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Video with multiple representations approach to promote students' conceptual understanding of intermolecular forces

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ABSTRACT

A number of studies have reported that the main cause of misconceptions are the abstract concepts and students' low ability to integrate multiple representations (macroscopic, sub-microscopic and symbolic) in chemistry is also a cause of misconceptions. The aim of this study is to develop the video using multiple representations approach to improve students' conceptual understanding. The method used is the analyze, design, development, implementation, and evaluation or ADDIE development model. Tests (pre and post) and questionnaire were used to collect the data. A video of intermolecular forces has been developed and tested to 82 first-year cohort students of the Chemistry Education Study Program who had taken basic chemistry courses. The average scores were increased from 57.31 (pre-test) to 78.19 (post-test) with the average gain is 20.88. The statistically significant increase in scores (p=0.000) was found, which signifies that the video could support students' conceptual understanding. In addition to that, majority of students showed a positive response to the video as 99% (N=82) of them either agree or strongly agree with the statements of the questionnaire. This result verified that the video was successfully maintain students' attention.

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1. INTRODUCTION

Understanding the physical basis, the principles required to describe intermolecular forces (IMFs) and consequences of IMFs is an essential element in core chemistry education [1]–[3]. An understanding of IMFs helps students predict a number of physical properties of substances, such as relative boiling points, changes in states of matter [4] and the ability to predict whether a given solute will be soluble in a particular type of solvent. However, many students find it difficult to understand the concepts [5]–[7]. Therefore, students develop a wide range of alternative conceptions [8]. Research by Tan and Chan [7] found that some students at grade V and VI (age 16-17 years and 17-18 years) had difficulty in understanding the nature of hydrogen bonding and dipole-dipole interactions. In addition, some students find it hard to describe the IMFs involved within the molecules. A number of studies have reported common misconceptions related to this concept [1], [5], [6], [8]–[11] which are summarized in Table 1. This misconception indicated that students did not understand the concept of IMFs. Therefore, a visual media is needed to be used in learning. The misconceptions described in these studies were used to inform the structure and content of the video of IMFs developed in this study. This can result in perceived difficulties in student understanding of topics especially if the learning process is not supported by suitable learning resources that effectively represent abstract objects with dynamic characteristics through visualization [12].

Table 1. Summary of common misconceptions related to IMFs [2]

	Students' misconceptions
1.	IMFs are stronger than intramolecular forces (for example hydrogen bond is stronger than covalent bond)
2.	IMFs are present in polar molecular substances such as water
3.	IMFs occur within a covalent molecule
4.	Intramolecular bonds break on change of state, rather than IMFs
5.	IMFs are the forces within the molecule
6.	Strong IMFs exist in a continuous covalent (network) solid
7.	IMFs are influenced by gravity
8.	IMFs led to reactions
9.	Unpaired electrons are necessary for hydrogen bonds to form

According to Sanger and Greenbowe [13], visualization can help students overcome the abstract concepts. One of the chemistry concepts that requisite linking skills among macroscopic, microscopic, and sub-microscopic [14]. For instance, the IMFs concept is utilized to predict the solubility of a substance based on the principle of "like dissolved like" and the boiling point of organic compounds [15]. Many established approaches to teaching and learning in this topic require explanations that make significant use of visualization, such as the use of molecular models, video, images, and animation [16]. Although many toll-like receptors (TLRs) have been developed to help students visualize abstract concepts, studies on the effectiveness of these TLRs are limited. TLRs that related to computer assisted learning were reported by several researchers [16]–[18]. Video-based TLRs have the potential to allow students to visualize the formation of IMFs as well as the effects of IMFs on physical and chemical properties through microscopic level representations.

Arsyad [19] defines video as the images in frames, where frame by frame is projected through a lens the projector mechanically so that the screen shows a live image. Research by Cruse [20] defined the video as a form of multimedia that conveys information through two simultaneous sensory channels: aural and visual. Videos can use multiple presentation modes, such as verbal and pictorial representations in the case of on-screen print and closed captioning/subtitling [21]. This multiplicity means that video is capable of simultaneously communicating information to students through a number of learning modalities and can provide students with multiple entry points into the content [22]. Presenting the dynamic chemical scenario required to successfully describe IMFs in video format can potentially give students the opportunity to picture the process that at the microscopic level. A number of studies support the concept of using video resources to support the visualization of the abstract concepts [23] and can attract students' attention [24].

2. RESEARCH METHOD

The design used in this research is the analyze, design, development, implementation, and evaluation (ADDIE) development model which consists of five steps (analyze, design, development, implementation and evaluation) [25]. The ADDIE development model was proposed [26] to develop learning designs, which are then also used to develop learning strategies and methods, media, and teaching materials. The steps in the ADDIE model in this study are as: i) Analysis phase; ii) Design stage; iii) Development stage; iv) Implementation stage; and v) The evaluation stage.

At the first stage, a need assessment will be carried out by reviewing articles from both domestic and foreign countries to check what misconceptions are experienced by students. This stage aims to determine the topic and format of learning resources to be developed. Then, the design stage begins with compiling a storyboard and plotting the learning resources to be developed. After that, a draft learning resource will be developed. At this stage the research instruments will be arranged in the form of conceptual tests and questionnaires.

For the third stage, the draft produced in the previous stage will be developed into a learning resource that is ready for initial trials. Initial trials were also carried out on the instruments that had been produced. The initial trial aims to see the readability of instruments and learning resources in terms of time, ease of implementation, and language. The results of this initial trial will be used as revision material for instruments and learning resources prior to the implementation stage. As in the implementation stage, tests and questionnaires will be given to participants prior to implementation. Furthermore, the test result data will be analyzed. Furthermore, implementation of the resulting learning resources is carried out. After the implementation of the tests and questionnaires will be given again to the participants. In the last stage, an analysis is carried out from the results of the data collected in the previous stage. Before the analysis will be carried out tabulation based on the data obtained. After the analysis is complete, the data will be interpreted.

2.1. Participants

The number of participants who participated in this study were 82 first-year students of the Chemistry Education Study Program, Tanjungpura University, Indonesia. All participants had taken basic chemistry courses. All students were voluntarily participated in this study to learn with the video as well as fill out the questionnaire towards the video and conceptual tests.

2.2. Data collection

The data in this study were collected in two ways, which are questionnaire and a test (pre and post). Questionnaires are used to collect student responses related to the learning resources developed. The responses in question are responses, perceptions, suggestions, and comments. Questionnaires were given before and after the implementation of learning resources. Furthermore, the data obtained from the questionnaire was also used to revise the video.

The second data collection technique is the conceptual test. The conceptual test in this study was compiled by the research team to then validate the content by the Chemistry Education lecturer prior testing. The test used in this study is a restricted response test. The form the test provides certain limits or signs to test takers in answering the questions. These boundaries include the format, content, and scope of the answers [27]. The validation sheets are given to the validator to validate the content and the performance of the video. In addition, question validation sheets are also given to the validator to validate the conceptual questions that will be used as pre-test and post-test. The validators involved in this study were two lecturers in the Chemistry Education Study Program.

2.3. Data analysis

The data that has been collected is then analyzed quantitatively. Data in the form of responses, suggestions, comments, and perceptions is also used as material to revise the learning resources developed. The results of students' answers on the pretest and posttest were tabulated to calculate the score and analyzed quantitatively using IBM SPSS 24.

2.4. Determining the topic and format of learning resources through literature study

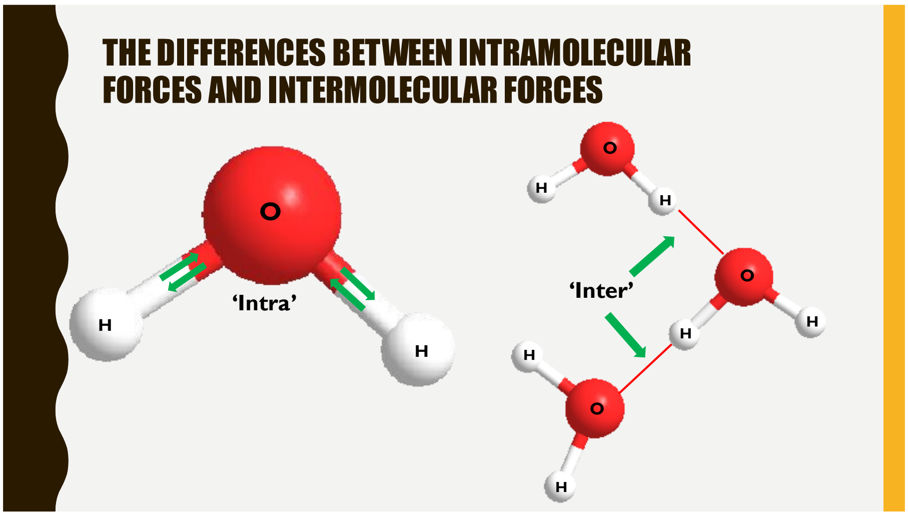
There are several results that have been obtained in this study, including the results of literature studies from articles related to misconceptions. This literature study was conducted as a first step to identify misconceptions faced by students and students in studying chemistry. The purpose of this literature study is to obtain information related to misconceptions or alternative concepts, difficulties in studying chemistry and the factors that cause these misconceptions. The results of this literature study will be used to determine the topic and format of the learning resources developed. In this case the topic that is determined is IMFs.

The number of students who have difficulty understanding the concept of IMFs as reported by several researchers [1], [2], [5], [6], [8] the considerations of researchers in determine the topic of learning resources. In addition, the media or learning resources developed for this topic are still limited [4], [7]. Meanwhile, the learning resource format developed is video, because it has the potential to display dynamic visual representations of the motion of atoms and molecules. Representing the movement of atoms and molecules is the key so that students can develop accurate representations as stated by Vavra *et al*. [28] that the function of images is to help students process and analyze information more efficiently so as to reduce brain work. In addition, videos also have the potential to demonstrate simulations of important concepts such as dipoles induced by the presence of other molecules nearby.

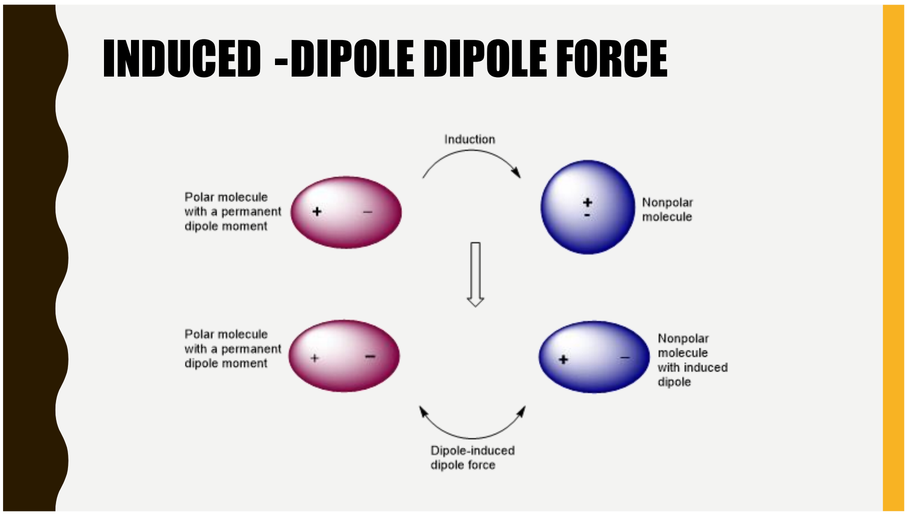
2.5. Development of video of intermolecular forces

The IMFs video developed in this study is a screen-captured video based on a PowerPoint slide. The resulting slides were then recorded and edited using Movavi Video Editor 12 software. The chemical structure images displayed on the video were created using ChemDraw Professional 16.0. The next step was to create scripts for the narration that accompanied the video. An outline of what needs to be said on each slide was written at the storyboarding stage. The script expanded on this by providing a detailed explanation of the concepts presented visually on each slide. The scripts were validated by both supervisors in terms of scientific content and language.

The video on IMFs developed in this study presented explanations of the key concepts required for an understanding of IMFs at the level of an introductory chemistry course. The images presented in the video supported the explanations of specific concepts such as the differences between dipole-induced dipole force and made the video visually appealing as seen in Figure 1. Figure 1(a) emphasizes the key differences between intermolecular and intramolecular forces. Figure 1(b) shows the induction process between polar molecule and non-polar molecule.



(a)



(b)

Figure 1. Sample slide of the video (a) the differences between intramolecular and IMFs and (b) induction of polar and nonpolar molecule

3. RESULTS AND DISCUSSION

3.1. Students' conceptual understanding

Both pre-test and post-test scores were marked and tabulated to analyze students' understanding of IMFs. Students' scores of both tests were analyzed using Microsoft Excel and SPSS. The maximum score for both tests is 100. The scores of the individual pre-test and post-test score presented in Table 2. The performance of all students improved between the pre-test and the post-test. There were two students scored 100 out of 100 for post-test.

Table 2. Pre-test and post-test range score

Score range	Pre-test	Post-test
<49	42	0
50-59	15	7
60-69	24	32
70-79	18	21
80-89	1	21
90-100	0	20

Students' pre-test and post-test scores were classified into six different categories as presented in Table 2. 42% of students achieved pre-test scores in the lowest category (below 49/100) whereas no students achieved scores in this category on the post-test. This may suggest that there is a possibility that some students' experienced misconception related to this topic as well as students' poor understanding. There were 15% of students' pre-test scores fell in the second category (50-59/100) and 8% of students had post-test scores in the same category. Even though the percentage of this range reduced in the post-test, the result implies that students who were in this category may still having alternative conceptions related to IMFs.

The most striking percentage is, almost 20% of them got between 90-100 points at post-test. Overall, students' post-test scores were better compared to those pre-test's scores as none of them got less than 50 points. The better performance on the post-test is possibly due to the combination between audio (explanation), text and visual (images) in the video [29]. They found that, the combination of visualization (in this case animation) and verbal or textual information enhanced students' understanding of scientific explanation and concepts. They conducted an experiment involving 30 undergraduate students who viewed an animation of a bicycle tire pump. The students who presented both words and images performed better in problem solving activities than the students who presented in with words only or images only to clarify the concepts. Moreover, Heliawati *et al*. [30] reported that the use of articulate storyline 3 multimedia based on gamification could enhance students' critical thinking skills with the average score and N-gain are 81.50 and 72% (N=64) respectively. Based on the findings, they concluded that effective understanding of scientific explanations requires a mapping between words and pictures.

The diagram and figures presented in the video were helped them understand and visualize the process of IMFs (26 of students noted that the diagram and images presented in the video as the most useful part and the video was a useful resource and the figures were helpful as it allows me to visualize the process of IMFs). A similar finding was reported by Ardac and Akaygun [31] who stated that learning resources based on multimedia representations can be very effective in helping students visualize the chemical process at the molecular level and recalling memories of facts, concepts, and principles. Research by Bergsma [32] stated that visual message of multimedia is processed in a different part of the brain than that which processes textual and linguistic learning, and the limbic system (a complex system of nerves and networking in the brain) responds to these pictures by triggering instinct, emotion, and impulse. According to Khairudin *et al*. [33] argued that memory is strongly influenced by emotion, with the result that educational videos can have a powerful ability to relay experience and influence cognitive learning.

The table describes the percentage of students' range score of pre- and post-test. The pre-test and post-test data were then analyzed using a paired-sample t-test. The result of this analysis demonstrates that there is a statistically significant difference (as verified by a paired-sample t-test) between student performance in the pre and post-test (with p-value <0.001) as seen in Table 3. No further instruction in the topic in the topic before the post-test was ensured by the lecturer (who taught the general chemistry course). The average (mean) scores of the pre and post-tests were 53.78 and 74.27 respectively. The difference in student performance in these two tests appears to demonstrate the effectiveness of the video as a learning resource.

Table 3. The result of paired-sample t-test

Tests	Mean	N	SD	Correlation	t Value	Gain	p Value
Pre-test	53.78	82	13.912	0.905	-31.111	20.488	0.000
Post-test	74.27	82	13.220				

The table presents the outcomes of students' pre- and post-test score analyzed by SPSS paired-sample t-test. The findings are consistent with those reported by Muchson [16] who developed the interactive multimedia resource in compact disc (CD) format for teaching IMFs topic. The software was designed by combining the text, animation, images, audio and video to emphasize the three levels of representations, especially the sub-microscopic level to visualize the abstract concepts in IMFs. The software was used for second year undergraduate students who studied chemical bonding in Malang, Indonesia. The use of the software in the class resulted in an increase in students' average scores (identical pre-test and post-test) from 12.2 to 20.2 (out of 25) or about 65.5%.

A similar result was reported by Barbosa *et al*. [34] in a study of the impact of the computer software designed to help undergraduate chemistry students in Brazil to learn about IMFs. The software Interactions is user-friendly and easy to navigate and was developed using the Adobe Flash platform as it is easy to run in Microsoft Windows, Apple Mac OS, and almost all Linux releases. The software presented a short introductory text along with graphical simulations, figures, video and animations. To measure the effectivity of the software, a questionnaire using the Likert scale which consist of eight statements were used to gather students' opinions regarding to interface, language, content, and usefulness. The questionnaire was given in electronic and printed version to 121 chemistry students from 8 universities in Brazil. Based on students' responses, they concluded that the software was an important teaching tool to complement the contents in textbooks with 90% of agreement, 91% of students agreed that the software contributes to the learning of the concepts related to the IMFs and 88% of students agreed that the software can improve student performance.

In addition, Barbosa *et al*. [34] also evaluated the impact of the software to students understanding with 131 first-year students of five different undergraduate courses (biology, animal science, food engineering, pharmacy, and chemistry) understanding by giving a printed diagnostic test and final test with 4 similar questions. Students experienced better scores in the final test with the increased scores of 65.2% on average which proved the effectivity of the software to improve students' understanding in IMFs topic. Research by Eliyawati, Rohman, and Kadarohman [35] also reported similar findings of the impact that video resources can have in the teaching and learning process in chemistry. In their study, a multimedia (video) resource was designed to improve students' understanding of electrolyte and non-electrolyte concepts by integrating macroscopic, sub-microscopic and symbolic levels for grade 10 high school students (age 15 year) in Bandung Indonesia. A similar 18 questions (initial test and final test) were used to measure students understanding. Following implementation of the multimedia resource in the experiment class, students' mean scores in the final test increased from 43.97 to 86.03 (out of 100).

The increasing score of the post-test probably due to the use of the three levels of representations (macroscopic, symbolic, and sub-microscopic) in the software, as reported by Wu, Krajcik, and Soloway [36] in their study that the use of a computer-based visualizing tool, eChem, which allowed students to build molecular models and view multiple representations (macroscopic, symbolic, and sub-microscopic) simultaneously had promoted students' understanding of chemical representations. 71 students of grade 11 (age 16-17) involved in this study. The outcomes of pre-test and post-tests' score showed that students' understanding of chemical representations improved substantially ($p<.001$, effect size=2.68). The use of the visualization tool that illustrates symbolic and microscopic representations encourages students to engage in a discussion of underlying concepts. In addition, the found that students who were highly engaged in discussions while using eChem made referential linkages between visual and conceptual aspects of representations. This in turn may have deepened their understanding of chemical representations and concepts. The findings suggested that the model rotation feature provided by eChem assists students in making visual connections between 2-D and 3-D models, hence that computerized models can serve as a vehicle for students to generate mental images and improved students' understanding.

3.2. Students' views and responses of video

Figure 2 shows that student responses related to the video. 100% of students agreed (agree or strongly agree) with statements 1, 3 and 6 (I enjoyed watching the video, the explanations helped me to understand the concepts, and the presentation of the IMFs is good). Statement number 5 (this video did not help me in understanding the concepts of IMFs) was used to confirm the consistency of students' responses to other statements. Among the seven statements used in the questionnaire, six of them were positive statements (statement no 1, 2, 3, 4, 6 and 7) while statement number 5 is the negative statement. Student responses to statement 5 (this video did not help me in understanding the concepts of IMFs) is consistent with all the statements where 100% of respondents did not agree with the statement. For statements 2 and 7, 98% of students agreed that the all pictures and figures presented in the video were clear (statement 2) and that the pictures presented in the video are useful (statement 7). Overall, the majority of students responded positively to the video.

The second section of the questionnaire consisted of four open-ended questions. A summary of student responses to these questions is shown in Table 4. When asked "which parts of the video were most useful?" The key themes raised by students stating "the diagram and images presented in the video" (26 students), "all parts of the video" (48 students) and "the explanation of concepts presented in the video" (8 students). The second question asked students "which part of the video were least useful?". Students responded to this by stating "the text used to explain the concepts of presented in slide 6" (21 students), while the rest of them (59 students) responded with "none". In spite of the changes made to the pace of the video based on the feedback from the pilot study, students commented on issues with the pace of the closing slides (23 students). Student comments also indicated that the use of multiple forms of representations (i.e., video, images, and audio) was a helpful way of presenting these concepts to students new to this area of chemistry. Based on students' general comments, the video was noted too useful.

"*In my opinion, the video is a useful resource, the images, such as the molecule without dipole and molecule with instantaneous dipole to illustrate the polarization process, presented in the video help me understand the concepts.*"

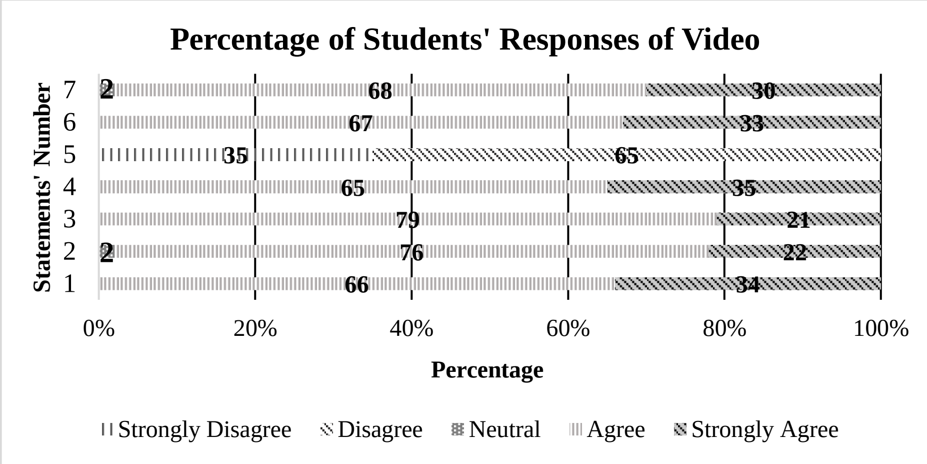


Figure 2. Students' responses of video (N=82)

Table 4. Students' comments and suggestions related to the video

Comments/suggestion	
The most useful part of the video	Diagrams and images presented in the video (26 students) All parts of the video (48 students) The explanation of concepts presented in the video (8 students)
Less useful	The text in the last few slides (summary slides) (21 students) None (61 students)
Changes	Reduce the pace of the last few slides (the summary part) is it hard to follow (23 students) None (59 students)
General comments	Found it useful though and the diagrams were helping (7 students) Well presented (20 students) Overall, the video was pleasing to look and the content was easy to read (12 students) The video was a useful resource and the figures were helpful as it allowed me to visualize the process of IMFs (26 students) The video was helped to understand the concept along with the diagram (17 students)

4. CONCLUSION

Data collected through pre- and post-tests assessed the impact of the video on student learning. The increased scores between pre- and post-tests provided evidence that video of IMFs had improved students' understanding of the topic. Also, based on the analysis of students' answers (pre- and post-test), students had an improved understanding after learning with the video. It is indicated that video of IMFs had a positive impact in supporting students' understanding of this topic. The questionnaires and interviews showed that students found the video is a good way to learn. Positive responses towards the video confirmed that the resources were effective at providing an engaging learning experience.

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