimedia, and 3) the effectiveness of the multimedia in improving the mastery of pre-service science teachers' science processes and concepts about Hess' Law. The method used in this study is quasi-experimental; pre-test and post-test were addressed through a questionnaire and test. Data analysis was performed through multimedia quality data, based on the multiple representations and t-test. The results showed that the pre-service science teachers could learn Hess' Law material more efficiently, faster, more actively, and more independently. They were also motivated to learn by using the multimedia. The results of the t-test for the difference before and after treatment was significant ($p <.005$). Suggestions and recommendations for teacher educators, policymakers, and pre-service science teachers are provided.

Keywords: multimedia, multiple representations, Hess' Law, effectiveness, learning outcomes

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INTRODUCTION

Physical Chemistry is one of the sciences that contribute to abstract phenomena. Many of the learning materials in chemistry learning are difficult to illustrate in real form and two-dimensional images. In the process of learning Physical Chemistry, pre-service science teachers are often faced with abstract materials beyond their daily experience resulting on the material to be difficult to teach and understand (Allred & Bretz, 2019). These phenomena are known as "multiple representations."

Representations are categorized into two groups, namely internal and external representations. Internal representations are defined as individual cognitive configurations that originate from behaviors that describe several aspects of physical processes and problem-solving, while external representations are the structured physical situations as the embodiment of physical ideas (Bayraka & Bayramb, 2010; Chandrasegaran et al., 2007). Johnstone, as cited in Chittleborough and Treagust (2007), divides chemical phenomena into three levels, namely. Firstly, the macroscopic level obtained through real phenomena may directly or indirectly be part of student experiences daily. It can be perceived by five senses, for example, changes in color, temperature, and pH of the solution where the formation of gases and deposits can be observed when a chemical takes place. Secondly, the sub-microscopic level consists of real chemical phenomena, which indicate a particular level that cannot be seen. The sub-microscopic representation is closely related to the theoretical model underlying the particle level explanation. The representation model at this level is expressed symbolically, starting from simple action to sophisticated computer technology, such as with words, two-dimensional images, and three-dimensional images. Lastly, the symbolic level consists of representation images, algebra, and computerized forms (Ercan, 2014; Rodriguez et al., 2019).

Hess' Law is material in the Physical Chemistry course, which is incorporated in the scientific and subjects' group (Spera & Liebman, 2018). The existence of this Hess' Law material is important, but many pre-service science teachers are less enthusiastic and interested to learn it, which is marked by the low learning outcomes. Chemical education learning in Indonesian universities has been mostly done with lectures and discussions (Anwar, 2017). Even though this lecture material requires active involvement from the students, it is deemed necessary to use multiple multimedia-based representing the Hess' Law, which can help the students, including pre-service science teachers understand the Hess' Law. Through the multiple representations-based multimedia, the gap between ideal conditions and real conditions could be narrowed. In real conditions, learning resources are usually only in the form of reading books/texts (Battino, 2020). Through the multiple representations-based multimedia, the learning process is expected to be more effective and more efficient. The level of mastery of the concepts and science process of pre-service science teachers towards the Hess' Law material are expected to be better. Therefore, this study is to determine; 1) the attitudes and motivations of pre-service science teachers in learning Hess' Law using multimedia based on multiple representations (macroscopic, microscopic, and symbolic) of Hess' Law; 2) the learning outcomes of the participated pre-service science teachers after experiencing the learning through the multimedia, and 3) the effectiveness of the multimedia in improving the mastery of pre-service science teachers' science processes and concepts about Hess' Law. Three research questions were added within this study: 1) what are the attitudes and motivations of pre-service science teachers in learning Hess' Law using multimedia based on multiple representations (macroscopic, microscopic, and symbolic), 2) what are the learning outcomes of the participated pre-service science teachers after experiencing the learning through the multimedia, and 3) How effective does the multimedia improve the mastery of pre-service science teachers' science processes and concepts about Hess' Law.

Literature Review

Hess' Law is a correlation in Physical Chemistry (Spera & Liebman, 2018). The Law elaborates that the total number of enthalpy change during the complete courses of chemical reactions are similar to the reaction that is based on a single step or multiple steps (Sciubba, 2016).

Macroscopic, microscopic, and symbolic in this study are interconnected and contributed to pre-service science teachers to be able to understand the abstract material of Physical Chemistry. This is supported by the statement of Tasker' et al. (2006), that chemistry involves processes of change that are observed in terms of (e.g., changes in colors, odors, and bubbles) in macroscopic or laboratory dimensions, but in terms of changes that cannot be observed with eyes, such as changes in structure or processes at the sub-micro or imaginary molecular level can only be done through modeling. These changes at the molecular level are then depicted at the abstract symbolic level in two ways, namely qualitatively using special notation, language, diagrams, and symbolically and quantitatively using mathematics (equations and graphs).

Based on the characteristics of Physical Chemistry, the modes of representation of Physical Chemistry are classified in terms of levels of representation, namely macroscopic representation, submicroscopic representation, and symbolic representation (Chandrasegaran et al., 2007). Macroscopic representation is a chemical representation obtained through tangible observation of a phenomenon that is seen and perceived by the sensory level or can be obtained in the daily experience of the learner (Prokša et al., 2018). Subcompact microscopic representations are chemical representations that explain the structure and processes at the particle level (atoms or molecules) against the macroscopic phenomena (Verma, 2020).

Sub-microscopic representation is closely-related to the theoretical model underlying it, so pre-service science teachers can explore the dynamics that occur at the particle level. The mode of representation at this level can be expressed starting from simple to good technology, for example the use of words, two-dimensional images, three-dimensional images, both still and moving (animated) or simulation. Symbolic representations are chemical representations qualitatively and quantitatively, namely chemical formulas, diagrams, drawings, equations, stoichiometry and mathematical calculations (Acree et al., 1995; Domagk et al., 2010; Treagust et al., 2003).

Although macroscopic observations of chemical phenomena are chemical bases, the explanation of these phenomena is actually based on the representation of submicroscopic and symbolic levels. Consequently, an important aspect of reducing explanation depends on the ability of pre-service science teachers to understand the role of each level of representation and the ability to transfer one level to another level. Acquisition of knowledge without a clear understanding will cause pre-service science teachers to experience confusion because, at the same time, they have to deal with macroscopic, submicroscopic, and symbolic levels. There are two categories of learners' understanding the ability to apply knowledge, namely; instrumental understanding (knowing how) and relational understanding (knowing why); the level of instrumental understanding reflects learning process (Schwedler & Kaldewey, 2020).

METHOD

The population of this study is all Chemistry Study Program pre-service science teachers in Indonesian universities that attend Physical Chemistry courses. We applied a simple random sampling for this study. Two tests were conducted; small-group test and field test. The sample for the small group test consisted of twelve pre-service science teachers. The sample for the field test consisted of twenty-four pre-service science teachers attending a Chemistry Study Program of a university in Jambi, a province in the southern part of Sumatra, Indonesia. This study report is a part of a research and development research with Analyis, Development, Design, Implementation, and Evaluation (ADDIE) model that was fully funded by the 2018 Higher Education Applied Research Grants. It takes two years to finish all projects.

The review of literature helped researchers to analyze the theories and concepts and to determine methods and instruments to be adapted (Hair et al., 2016; Prasojo et al., 2020). We adapted and constructed survey instruments from previous related studies. For face and content validity, a panel of three users and three experts was involved in discussing the adapted instruments. The process was done through an interactive interview. The experts were Indonesian professors in the fields of Physical Chemistry. After the discussion, the experts suggested revising some items and eliminating a few others. Based on their understanding, suggestions, and recommendations, the eliminated items did not suit Indonesian higher education contexts and settings. The item revision and elimination were procedures that have been suggested by many researchers within the content validity through the evaluation process provided by the procedures, including the review process by a panel of experts (Habibi et al., 2020; Lynn, 1986)

The independent variable was a learning system using multimedia based on multiple representations (macroscopic, microscopic, and symbolic) of Hess' Law and the dependent variable is student learning outcomes on the Hess' Law material. This study used quasi-experimental research methods. The study design can be seen in Table 1.

The data were obtained from pre-service science teachers in the form of multimedia quality data, motivation and benefits data, and student learning outcomes. Multimedia quality data, motivational data, and benefits obtained through questionnaires, student learning outcomes data obtained through learning outcomes tests, learning outcomes tests used for the Hess' Law material are objective questions.

Tabel 1
Research design

Sample	Pre-test	Treatment	Post-test
A	Y_1	X	Y_2

Data analysis of learning outcomes is done by the t-test. The significant level (α) used in this study is 5% with a probability (1 - α) dk = (n1 + n2 - 2), if -table <t count <table, then H0 is accepted, which means there is no average significant difference between the pre-test results and the post-test results, and H0 is rejected for other t-values.

FINDINGS AND DISCUSSION

Analysis of multiple small group multimedia trial based data analysis (macroscopic, microscopic, and symbolic) of Hess' Law

Analysis of multimedia quality assessment based on multiple representations (macroscopic, microscopic, and symbolic) of Hess' Law in small group trials for aspects of learning, content/material, and media can be seen in Tables 2 and 3.

Table 2
Frequency distribution assessment of aspects of learning, content/media, and media in a small group multimedia test based on multiple representations (macroscopic, microscopic, and symbolic) of Hess' Law

Criterion	Pedagogy		Content		Media	
	Frequency	%	Frequency	%	Frequency	%
Very good	7	58.3	6	50	4	33.3
Good	5	41.7	6	50	8	66.7
Sufficient	0	0	0	0	0	0
Less	0	0	0	0	0	0
Very less	0	0	0	0	0	0
Total	12	100	12	100	12	100

Table 2 shows the distribution of assessments in the multimedia, small group test based on multiple representations (macroscopic, microscopic, and symbolic) of Hess' Law. The mean multimedia quality assessment based on multiple representations (macroscopic, microscopic, and symbolic) of Hess' Law in a small group test in terms of learning or pedagogy, content/material, and media are included in the criteria.

Table 3
Quality of multimedia based on multiple representations (macroscopic, microscopic, and symbolic) of Hess' Law results of small group trials

Assessment	Mean	Criterion
Pedagogy	4.21	Good
Content	4.17	Good
Media	3.77	Good
Total mean	12.15	Good
Mean average	4.05	

Analysis of data field trials based on multiple multimedia representations (macroscopic, microscopic, and symbolic) of Hess' Law

In this part, we report the multimedia quality based on multiple representations (macroscopic, microscopic, and symbolic) of Hess' Law, Motivation and benefits aspects, and Learning outcomes.

Multimedia quality based on multiple representations (macroscopic, microscopic, and symbolic) of Hess' Law

Analysis of multimedia quality assessment based on multiple representations (macroscopic, microscopic, and symbolic) of Hess' Law in the field trials for aspects of learning, content/material, and media can be seen in Tables 4 and 5.

Table 4
Frequency distribution Assessment of aspects of learning, content / media, and media in the pilot multimedia field based on multiple representations (macroscopic, microscopic, and symbolic) of Hess' Law

Criterion	Pedagogy		Content		Media	
	Frequency	%	Frequency	%	Frequency	%
Very good	14	58.3	13	54.2	10	41.7
Good	9	37.5	9	37.5	13	54.1
Sufficient	1	4.2	2	8.3	1	4.2
Less	0	0	0	0	0	0
Very less	0	0	0	0	0	0
Total	24	100	24	100	24	100

Table 4 shows that the distribution of assessments in the multimedia field test is based on multiple representations (macroscopic, microscopic, and symbolic). The mean multimedia quality assessment based on multiple representations (macroscopic, microscopic, and symbolic) of Hess' Law in the field test in terms of learning, content/material, and media are included in good criteria.

Table 5
Quality of multimedia based on multiple representations (macroscopic, microscopic, and symbolic) of Hess' Law results of field trials

Assessment	Mean	Criterion
Pedagogy	4.17	Good
Content	4.13	Good
Technology	4.18	Good
Average	12.48	Good
Overall score	4.16	

Motivation and benefits aspects

In general, the pre-service science teachers stated that multimedia based on multiple representations (macroscopic, microscopic, and symbolic) of Hess' Law can foster motivation and provide benefits in voltaic cells' learning process, a result that similar to the previous research (Bayraka & Bayramb, 2010). More detailed on the data analysis can be seen in Table 6.

Table 6
Analysis of data on motivational aspects and benefits in multimedia field trials based on multiple representations (macroscopic, microscopic, and symbolic) of Hess' Law

No	Indicator	Yes (%)	No (%)
1.	The material for Hess' Law was easy for me to learn through multimedia based on multiple representations (macroscopic, microscopic, and symbolic) of Hess' Law	100	0
2.	The concept presented is easy for me to understand	91.7	8.3
3.	The Hess' Law material presented challenged me to study better	95.8	4.2
4.	I want to learn a lot through multimedia based on multiple representations (macroscopic, microscopic, and symbolic) of Hess' Law	100	0
5.	Multimedia based on multiple representations (macroscopic, microscopic, and symbolic) of Hess' Law gives me the opportunity to learn at my own pace	100	0
6.	multimedia based on multiple representations (macroscopic, microscopic, and symbolic) of Hess' Law helped me in learning Hess' Law	100	0
7.	Working on evaluations helped me understand Hess' Law material	100	0
8.	Hess' Law material presented through multimedia based on multiple representations (macroscopic, microscopic, and symbolic) of Hess' Law made me learn faster	79.2	20.8
9.	I enjoy using multimedia based on multiple representations (macroscopic, microscopic, and symbolic) of Hess' Law for learning	100	0
10.	I want to learn using multimedia based on multiple representations (macroscopic, microscopic, and symbolic) of Hess' Law results in other courses	91.7	8.3
11.	Without being accompanied by a lecturer, I experienced confusion and a lack of confidence	25	75
12.	The presentation is an interesting material with a variety of media (text, images, and videos)	100	0
13.	The instructions make me confused	16.7	83.3
14.	I study the material coherently	100	0

All pre-service science teachers (100%) who were respondents in the field trial stated that the material is easy to learn; Respondents want to learn a lot through multiple multimedia-based representations (macroscopic, microscopic, and symbolic) Hess's Law , meaning they are motivated to learn as much material as possible; By using multiple multimedia-based representations (macroscopic, microscopic, and symbolic) of Hess' Law respondents can learn according to their abilities; Multimedia based on multiple representations (macroscopic, microscopic, and symbolic) of Hess' Law helps respondents in learning the material of Hess' Law ; Respondents can measure their understanding by working on evaluation questions that exist in multimedia based on multiple representations (macroscopic, microscopic, and symbolic) of Hess' Law ; Respondents feel happy to learn through multimedia based on multiple representations (macroscopic, microscopic, and symbolic) of Hess' Law, meaning multimedia based on multiple representations (macroscopic, microscopic, and symbolic) of Hess' Law is not boring and interesting; Presentation of material with a variety of interesting media (text, pictures, videos), this becomes a motivator for pre-service science teachers in learning; Respondents study the material coherently.

Most respondents (91.7%) stated that the concepts presented in multimedia are based on multiple representations (macroscopic, microscopic, and symbolic). The Hess' Law is easy to learn. Some respondents (95.8%) stated that they felt challenged to learn better because the material was relatively easy to learn and they were actively involved in the learning process. Some respondents (79.2%) stated that they could more quickly learn the material of the Hess' Law. Some respondents (91.7%) stated that they wanted to learn with multimedia in other subjects. Only a small proportion of respondents (25%) stated that they were confused and were not confident if they were not accompanied by a lecturer, meaning that 75% of respondents were able to study independently with the Hess' Law. Only a small proportion of respondents (16.7%) stated that the instructions provided made them confused, meaning 83.3% of respondents found it easy when using multiple multimedia-based representations (macroscopic, microscopic, and symbolic) of Hess' Law in learning so that the learning process went smoothly.

In general, it can be concluded that multimedia based on multiple representations (macroscopic, microscopic, and symbolic) of Hess' Law provides benefits for pre-service science teachers who learn to use them. Pre-service science teachers also become more motivated in learning the material presented. It can be said that multimedia is based on multiple representations (macroscopic, microscopic, and symbolic) of Hess' Law contributes positively to the learning process of the Hess' Law. Similar studies on the benefits of multimedia can also be seen from previous studies (Ercan, 2014).

Learning outcomes

To find out the effectiveness of multimedia based on multiple representations (macroscopic, microscopic, and symbolic) of the Hess' Law in the field trial carried out pre-test and post-test data analysis at the end of learning. Data analysis was performed by means of the different statistic tests using the t-test for paired samples. Multimedia based on multiple representations (macroscopic, microscopic, and symbolic) of Hess' Law is said to be effective if there is a significant increase in scores between pre-test and post-test. Statistical test analysis was carried out with the help of the SPSS program. After pre-test and post-test data were examined to be normally distributed, the t-tests were performed.

It is necessary to formulate a hypothesis to make a decision whether the pre-test and post-test mean scores differ significantly or not with the following formula:

H0: The two mean test scores are identical (pre-test and post-test scores are not significantly different), H1: The two mean test scores are not identical (pre-test and post-test scores are significantly different). Decision making is based on probability values, namely: 1) H0 is accepted if probability > 0.05 and 2) H1 is accepted if probability <0.05

From the paired samples test table, the Sig. (2-tailed) or the probability is 0.000 less than 0.05. So it can be concluded that H0 is rejected, which means the pre-test and post-test scores differ significantly. Therefore, there was a significant increase from the test scores before using multiple multimedia-based representations (macroscopic, microscopic, and symbolic) of Hess' Law to test scores after using multiple multimedia-based representations (macroscopic, microscopic, and symbolic) of Hess' Law. Based on the results of statistical analysis, it can be concluded that multimedia-based multiple representations (macroscopic, microscopic, and symbolic) of Hess' Law are effectively used in the learning process of the voltaic cells (Anwar, 2017; Battino, 2020).

CONCLUSION

Multimedia quality criteria based on multiple representations (macroscopic, microscopic, and symbolic) of Hess' Law from the aspects of learning, content/material, and media are included in both criteria with an average score of 4.05 for small group trials and 4.16 for trials field. Pre-service science teachers can learn Hess' Law material more easily, faster, more active, less boring, more independent, and motivated to by using multimedia based on multiple representations (macroscopic, microscopic, and symbolic) of Hess' Law. The results of the t-test mean, pre-test and post-test scores, showed that the mean pre-test and post-test scores differed significantly with a probability value of 0.000 smaller than 0.05. Multimedia based on multiple representations (macroscopic, microscopic, and symbolic) of Hess' Law is effectively used in the learning process of Hess' Law.

Multimedia based on multiple representations (macroscopic, microscopic, and symbolic) of Hess' Law can be utilized in the learning process of Hess' Law so that learning is more effective and efficient and student motivation and independence can be improved. For pre-service science teachers, this study aims to be a guide to understand the benefits of the multimedia; therefore, they can generate the findings for their teaching, developing material for their instructional activities. However, the current study has some limitations. The sample of the study is still limited to few students; more samples are required for future studies. Besides, other methods like observation, interview, and survey are also suggested to conduct. Establishing other moultimedia material for other courses is necessary to enrich the learning cources in Chemisrty education.

SUGGESTION

Chemistry teacher educators should have more resources to help pre-service science teachers develop their perception and understanding of Hess' Law. The presence of the multimedia enriches resources for Chemistry education to understand more about Hess' Law material. However, more comprehension of resources based on Hess' Law in different contexts and settings are recommended for future researchers to adapt. Other approaches to research, such as qualitative and quantitative, are also recommended to conduct. A qualitative culture can address a more-in-depth understanding through its advantages, while the quantitative method can have a wider study that involves a better number of subjects and enhances the generalization of the findings. The findings are valid for Indonesian education and language science teachers' context. Thus, it is hoped it can be beneficial for all stakeholders in Chemistry education.

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